ISSN (online) 2543-912X ISSN 2543-6597

Engineering Management in Production and Services

Volume 13 Issue 4 2021

Bialystok University of Technology

International Society for Manufacturing, Service and Management Engineering

ISSN 2543-6597

Bialystok University of Technology
Faculty of Engineering Management

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ISMSME
International Society for Manufacturing, Service and Management Engineering

Engineering Management in Production and Services

Volume 13 • Issue 4 • 2021

www.empas.pb.edu.pl

Frequency

ECONOMICS AND MANAGEMENT
is published quarterly since 1998

As of the beginning of 2017 the journal
is published under a new name:
ENGINEERING MANAGEMENT
IN PRODUCTION AND SERVICES

Submission

Papers for submission should be prepared according to the *Authors Instructions* available at www.empas.pb.edu.pl

All papers should be submitted through the electronic submission system

Publisher

Bialystok University of Technology
Wiejska 45A, 15-351 Bialystok, Poland

The International Society
for Manufacturing Service
and Management Engeneering (ISMSME)

Indexation

Journal is indexed in SCOPUS, Ei Compendex, EBSCO Business Source Ultimate (Complete), Norwegian Register for Scientific Journals, Series and Publishers, Index Copernicus, ERIH PLUS, Google Scholar, Central European Journal of Social Sciences and Humanities, Research Papers in Economics (RePEc), BazTech and BazEkon databases

Editor-in-Chief

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Table of contents

Volume 13 • Issue 4 • 2021

sciendo

received: 4 August 2021
accepted: 1 December 2021

pages: 7-21

ACHIEVING CAREER SATISFACTION THROUGH FOSTERING INNOVATION: LESSONS FROM THE ENGINEERING PROFESSION IN THE AUSTRALIAN PUBLIC SECTOR

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ABSTRACT
This paper proposes a novel approach that integrates the capability of empirical validation of structural equation modelling (SEM) and the prediction ability of Bayesian networks (BN). The Hybrid SEM–BN approach was used as a decision support framework to examine the interplay between salient organisational constructs and their ability to influence engineers' career satisfaction in the Australian Public Service (APS). The results emphasise that the ambidextrous culture for innovation was the most important factor that needed to be implemented in their organisation. Managerial implications are recommended for senior managers on how they can implement innovation culture to increase workplace innovation, which could, in turn, help reduce the turnover rate of engineers employed in the APS.

KEY WORDS
structural equation modelling, Bayesian networks, career satisfaction, engineer, Australia

10.2478/emj-2021-0028

INTRODUCTION

Australian federal departments employ engineers to perform in-house engineering functions, tasks, and projects; to plan, develop, and maintain public works and environmental programmes; to maintain the mission and services legislatively mandated and to manage and oversee work contracted to private engineering firms. Administrative reforms have had significant consequences on the number of engineers in the Australian Public Service (APS). Engineers have been

Wipulanusat, W., Panuwatwanich, K., Stewart, R. A., Sunkpho, J., & Thamsatitdej, P. (2021). Achieving career satisfaction through fostering innovation: lessons from the engineering profession in the Australian public sector. *Engineering Management in Production and Services, 13*(4), 7-21. doi: 10.2478/emj-2021-0028

impacted by these reforms, including privatisation, competition policy, contracting out, and commercialisation. Evidence indicates a decline of between 20 and 50 per cent in the number of professional engineers in the Commonwealth, State, and local government public sectors between 1990 and 1999 (Engineer Australia, 2012). Yates (2001) predicted that if the rate of decline in the number of APS engineers continued unchanged, then by the year 2008, the shortage of engineering professionals would become a critical problem for government agencies. A decade later, this prediction was realised, and most federal departments faced a shortage of engineering professionals. For example, in 2010, engineers were among the top four professions in which public services had the most problems recruiting new graduates and retaining existing employees (Engineer Australia, 2012; Yates, 2012). According to the State of the Service Report 2012–2013, the predominant occupational groups where skill shortages were reported were engineering and technical, accounting and finance, as well as ICT occupations. More than 40 per cent of the engineers who worked in these occupations indicated their intention to leave their agencies within 12 months (Australian Public Service Commission, 2013). The main reason reported regarding the decision to leave their agency was a lack of future career opportunities. In the survey of APS engineers who had indicated they would leave their agency in the next two years, one of the most common departure reasons was a lack of chance to participate in innovative projects (Yates, 2012). From 2015 to 2019, an engineer shortage is still a critical obstacle in which the number of job vacancies for engineers always increases (Lester, 2019). The federal government needs to implement innovation policies to recognise engineers' significant role in turning creative ideas into innovative initiatives.

Within an organisation, a manifestation of socio-psychological phenomena, in the form of "climate", acts as a critical determinant of employee motivation and behaviour and drives the innovation process (Wipulanusat, Panuwatwanich, & Stewart, 2018). More specifically, several research studies have attempted to investigate the extent to which climate for innovation, consisting of leadership and organisational culture, can act as either a stimulant or an impediment to creativity and innovation (Demircioglu & Berman, 2019; Panuwatwanich, Stewart, & Mohamed, 2008; Wipulanusat et al., 2020). Understanding these socio-psychological processes provides a practical way to stimulate workplace innovation within the complicated social systems, which, in turn, encourages engineers' career satisfaction in Australian federal departments.

A career is widely regarded as the lifelong sequence of employees' role-related experiences, despite being conventionally acknowledged to be limited to professionals or those promoted through organisational hierarchies (Hall & Chandler, 2005). Career satisfaction is the positive psychological achievements that employees obtain from their careers' intrinsic and extrinsic facets, including salary, advancement in job rank, feelings of pride, and developmental opportunities (Greenhaus, Parasuraman, & Wormley, 1990; Nair et al., 2019; Adeniji et al., 2019; Ohunakin et al., 2018; Tobing, 2016). Some researchers have described that employees consider their career progress to be compatible with their own goals, values, and preferences (Barnett & Bradley, 2007). Career satisfaction is also identified as employees' feelings of satisfaction or dissatisfaction with their entire career (Lounsbury et al., 2008).

Therefore, there are research deficiencies and gaps regarding the influence of socio-psychological factors on organisational outcomes (i.e., workplace innovation and career satisfaction) within the innovation process for engineers in federal departments. This suggestion emphasises the importance of identifying the key factors that impact workplace innovation and investigating successful workplace innovation practices, leading to increased career satisfaction. Such research can provide empirical evidence to support the relationship between these constructs.

Therefore, federal departments should prioritise assessing and enhancing career satisfaction because receptiveness to career satisfaction should be a key metric of public sector performance. Engineers cannot contribute to their departments if organisations do not promote career satisfaction. This paper aims to study which factors lead engineers to more substantial commitment in the APS by correlating innovation climate, workplace innovation, and career satisfaction.

The study presented in this paper considers the concepts of climate for innovation, workplace innovation, and career satisfaction through individual engineering professionals' lens in the APS. The study was limited to Australian federal departments currently facing a shortage and high attrition rate of engineering professionals. This study aims to apply a coherent and comprehensive approach to help engineers increase career satisfaction, which could help attract and retain the engineering workforce in the APS.

1. Literature review

1.1. Conceptual model

The main objective of this paper is to understand the innovation-conducive conditions and processes within the public sector. Researchers have long studied the relationship between organisational attributes, the organisation's propensity to innovate, and organisational outcomes. It is essential to focus on organisational attributes because they provide practical implications that can be applied for improving the organisational outcome. Socio-psychological constructs (consisting of leadership for innovation and ambidextrous culture for innovation) can be expressed in the form of a climate for innovation, which will improve workplace innovation and career satisfaction in public sectors.

Leadership for Innovation (LFI) is the extent to which leaders are willing to take risks on new initiatives and adopt novel perspectives. Innovative leadership is considered to be present in leaders, having behaviour geared towards applying creativity in innovative projects within the work context (Karia & Abu Hassan Asaari Muhammad, 2019). Leaders play an important role in developing the process, structures, and climate for an organisation to become innovative and to motivate team expectations toward innovations (Chan, Liu, & Fellows, 2014; Oke, Munshi, & Walumbwa, 2009; Orazi, Turrini, & Valotti, 2013).

Ambidextrous Culture for Innovation (ACI) is defined as an organisation's shared norms, beliefs, assumptions, and fundamental values to establish and maintain a balance of exploration activities and exploitation activities to facilitate innovation in the work environment and reflect innovative practices, procedures, policies, and structures (Kim & Yoon, 2015; Solís & Mora-Esquivel, 2019; Wipulanusat, Panuwatwanich, & Stewart, 2017). The ACI construct incorporates two dimensions: innovative culture (ACI1) and performance-oriented culture (ACI2).

Workplace Innovation (WIT) is the generating force by an individual or a team of individuals changing how organisations manage, organise, and deploy people and technology. It means implementing new interventions and supportive technologies into the workplace (Pot, 2011; Totterdill & Exton, 2014). Workplace innovation introduces new forms of work and combines structural and cultural practices, enabling employee participation, ultimately enhancing work quality and organisational performance (Carranza, Garcia, & Sanchez, 2020). WIT construct consists of two dimensions: individual creativity (WIT1) and team innovation (WIT2).

Career Satisfaction (CSF) means employees' affective reaction in satisfaction with their entire career (Dubbelt, Demerouti, & Rispens, 2019). It also measures employees' psychological accomplishments on their skills and abilities in their career from the intrinsic and extrinsic aspects of their careers, including salary, promotion, honour, and career path (Barnett & Bradley, 2007; Demircioglu, 2018; Lounsbury et al., 2008). The CSF construct is composed of two dimensions: meaningful work (CSF1) and reward and recognition (CSF2).

1.2. Hypothesis development

Extensive researches have studied the relationship between leader, culture, innovation, and career satisfaction. Kim and Chang (2009) performed a survey to assess the capability for innovation throughout the Korean central government's 46 ministries. According to the findings, management style, innovative culture, performance-based incentives, and knowledge management appeared to boost governmental organisations' ability to innovate. McAdam, Moffett, Hazlett, and Shevlin (2010) applied structural equation modelling to examine 395 SMEs in the UK, which presented the results that innovation leadership and innovative culture positively impact innovation implementation. A study of innovative behaviour in federal agencies in the United States (US) by Fernandez and Pitts (2011) revealed that front-line employees were motivated to generate bottom-up innovation by reward and recognition, training and development, employee empowerment, and participation in decision-making.

Kim and Lee (2009) also examined the impact of the management ability for innovation adoption and implementation in the Korean Government. They claimed that adopting and implementing innovative projects necessitated full-scale management capacity, including innovative leadership, a quality workforce, procedures and structures conducive to inventive behaviour, and the reduction of adverse external influences. The most crucial aspect in encouraging the dynamics of governmental innovation is innovative leadership, which is defined by effective change management, leadership commitment, and workforce stability. Parry and Proctor-Thomson (2002) carried out a nationwide leadership survey to examine

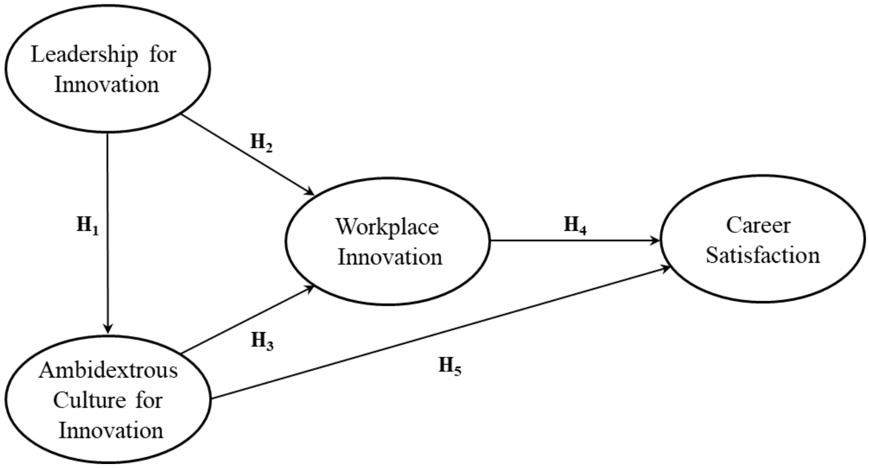

Fig. 1. Conceptual model

organisational aspects associated with innovation in the New Zealand public sector. This study employed structural equation modelling to explore hypotheses on the relationships between leadership manifestations, organisational culture, and innovation. The impacts of transformational leadership on organisational outcomes were shown to be supported by its influence on facilitating a transformational culture and transactional culture on the climate for innovation. A Taiwanese study confirmed that organisations have to focus on workplace innovation to derive the optimum R&D employee's career satisfaction (Cheng, Lai, & Wu, 2010). In the Australian public sector context, Demircioglu and Berman (2019) revealed that innovation culture encourages creativity and innovation in the workplace and increases career satisfaction, thereby decreasing employee turnover intention.

It can be seen that the majority of the variables discussed above correspond to both socio-psychological constructs underlying the climate for innovation, consisting of leadership for innovation and ambidextrous culture for innovation. Workplace innovation is also related to career satisfaction. Also, ambidextrous culture for innovation can further increase career satisfaction. The following research question is formulated: What is the interaction between leadership for innovation, ambidextrous culture for innovation, workplace innovation in enhancing career satisfaction? Therefore, as shown in Fig. 1, a conceptual model has been proposed to empirically investigate the hypotheses between these constructs, which will provide an answer to the research question. The test results can provide critical contributions to the literature concerning the factors affecting innovation outcomes in public sectors.

H1: Leadership for innovation positively impacts ambidextrous culture for innovation.

H2: Leadership for innovation is positively related to workplace innovation.

H3: Ambidextrous culture for innovation positively influences workplace innovation.

H4: Workplace innovation is positively associated with career satisfaction.

H5: Ambidextrous culture for innovation positively impacts career satisfaction.

1.3. Data and measurement

Data were derived from the Australian Public Service Commission (APSC) dataset. The 2014 APSC dataset was used because this is the last year that APSC revealed the occupation of the respondents. The sample for this study was drawn from engineering professionals. There were 3 125 valid samples of engineers in federal departments. The majority of respondents were male (86 %) and worked in an operational role (68 %). Concerning education, 78 % graduated with a bachelor's degree. Most of them (73 %) had more than five years of tenure. In conclusion, the demographic profile of respondents represented the distribution of the population.

The questions in the survey were self-reported questionnaires using a five-point Likert scale. These questions were grouped according to the definition of each construct. Leadership for innovation was measured using eleven items (e.g., "My supervisor encourages people to find new ways of doing work"; α=.95).

Ambidextrous culture for innovation was measured with eleven items (e.g., “My agency emphasises innovation”; α=.89). Workplace innovation consisted of seven survey items (e.g., “I would be supported if I tried a new idea”; α=.85). Finally, eight survey items were used to represent career satisfaction (e.g., “I enjoy the work in my current job”; α=.85).

2. Methodology

The present study adopted an integrated approach combining structural equation modelling (SEM) and Bayesian network (BN). SEM provides an advantage over traditional regression analysis because it simultaneously estimates covariances between measured variables while estimating the regression paths of multiple dependent variables (van Horn et al., 2016). BN is an increasingly popular data-mining technique due to its state-of-the-art representation of probabilistic knowledge. BN represents graphical interaction between causes and effects and allows for modelling the level of uncertainty, which can change with new evidence (Boehmke et al., 2016; de Oliveira, Dalla Valentina, & Possamai, 2012). BN’s unique nature and merit provide a visual tool for a decision support model for solving problems relating to complexity, uncertainty, and probabilistic reasoning.

While both methods are crucial for quantitative analysis, they have different characteristics that need to be considered. First, as SEM is theory-based, it quantifies and evaluates assumed causal relationships using statistical data, whereas BN is a graphic model based on probability theory (Anderson & Vastag, 2004; Gupta & Kim, 2008). Second, SEM is appropriate for empirical validation based on theoretical causal relationships, whereas BN can be data-driven and construct causal maps based on background knowledge and historical data (Kayakutlu et al., 2017; Wu, 2010). Third, BN is appropriate when training with new data because it does not affect a model’s structure, thereby supporting a useful scenario analysis. Simultaneously, SEM is unsuitable for training with new data because it may change the casual relationship structure (Ekici & Ekici, 2016; Gupta & Kim, 2008). Fourth, SEM is more suitable for linear relationships because although it can accommodate non-linear relationships, the process requires complex coding and results in output which is complicated and difficult to interpret (Anderson et al., 2004). In contrast, BN can easily model non-linear relationships, thus evaluating the impact of changes in the model (Anderson & Vastag, 2004; Gupta & Kim, 2008). Fifth, SEM is parametric in distribution and function, so it is necessary to satisfy univariate and multivariate normality and statistical assumptions, as well as to justify theoretical evidence (Cardenas, Voordijk, & Dewulf, 2017). BN, being non-parametric, does not need to follow the specific function form and strict statistical assumptions because the computational process is the calculation of the probability distribution of the variables in the model (Ekici & Ekici, 2016). Sixth, SEM can only predict dependent variables, provided the independent variables are specified, whereas BN can calculate the probabilities for both dependent and independent variables (Lauría & Duchessi, 2006). Seventh, SEM relationships, presented in the dimensionless regression metric in terms of standardised regression weights, have no empirical metric making them appropriate because the latent constructs have not been measured (Anderson & Vastag, 2004). However, BN provides descriptions in terms of probabilities, which especially suit prediction and diagnosis by changing the probability of variables, so they are more comfortable for decision-makers to understand (Blodgett & Anderson, 2000; Ekici & Ekici, 2016). Finally, SEM is the appropriate method for describing theoretical constructs with no requirement for probabilistic inference to observable variables. If the prediction and diagnostics of observed variables is the required objective, then the BN should be adopted (Andersen & Kragh, 2015).

Many researchers (e.g., Chan et al., 2014; Panuwatwanich et al., 2008; Sarros, Cooper, & Santora, 2008; Wipulanusat et al., 2018) have conducted SEM to investigate conceptual models within the innovation research field. The SEM provides an empirically validated model based on innovation theory, which is appropriate for latent variable modelling. The linking of SEM to BN is achieved by determining the scores of the latent factors used in SEM, which can be utilised as raw data for latent variable modelling in BN based on the assumptions under which BN represents causality (Gupta & Kim, 2008). However, there is a lack of research examining the cause-and-effect relationships between these variables and the innovation outcomes. Therefore, this paper presented empirical research, which is necessary to increase the theoretical understanding of how innovation outcomes can be enhanced. In an attempt to shed additional light on this issue, the study developed a hybrid SEM–BN approach as a decision support framework for innovation management. This paper adopts an integrated approach that combines novel methods based on empirical validation of SEM and prediction ability of

BN (Gupta & Kim, 2008; Hsu et al., 2009; Li et al., 2018). This study combined SEM with BN to study the influence of climate for innovation, consisting of leadership for innovation and ambidextrous culture for innovation, on workplace innovation and career satisfaction.

3. Structural equation model

SEM is a statistical technique used to assess the causal relationships among model constructs, which also explains the covariance among a set of variables. In particular, SEM allows a simulant analysis that incorporates the observed (measured) and unobserved variables (latent/constructs), independent and dependent variables, in a graphical language, which is a powerful approach to present complicated relationships and related estimated parameters (Hair et al., 2010). The main objective of SEM is to test how a model derived from theory has a close fit to the sample data (Hair et al., 2010). SEM analyses are typically conducted in two steps: validating a measurement model and fitting a structural model (Byrne, 2010; Hair et al., 2010). A measurement model, achieved through confirmatory factor analysis (CFA), examines the loading relationships between latent variables and their corresponding observable variables, while structural models examine the hypotheses relationships among the unobserved variables through path analysis.

The measurement model consists of two equations, with terms defined as follows (Iacobucci, 2009; Wipulanusat, Sunkpho, & Stewart, 2021):

$$x = \Lambda_x \xi + \delta \quad (1)$$

$$y = \Lambda_y \eta + \varepsilon \quad (2)$$

Where:
x represents a column vector of exogenous, or independent, variables;
Λ_x represents the correlation matrix of exogenous factor loadings of x on ξ;
ξ represents a vector of the independent latent variables, exogenous constructs;
δ represents a column of measurement errors in x;
y represents a column vector of endogenous variables;
Λ_y represents the matrix of endogenous factor loadings of y on η;
η represents a vector of latent dependent, or endogenous, constructs;
ε represents a vector of measurement errors in y.

The structural model is an expression that is written by the following equation (Iacobucci, 2009; Wipulanusat et al., 2021):

$$\eta = \beta\eta + \Gamma\xi + \zeta \quad (3)$$

Where:
β represents a matrix of direct effects between endogenous variables;
Γ represents a matrix of regression effects of the exogenous variables;
ζ represents a column vector of the error terms.

The Analysis of Moment Structures (AMOS) version 22 was used to evaluate quantitative data using SEM, allowing the data from the SPSS analysis set to be automatically used in the AMOS computation (Byrne, 2010). Furthermore, AMOS visuals combine a simple graphical user interface with a robust computing algorithm, making its use appealing and providing calculations of the most critical parameters. The complete details of model development and assessment were explained in Wipulanusat et al. (2018). The structural model demonstrated an acceptable fit to observed data (χ^2= 300.89, *df* = 15, GFI = 0.98, CFI = 0.98, TLI = 0.95, IFI = 0.98, SRMR = 0.02, and RMSEA = 0.08), as shown in Fig. 2.

Following the conceptual model's satisfactory results, a model comparison should be conducted to confirm the final structural model to explain the data best. The model comparison aims at evaluating the model fit and comparing the fit of competing and theoretically plausible models (Byrne, 2010). This study employs a hierarchical analysis to compare the conceptual model with its nested models. A nested model refers to a subset of an original conceptual model, which has a specific link being added (model building) or removed (model trimming). This paper used the model trimming for the nested model, which was done by removing the path from ACI → CSF.

For the model comparison, parsimony fit measures such as the Akaike Information Criterion (AIC) is suitable for model comparison since they evaluate parsimony and fit (Arbuckle, 2013). AIC calculates predictive fit indices and illustrates how well a model could be supposed to fit sample data from the same population (Weston & Paul, 2006). AIC is mainly useful for selecting between the comparison of models rather than providing whether a single model fits the data. AIC is not appropriate for determining how well

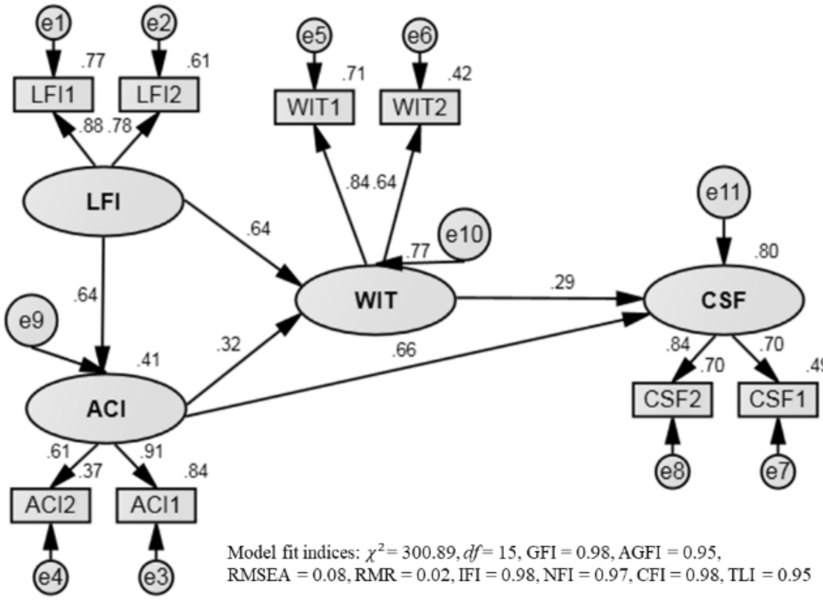

Fig. 2. Structural model
Source: (Wipulanusat et al., 2018).

a single model fits the data, but it is commonly used to select amongst models. The model which has the lowest AIC is considered to have a better fit.

As shown in Tab. 1, some fit indices in the nested model did not meet acceptable levels (i.e., AGFI = 0.89 and RMSEA = 0.11). In the case of the nested model, its AIC was 690.06, while the AIC value for the conceptual model was 342.90. The smaller AIC value demonstrated better parsimony for the conceptual model and a better fit than the nested model (Arbuckle, 2013). These AIC results supported the conceptual model as a parsimonious model and the preferred model to exemplify the survey data. Therefore, the conceptual model (Fig. 1) was confirmed as the structural model.

The structural model has provided fundamental background knowledge concerning how the climate for innovation is conceptualised, and the specific factors related to workplace innovation and career satisfaction. Table 2 presents the standardised coefficients from the structural model. Leadership for innovation was defined as an exogenous factor (γ). The remaining constructs were considered as endogenous factors (β). Leadership for innovation has a significant impact on ambidextrous culture for innovation (0.64, p<0.001) and workplace innovation (0.64, p<0.001). Ambidextrous culture for innovation has an influence on workplace innovation (0.32, p<0.001). Workplace innovation is also related to career satisfaction (0.29, p<0.001). Also, ambidextrous culture for innovation is a crucial antecedent for career satisfaction (0.66, p<0.001). Therefore, the structural model has been presented in this study to reveal the relationships between these constructs empirically.

Tab. 1. Comparison of the fit indices

Fit Indices	Nested Model	Conceptual Model
χ^2	650.06	300.90
df	16	15
GFI	0.95	0.98
AGFI	0.89	0.95
CFI	0.95	0.98
RMSEA	0.11	0.08
AIC	690.06	342.90

Tab. 2. Structural equations

Paths	Structural equations	Coefficient
LFI → ACI	$Z_{ACI} = 0.64(Z_{LFI})$	γ = 0.64
LFI → WIT	$Z_{WIT} = 0.64(Z_{LFI}) + 0.32(Z_{ACI})$	γ = 0.64
ACI → WIT		*β* = 0.32
ACI → CSF	$Z_{CSF} = 0.66(Z_{ACI}) + 0.29(Z_{WIT})$	*β* = 0.66
(WIT → CSF		*β* = 0.29

Note: $^{***}p < 0.001$; S.E., Standard Error; C.R., Critical Ratio

4. Bayesian networks

The structural model was subsequently adopted as a causal map to develop the directed acyclic graph (DAG) consisting of connected nodes representing important domain variables and arcs representing causal relationships between nodes. The BN uses a conditional probability table (CPT) to explain the probability of each node and describes the strength of the causal relationship between these nodes (Wipulanusat et al., 2020). There are N variables in the DAG. Nodes are variables presenting as $X_1, X_2,\ldots, X_n$. The set of parent nodes with an arc to X_i can be denoted by π_i, while $P(X_i \mid \pi_i)$ represents the conditional probability distribution (Wipulanusat, Panuwatwanich, Stewart, Parnphumeesup, & Sunkpho, 2020). The joint probability of the BN is referred to as the following formula:

$$P(X_1,X_2,\ldots,X_n) = \prod_{i=1}^{N} P(X_i|\pi_i) \quad (4)$$

The BN was developed based on an empirically tested structural model. The first step involved constructing a causal map, also known as the DAG, developed by analysing the sequence of constructs in the structural model. Developing the DAG started with the between-construct relationships from the theoretically validated structural model. Leadership for innovation (LFI) was confirmed to be a common cause of ambidextrous culture for innovation (ACI) and workplace innovation (WIT). Furthermore, culture for innovation (ACI) was found to be the direct cause of workplace innovation (WIT) and career satisfaction (CSF). This relationship between A and B is generated from a common cause C, represented as A ← C → B. The causal relationships were classified as follows: ACI ← LFI → WIT and WIT ← ACI → CSF. Once all causal relationships between constructs have been established, the DAG was developed based on an empirically validated model, as depicted in Fig. 3. Data entry for each node was the average value of the relevant questionnaire items of the construct. Based on the chance of occurrence, each node was discretised by categorising a five-point scale into three states: [1-2.5] as low, [2.5-4] as medium, and [4-5] as high. Netica software was used to construct the BN. The DAG and corresponding data were entered into the software for the parameter learning process.

In the next step, the counting algorithm was adopted for quantifying the CPT of each node. This is because it is the most straightforward method and a true Bayesian learning algorithm. When the CPTs were learned, the belief bars were used to present all node probabilities in the BN, as shown in Fig. 4. For example, the belief on the leadership for innovation node indicates that the medium state equals 59.5 per cent, which can be written as P(leadership for innovation = medium) = 0.595. The BN consists of four nodes and five causal relationships. In this situation, a mean LFI (59.5 per cent), a median ACI (70.5 per cent), and a median WIT (73 per cent) are likely to occur. These three nodes lead to the medium CSF node (70 per cent).

The mean value and standard deviation are displayed at the bottom of each node. The mean value of the career satisfaction node, for instance, is 3.28. Thus, there is significant room for development through increasing career satisfaction of engineers in the APS.

The first scenario of improvement emerges when there are the odds of 100 per cent occurrence of high leadership for innovation together with evidence of ambidextrous culture for innovation, as shown in Fig. 5. The probability of high career satisfaction rose from 19.3 to 53.0 per cent, representing an increase in the mean value of career satisfaction by 18.3 per cent (3.28 → 3.88).

In this scenario, innovation leaders can inspire employees to be innovative by fostering an innovation culture. Leadership for innovation, also known as innovation leadership, represents the ability and actions that develop and promote an organisational climate in which individuals can participate in innovation activities to acquire essential ideas. Innovation leadership is concerned with establishing, leading, and managing innovation processes and encouraging effective employee involvement in the process. A culture for innovation is an organisational culture that genuinely values and encourages innovation, allowing people to make it happen. A strong innovation culture is the prime mover that enables the organisation to improve continually, progress, and innovate.

Consequently, the BN allows entering evidence for each node and observing the change in other nodes' posterior probabilities. The inference was conducted to determine how much the mean values of related factors need to be improved for achieving the high state of career satisfaction. In this scenario, the career satisfaction node is assumed as the high state, as shown in Fig. 6.

Engineers' career satisfaction is crucial, considering that engineer shortage remains a critical challenge as the number of vacant jobs for engineers continues

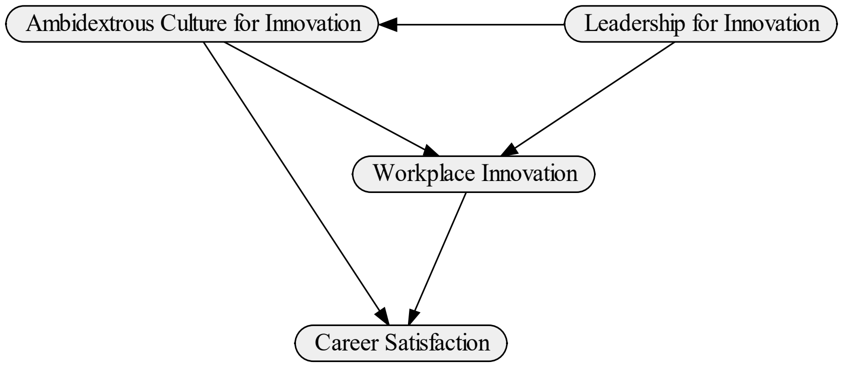

Fig. 3. Directed acyclic graph

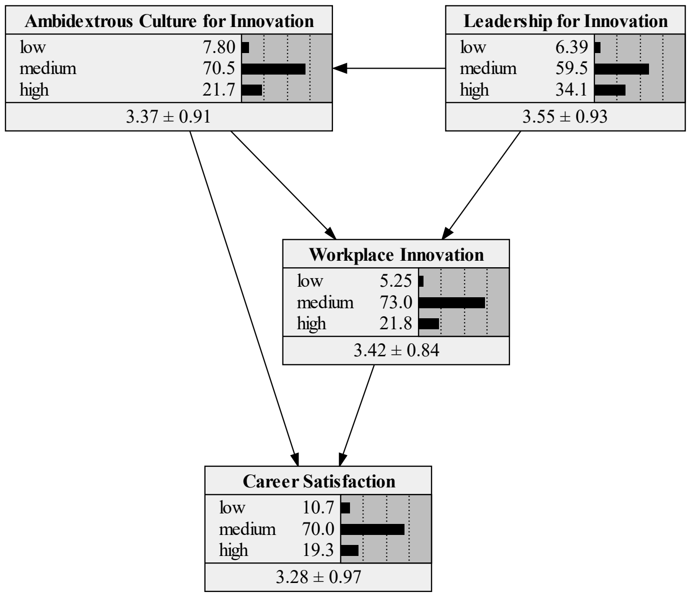

Fig. 4. Bayesian network

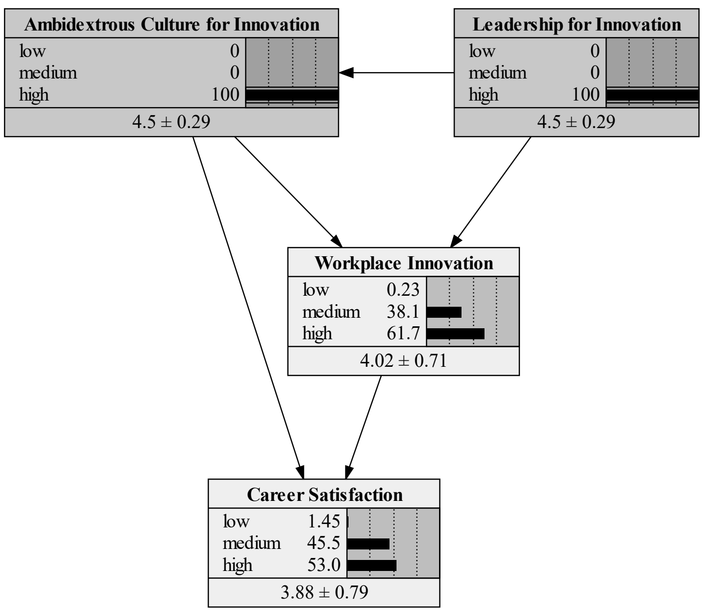

Fig. 5. Effect of high LFI and High ACI

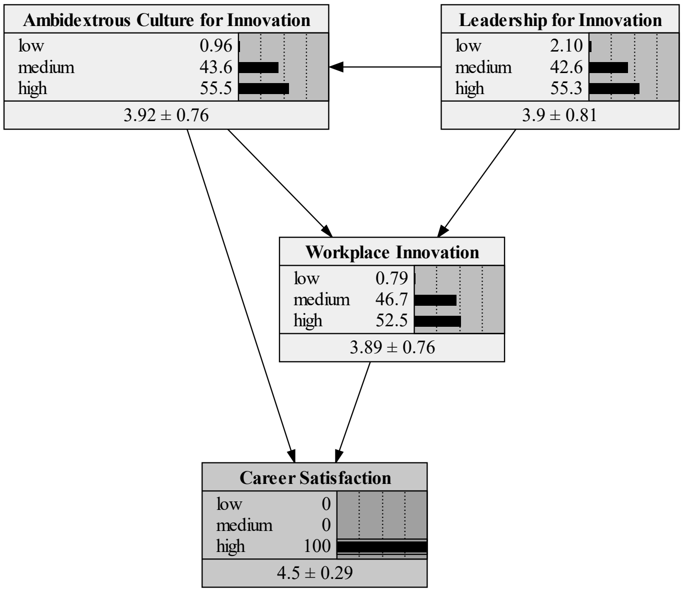

Fig. 6. Best scenario for career satisfaction

to rise in the APS. Improving engineers' career satisfaction could make engineering a more appealing profession. The APS should boost their engineers' intrinsic motivation to enhance their career satisfaction (Bielefeldt & Canney, 2019). Intrinsic motivation is based on the enjoyment of the engineering job itself. According to the job characteristics model, the optimal design of occupations is the most effective technique to motivate engineers. Job features such as independence, skill diversity, task uniqueness, task relevance, and assessment should be emphasised if work-related motivation needs to be promoted (García-Chas, Neira-Fontela, & Varela-Neira, 2016).

As presented in Tab. 3, increases in the change rates of the mean value of related factors were reported as part of the results. There was a slight change rate on the mean value of leadership for innovation (9.86 per cent), while ambidextrous culture for innovation needed to be increased considerably (16.32 per cent). There was a moderate increase in workplace innovation (13.74 per cent). Although this optimistic scenario may be challenging to implement, increasing the mean values of factors from 9.86 to 16.32 per cent should be considered to achieve a high career satisfaction of engineers in the APS.

Once the BN is constructed, the next step is to evaluate the model's ability for predictive correctness. To assess the performance of the BN, a confusion matrix was adopted for this study. The confusion matrix was used to determine classification accuracy from an error rate. It was developed with columns corresponding to the predicted values from the BN and rows representing the actual values from respondents' answers. To evaluate predictive power, 100 cases from the spreadsheet were randomly selected for analysis. As the BN's ultimate aim was to develop strategies for promoting career satisfaction, this node was specified as an output for calculating the confusion matrix. Table 4 presents the results of the confusion matrix developed to determine the robustness of the BN.

As evident from the confusion matrix, the total error rate was equal to 24 per cent, which indicated the model was 76 per cent accurate in its predictions for the career satisfaction node. The error rate of the BN indicated that the developed network had an

Tab. 3. Prior and the posterior mean value of factors

Factors	Mean value		Change rate (%)
	Prior	Posterior	
LFI	3.55	3.90	9.86
ACI	3.37	3.92	16.32
WIT	3.42	3.89	13.74

Tab. 4. Confusion matrix for the robustness test

Actual from responses	Predicted from the BN		
	Low	Medium	High
Low	2	5	1
Medium	1	68	4
High	0	13	6
Total error rate = 24 %			

acceptable level of accuracy. As part of the BN process, scoring rules were also calculated to provide an assessment of the degree of fit over a set of variables. These scoring rules comprise logarithmic loss, quadratic loss, and spherical payoff. Of the three scoring rules, the logarithmic loss is the one that calculates the value independently of the chance of the output that literally occurs (Dlamini, 2010). The logarithmic loss ranges between zero and infinity — the closer to zero, the better the model's goodness of fit. The quadratic loss varies between zero and two, where a lower value corresponds to better execution of the BN. Finally, the spherical payoff has a value between zero and one, indicating a perfect fit between the model and the data (Fuster-Parra et al., 2014; Mohammadfam et al., 2017). These indices are calculated by the following equations (Marcot, 2012):

$$\text{Logarithmic loss} = MOAC\ [-\log\ (P_c)] \quad (5)$$

$$\text{Quadratic loss} = MOAC\ [1 - 2P_c + \sum_{j=1}^{n} P_j^2] \quad (6)$$

$$\text{Spherical payoff} = MOAC \cdot [\frac{P_c}{\sqrt{\sum_{j=1}^{n} P_j^2}}] \quad (7)$$

Where MOAC represents an abbreviation for the mean over all cases (i.e., all cases in which the case file contains a value for the node in question). P_c stands for the predicted probability for the correct state, P_j stands for the predicted probability for state j, and n is the total number of states (Chanpariyavatevong et al., 2021).

The logarithmic loss and quadratic loss scores for the BN in this study were 0.6058 and 0.3454, respectively, while the spherical payoff was 0.8068. These scoring rule results indicated a reasonable degree of fit for the BN. No previous studies conducted in the area of innovation management report on these indices. However, they correspond to the indices presented by previous studies conducted in environmental and safety areas (Dlamini, 2010; Fuster-Parra et al., 2014; Mohammadfam et al., 2017). Thus, it can be concluded that the BN provided acceptable predictive abilities to examine the relationships between different factors in the innovation process for the APS.

5. Discussion and conclusions

While it is crucial to promote the career satisfaction of engineering professions in public sectors, little comprehensive research has been carried out to examine the innovation process within governmental agencies. This paper presents an integrating approach to link an empirically validated model based on structural equation modelling (SEM) with the Bayesian network (BN) method to understand the interplay between salient organisational constructs and their ability to influence career satisfaction in the Australian Public Service (APS).

According to the BN results, the ambidextrous culture for innovation was found to be the most crucial factor for increasing career satisfaction, in line with the previous research using a structural model conducted by Wipulanusat et al. (2018). Such a Hybrid SEM-BN approach can be used as a framework to devise strategies to improve engineers' career satisfaction in the public sectors. This paper proposes managerial implications for the commonwealth department to increase the career satisfaction of its engineers. The first managerial implication is that leaders should maintain a balance between an innovative and performance-oriented culture in their organisations. Innovative culture plays a significant role in improving innovation conditions, and the engineers can act as agents for innovation (Williamson, Lounsbury, & Han, 2013; Wipulanusat et al., 2019). Leaders must demonstrate the capacity to recognise the signs of imbalance between both cultures and prepare to restore the delicate balance when essential. Innovative leadership development programmes should also be adopted to prepare leaders involved in innovative initiatives effectively.

The second practical implication is based on developing creativity. Senior managers should provide opportunities for engineers to participate in the innovation process to create, develop, experiment with, and implement innovative solutions. Having the freedom to learn and take necessary risks under considerate guidelines can encourage continuous innovative behaviour in the workplace (Menzel, Aaltio, & Ulijn, 2007). Commonwealth departments that assign engineers to manage and develop current tasks while providing the engineers with enough innovative capability to predict possible solutions can achieve the transformation to confirm significant results and generate new solutions and production of innovative products, processes, or services, which results in increasing workplace innovation in their organisation. These integrated activities can help the APS functionally complementary achieve the ultimate organisational goal to optimise career satisfaction, which could reduce the turnover rate of these engineers (García-Chas et al., 2016). Because low career satisfaction may encourage engineers to change their job in the public sector, pursue a better fit for their values through a transition to work in the private sector, or, eventually, quit the engineer occupation and move into a different career (Bielefeldt & Canney, 2019).

The third managerial implication is that understanding engineers' career satisfaction is critical since human resources are an agency's most valuable intangible asset. Their attitudes influence organisational performance in the APS. Therefore, federal departments focus on attracting and retaining knowledgeable and well-educated engineers to work in their agencies, which can be achieved by supporting the innovation atmosphere. Public administrators should motivate and support engineers' creativity and design more fulfilling tasks and allow them greater autonomy. They should also explore methods to improve the innovation atmosphere in their agencies by motivating, encouraging, and acknowledging engineers who create innovative ideas and ensuring that agencies recognise the significance of their creativity, even if some of the ideas fail.

The fourth managerial implication is that federal departments, conventionally, are subject to more bureaucratic procedures, have more controls to avoid wrongdoing, and limit risk-taking activities. Public executives are likewise limited in their ability to use financial rewards to reward innovators. According to empirical research, financial rewards do not work effectively in the civil service (Demircioglu & Berman, 2019). Instead, executives should strive to enhance the innovation climate, promoting engineers' career satisfaction. Public agencies could train project managers to encourage engineers to contribute more ideas and change regulations to support more risk-taking initiatives in their projects.

Limitation and future research

This study has limitations that should be acknowledged. Some scholars argue that causality cannot be ensured by the results of any statistical techniques regardless of the level of complexity (e.g., Bullock, Harlow, & Mulaik, 1994). Scholars in the field of causal inference and SEM also agree that associations alone do not establish causal relationships (Weston & Paul, 2006). When a model is assessed and reveals a significant coefficient and model fit, a well-fitting structural model does not and cannot prove causal assumptions (Bollen & Pearl, 2013). However, the structural model can offer plausible causal relationships as it is proposed that causality can be determined by the underlying theory and research design (Lei & Wu, 2007). Therefore, this study was conducted by meeting the essential assumptions for causal inference. These assumptions included the data quality, the conformity of the hypothesis compared to theory, and the match between the hypothesis's substantive statement and the applied statistical method.

Future work should further examine the outcome of career satisfaction, such as how career satisfaction is related to career success in the public sector. This is because career satisfaction is a significant predictor of career success, defined as the accumulated positive work and psychological outcomes deriving from one's work experiences (Bretz & Judge, 1994). Career success has been conceptualised as extrinsic and intrinsic outcomes and is thus measurable using objective and subjective indicators. Objective career success indicates an extrinsic outcome, such as a sequence of official positions, salary changes, and formal structures and titles, all of which are publicly accessible and relatively tangible (Ng et al., 2005). In contrast, subjective career success is defined as employees' evaluations of their career progress and accomplishments, prospects for future advancement, development of new skills, and work-life balance relative to their targets and ambitions (Seibert & Kraimer, 2001).

However, having accomplished objective career success does not necessarily express that employees are satisfied with their careers (Hall & Chandler, 2005). Researchers have revealed that employees with a higher subjective career success feel happier about their careers relative to their own subjective judgments. Subjective career success demonstrates satisfaction over a long time frame and a wide range of outcomes, such as work–life balance and a sense of purpose (Ng et al., 2005; Seibert & Kraimer, 2001). Therefore, it is also significant to measure subjective career success as it has implications for employees' psychological well-being, self-managed careers, and their quality of work-life (Peluchette, 1993).

Acknowledgements

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and

Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Volume 13 • Issue 4 • 2021

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 1 July 2021
accepted: 10 December 2021

pages: 22-38

Barriers to implementation of business process governance mechanisms

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A B S T R A C T
One of the main challenges in implementing process-oriented management is establishing a governance mechanism in the organisation. It creates a coherent framework for the execution, management and perception of business processes, which is the foundation of consistent Business Process Management (BPM). Process governance (PG) refers to an organisation's ability to manage its relationships with all process stakeholders and support the value chain for its customers. Its implementation involves establishing process regulation mechanisms and stakeholder-oriented criteria to support prioritisation, cascading, and change management within BPM initiatives. A review of the domain literature reveals that while process governance has been discussed from several but separated perspectives (strategy, business roles, performance, and maturity), only a few studies identify and synthesise the barriers to its implementation in organisations. The paper mainly aims to identify and classify the key barriers to the implementation of process governance. The author's approach refers to the six core elements of Business Process Management capability and process governance frameworks. Research results confirm that most process governance barriers polarise around the competence gaps of the process stakeholders and the immaturity of the process-oriented culture of companies. Another significant group of constraints to process governance arises from the existing organisation's structure. They are mainly related to the proper division of responsibilities and a weak position or the lack of BPM centres of excellence. The research contributes to the literature on management by identifying potential barriers to business process governance that constrain BPM initiatives. The identified PG challenges can provide a basis for developing a theoretical framework for Business Process Management and models for BPM success factors.

K E Y W O R D S
business process management, process governance, success factors, barriers

10.2478/emj-2021-0029

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Introduction

Business Process Management (BPM) is becoming one of the leading approaches to governing contemporary organisations. It is confirmed by the market value of IT services and solutions in this area. It is predicted that the value of the global BPM market may increase by about 10 % by 2025, reaching USD 14–15 billion (Markets and Markets, 2020). Furthermore, more than 70 % of enterprises (Harmon & Garcia, 2020) have seen a significant increase in the

Jurczuk, A. (2021). Barriers to implementation of business process governance mechanisms. *Engineering Management in Production and Services, 13*(4), 22-38. doi: 10.2478/emj-2021-0029

BPM interest over the past two years. This is due to the growing need to respond more quickly to the changing market and customer expectations. It is also linked to the increasing effort to automate and robotise processes, as well as the perception of the business process itself as a service.

Although there are differences in specific BPM definitions (Jurczuk, 2019), it is generally considered a process-oriented management philosophy that uses modern IT systems and technologies to help manage the entire lifecycle of business processes (Elzinga et al., 1995). Due to the holistic approach, it addresses the area and challenges of organisational management related to both the business itself and the technologies driving its growth. The most frequently highlighted tangible effects of BPM implementation include cost reduction and improved quality of customer service, translating into improved competitiveness of the organisation (Harmon & Garcia, 2020). However, achieving specific benefits from implementing BPM is associated with the need to establish a formalised governance framework. They are aimed at developing situationally relevant organisations' structures, establishing a system of measures and monitoring processes and introducing an explicit division of roles and responsibilities for the functioning of processes in the organisation. Their establishment may lead to a tangible improvement in communication effectiveness and consistency of decision-making in the organisation (Markus & Jacobson, 2015).

Despite the well-established and mature nature of the BPM methodology (Huy et al., 2010), the success rate of BPM initiatives is relatively low and often stays below 50 % (Iqbal et al., 2015; Thennakoon et al., 2018, Funke & Syed, 2019). With that said, the success rate for large BPM projects (Syed et al., 2018) and those requiring collaboration between different functional units of the organisation is significantly lower (Spanyi, 2010). This may be due to an overlooked role of individual factors constituting BPM (Malinova et al., 2014). These include top management support, strategy alignment, methodology, clear responsibilities, culture, measurement and monitoring, and IT alignment (Trkman, 2010; do Amaral Castro et al., 2020). From the perspective of establishing and operating organisational governance mechanisms, this may be related to the lack of a comprehensive process governance (PG) approach (de Boer, 2015; Bandara et al., 2019). This factor is recognised as a key determinant of the success of BPM projects and initiatives (Kirchmer et al., 2015; Hernaus et al., 2016; Czarnecki, 2018). Moreover, PG also supports the management of organisational activities, spanning different functional areas (Spanyi, 2010; Hernaus et al., 2016). According to Scheer and Klueckmann (2009), governance mechanisms play an important role in facilitating the transition from unstructured to structured BPM. The pillars and success determinants of process governance are mainly roles and responsibilities, metrics, standards and the methodology (Jeston & Nelis 2008; Markus & Jacobson, 2015; Ensslin et al., 2017).

While the critical success factors of BPM are relatively well described in the literature (Trkman, 2010; Bai and Sarkis, 2013; do Amaral Castro et al., 2020), the problem of process governance (PG) barriers/constraints is not widely discussed in the literature (Spanyi, 2010; Valenca et al., 2013; Santana et al., 2011; Doyle & Seymour, 2020). A literature review on BPM did not reveal many papers that comprehensively considered barriers associated with establishing and operating process governance. The ongoing research in the area of process governance is mainly concerned with frameworks (Hove et al., 2015; Markus & Jacobson, 2015; Doebli, 2011; Kirchmer, 2017), the functioning of the process competence/excellence centre (Jesus et al., 2015; Bitkowska, 2018; Bandara et al., 2019), the role of the process owner (Hernaus et al., 2016; Danilova, 2018, Hrabal et al., 2020), and digital transformation (Fisher et al., 2020; Kerpedzhiev et al., 2021). Despite the multifaceted nature of these studies, their authors clearly indicate the relevance of process governance and the need for a further and more comprehensive exploration of this issue due to the changing and situational conditions of BPM implementation. The validity of exploring this issue is confirmed on the one hand by the growing interest in simplifying the activities of enterprises and on the other by the still relatively low success rates of BPM undertakings.

Therefore, the aim of the article is to identify key elements and retrospectively analyse barriers to establishing process governance in an enterprise. On the basis of the conducted literature study, including the results of post-implementation evaluations, the role of individual elements was indicated, and an attempt was made to classify the barriers to establishing PG using the Six Core Element BPM model and the key BPM process governance frameworks. The contribution of this article is a structured characterisation of the barriers and the development of the BPM capability framework in the area of process governance.

The remaining part of the article is organised as follows. The second part presents the theoretical background on process governance. The third part is devoted to the identification and discussion of PG barriers based on the results of literature studies.

On this basis, a synthetic approach to their typology is proposed. The fourth part formulates the final conclusions and recommendations concerning the PG implementation in an enterprise, research limitations and avenues for future efforts.

1. Process governance – theoretical background

Contemporary organisations are becoming increasingly aware that competitiveness improvement is possible by changing the orientation from functions to processes. Consequently, it leads to concentrating the organisation on process-based approaches, including Business Process Management (Harmon & Garcia, 2020). The Association of Business Process Management Professionals (ABPMP) defines BPM as a disciplined approach to identification, design, execution, documentation, measurement, monitoring and control of business processes to achieve consistent, focused results corresponding with the strategic objectives of the organisation. The key role of BPM is to coordinate the undertaken activities to maintain the consistency of the organisation's processes and the situational alignment of its tools and methods (ABPMP, 2013). This results in increased organisational performance through systematic and end-to-end operational improvements and business agility (Korhonen, 2007). Many researchers (Spanyi, 2010; Markus & Jacobson, 2015; Bandara et al., 2019) emphasise that achieving specific benefits from successful BPM initiatives requires a formalised governance framework.

The understanding of the general concept and role of process governance in the domain literature is relatively consistent (Ensslin et al., 2017). The primary PG objective is to ensure that BPM is implemented effectively to meet the expectations of the organisation and its stakeholders (Kirchmer, 2015). Process governance generally refers to an organisation's ability to manage relationships with all process stakeholders and value creation for their internal/external customers. It is defined as a set of guidelines and resources that an organisation uses to facilitate collaboration and communication when it undertakes process initiatives (Hove et al., 2015). Process governance was similarly characterised by de Bruin (2009), pointing out that its key elements are: establishing appropriate and transparent responsibility, establishing rules for making decisions, and rewards and motivation. Spanyi's definition (2010) of process governance also directly indicates its role to provide appropriate structures, metrics, roles and responsibilities to measure, improve and manage the performance of a company's end-to-end business processes. It is also emphasised that governance mechanisms must be consistent and established for the entire BPM activities and individual business processes (Rosemann & Vom Brocke, 2010).

Process governance is achieved primarily thanks to the use of acceptable, clearly understandable rules and regulations that create a consistent framework for the performance, management and perception of business processes. A mechanistic or organic approach is used to establish and implement them (Braganza & Lambert, 2000; Markus & Jacobson, 2015). In the first case, creating the foundations of governance is based on formal documents containing a strategy, business plan and descriptions of the roles and responsibilities of process owners/leaders. All decisions, agreements, and regulations are formally recorded. On the other hand, with the organic approach, leaders, by providing information about decisions and changes (informal personal interactions), strive to fully understand the external conditions that determine the functioning of the organisation, its goals and strategy. However, in relation to these approaches, it is worth emphasising that they should be treated as complementary methods. The formal approach does not guarantee capturing and describing all aspects ensuring the desired level of governance, while the informal approach does not create a permanent basis for BPM (Braganza & Lambert, 2000; Markus & Jacobson, 2015). Organisations try to adapt various appropriate forms and a framework of process governance and their conditions of BPM implementation (Bhat & Fernandez, 2007; de Boer et al., 2015; Bandara et al., 2019). However, no one universal established approach exists to implementing PG and/or there is no established structure and scope for such a project (Doebli et al., 2011; Valenca et al. 2013; Czarnecki, 2018; Hernaus et al., 2019).

Based on the literature review, an attempt was made to identify the essential elements and capabilities of an organisation that constitute the establishment of process governance. Table 1 presents a proposal for a synthetic set of core elements constituting process governance together with a reference to research results confirming their relevance. Considering the indicated dissimilarity and specificity of certain groups of PG elements (Braganza & Lambert,

Tab. 1. Generic elements of process governance mechanisms

PG approach	Process governance core elements	Related elements	Reference (selected examples)
Impersonal	Methodology and process management standards	BPM frameworks BPM Life-Cycle Process documentation Process architecture	Richardson, 2006 Bhat & Fernandez, 2007 DeBruin, 2009 Jeston & Nellis, 2014 Rosemannn & Vom Brocke, 2015 Jurczuk, 2019
	Measurement and performance	Process metrics Measurement system Performance linkage	Spanyi, 2010 Doebeli et al., 2011 Kohlbacher & Gruenwald, 2011 Rosemannn & Vom Brocke, 2015
Personal	Roles and responsibilities	Process owner BPM-related roles	Bhat & Fernandez, 2007 Davis &Brabänder, 2007 Spanyi, 2010 Vom Brocke et al., 2014 von Rosing et al., 2015 Danilova, 2018 Hrabal et al., 2020
	Cooperation bodies	Process improvement and governance charters/teams BPM Centre of Excellence (or Competence Centre or BPM Office)	Bhat &Fernandez, 2007 Davis & Brabänder, 2007 Jeston & Nelis 2008 Vom Brocke et al., 2014 von Rosing et al., 2015 Markus & Jacobson, 2015 Rahimi et al., 2016 Bitkowska, 2018 Bandara et al., 2019

2000; Spanyi, 2010; Markus & Jacobson, 2015; Danilova, 2018), their division into two categories representing impersonal and personal approaches to process governance was proposed. As Markus & Jacobson (2015) emphasised, impersonal or institutional mechanisms are advisable when business processes cross the boundaries of the organisation or its business units. At the same time, they are rarely effective without personal governance mechanisms that consider the need for coordination, process control and collaboration provided by the BPM leader, process owners and employees representing specific process roles (Vom Brocke et al., 2014).

The group of elements of the impersonal approach includes methodology and standards, measurement and performance. The personal PG mechanism includes issues related to the definition of process roles and the appropriate division of responsibilities. Moreover, within this element, the establishment of process teams and the Business Process Management Centre of Excellence (BPM CoE) were deliberately highlighted. In the domain literature, such a centre is also referred to as BPM Competence Centre or BPM Office. The distinction of this PG element is due to the establishment of the BPM CoE, which is crucial for the division of responsibilities and the communication and decision-making process related to BPM initiatives (Richardson, 2006; Davis & Brabänder, 2007; Jeston & Nelis 2008, Bitkowska, 2018).

To verify and realign the identified process governance core elements, they were matched with selected models and frameworks that have been referred to most frequently by other researchers analysing BPM issues (several citations in Google Scholar). The Business Process Management Six Core Elements model (Rosemann & Vom Brocke, 2010) was taken as the generic model for the PG capabilities of organisations. This is because it represents the widely accepted critical success factors of BPM. These are strategic alignment, governance, methods, information technology, people, and culture. For each of the elements of the model, Capabilities Areas are defined, which refer to the capabilities of the organisation that are crucial for the success of a BPM implementation. According to the accepted assumptions of the BPM Six Core Elements model, the governance factor represents activities and guidelines related to establishing appropriate and clear accountability in terms of roles and responsibilities for the different levels of BPM and designing decision-making and reward processes to guide process activities (Rosemann & De Bruin, 2005). The process governance frameworks proposed by Kirchmer (2017), and Braganza & Lambert (2000) were also used to assess the relevance of process governance core elements. They provide guidelines related to the establishment of PG in an organisation complementing the BPM Six Core Elements model. They represent the integration perspective of strategy, business processes and accountability (Braganza & Lambert, 2000) and the enterprise-specific execution of BPM (Kirchmer, 2017). The relevance analysis of the PG elements also considered the BPM guidelines developed by Jeston & Nelis (2014).

The core elements identified from the literature review are reflected in the selected process governance frameworks (Table 2). Two elements, "measurement and performance" and "roles and responsibilities", are directly included in all models and guidelines. BPM methodology and standards are included in the BPM Six Core Elements model (Rosemannn & Vom Brocke, 2015) and the guidelines developed by Jeston & Nelis (2014). In the analysed studies, the element related to establishing process teams and changes in the organisation's structure is implicitly indicated as the key to process governance. It is mostly considered in the context of defining roles and responsibilities, i.e., teamwork, distributed leadership, and empowerment.

In the investigated frameworks, the element related to the establishment of the BPM Centre of Excellence and the associated changes in the organisation's structure is usually not isolated. This factor is considered in the context of business roles and responsibilities. However, the analysis of the expert opinions and the results of the research carried out so far justify developing the existing frameworks (Table 1) and distinguish the governance bodies as a fourth and key element constituting the establishment of PG in the organisation. Due to the role of the BPM Centre of Excellence in the functioning of the governance mechanisms, it is proposed to separate this factor as a key PG element.

BPM standards and methodologies are mainly based on reference models. They play an important role in end-to-end improving and managing business processes (Spanyi, 2010). The literature indicates that the BPM implementation success significantly depends on understanding, adaptation and skilful application (Jurczuk, 2019). The undertaken BPM methodology standardisation efforts are aimed at unifying initiatives in terms of methods, tools, meas-

Tab. 2. Core elements of process governance — frameworks review

Reference model/framework	Citation number in Google Scholar	Process governance core elements			
		Methodology and process management standards	Measurement and performance	Roles and responsibilities	Cooperation bodies
BPM Six Core Elements model (Rosemann & De Bruin, 2005; Rosemann and Vom Brocke, 2010)	446	F	F	F	I
Process guidelines (book chapter) (Jeston & Nelis, 2014)	1468	F	F	F	F
Process Governance Framework (Braganza & Lambert, 2000)	75	I	F	F	I
Business Process Governance (Kirchmer, 2017)	66	I	F	F	I

Description: F — fully covered, I — indirectly covered, N — non covered ures and indicators, process architecture and document templates. Richardson (2006) and Santana et al. (2011) emphasised that the use of a domain-appropriate and formalised methodology makes it possible to establish consistent rules for process management and to standardise the rules and forms of their description. Moreover, BPM standards refer to a set of guidelines with respect to the establishment and management process measures, issue resolution, reward, and remuneration structures (Rosemannn & Vom Brocke, 2015).

Measuring the performance of business processes is fundamental from the perspective of their management and improvement. The fundamental role of this activity is to determine whether a business process meets the planned objectives (Kohlbacher & Gruenwald, 2011). From the PG perspective, an important issue of process monitoring is the consistency of the process performance assessment and the established strategic objectives of the organisation. Whereby the process governance mechanisms in place should ensure access, collection of the required process metrics and linking them to performance criteria (Rosemannn & Vom Brocke, 2015). It is also necessary to provide methodological support for the design, alignment of process measures (and measurement methods), and rules for feedback on measurement outcomes (Doebeli et al., 2011). These issues are closely linked to a consistent way of defining and allocating responsibility for this element of process governance (Kohlbacher & Gruenwald, 2011; Christiansson & Rentzhog, 2020).

The next PG element, i.e., roles and responsibilities, represents the entire range of BPM-related roles. While there is no agreement among researchers regarding the nomenclature and names of process roles themselves (ABPMP, 2013; Kettenbohrer, 2016; Hrabal et al., 2020), it is the importance of the human factor that is considered crucial for the successful management of business processes in an organisation (Kratzer et al., 2019; do Amaral Castro et al., 2020). From the perspective of BPM success, one of the most important process roles is undoubtedly the process owner (Ensslin et al., 2017; Danilova, 2018; Hrabal & Tucek, 2018). Their responsibilities include designing, documenting and standardising processes.

A process owner also participates in activities related to performance management, process improvement and innovation. A very important issue in the context of consistency of cross-functional decision-making is, first of all, the necessity of formal decision-making empowerment of the process owner in the structure of the organisation (Bandara et al., 2019). Furthermore, the effectiveness of process governance mechanisms depends on its ability to manage and lead process teams and to communicate and manage stakeholders (Funke & Reha, 2019). These tasks are performed within process teams and in cooperation with the BPM Centre of Excellence (or BPM Competence Centres or Business Processes Office) (Santana et al., 2011; Bitkowska, 2018; Hrabal et al., 2020).

Establishing a BPM Centre of Excellence (BPM CoE) and process teams as a PG part within the organisation means to formalise the roles and responsibilities of business process stakeholders. According to several researchers (Richardson, 2006; Rosemann, 2015; Hammer, 2015; Bitkowska, 2018), the BPM CoE plays a key role in process governance. The BPM CoE should be the main source of support for process owners, providing guidance, knowledge transfer and data exchange. With that said, the portfolio of its service may vary widely (Rosemann, 2015, Jeston & Nellis, 2014). The responsibilities of the BPM CoE generally include leading BPM, implementing the regulatory framework for BPM, offering project support, providing training, communication between process stakeholders and process management (Richardson, 2006; Hammer, 2015; Bitkowska, 2018).

The challenge of establishing a BPM CoE is its place in the structure of the organisation, which should be aligned with the operating conditions and the process maturity level of the enterprise (Christiansson & Rentzhog, 2020). Bitkowska (2018) considered it a centralised and separated organisational unit. Markus and Jacobson (2015) considered it a unit forming a separated level of the organisation's decision-making hierarchy (a hierarchy approach). Furthermore, the BPM CoE can operate through informal and formal lateral process stakeholder relationships (a horizontal approach). It is also possible for more than one BPM Centre of Excellence to operate within the structure of the organisation. The way the BPM CoE functions should ensure the coordination and management of BPM initiatives in the enterprise.

The core elements of process governance identified based on the literature review formed the basis for the analysis and synthesis of barriers to its implementation in an organisation. Their identification enabled some systematisation of the limitations and obstacles to the process governance mechanisms in an organisation and thus to the implementation of successful BPM initiatives.

2. Methodology and research process

The identified core elements were the basis for defining barriers to process governance implementation in organisations. Based on the literature review results, an attempt was made to perform a cross-sectional analysis and then a synthesis of barriers to implementing process governance mechanisms. This task was performed using the idea of conceptual framework analysis (CFA) process proposed by Jabareen (2009). This qualitative method supports building a conceptual framework for phenomena that are linked to multidisciplinary bodies of knowledge. It refers to the methodology for developing a theoretical or conceptual framework based on the analysis of different data sources presented by Miles and Huberman (1994). The use of this methodology to identify PG barriers allows the existing literature to be synthesised without analysing primary data (Paré et al., 2015). The overview of the research process is given in Table 3.

The first phase of this research was dedicated to mapping and selecting the literature related to the research area. The sources of information were publications considering Business Process Management, Business Process Orientation (BPO), BPM critical success factors and BPM/BPO maturity, process governance, corporate and IT governance. In the next phase of the research process, a review of the collected literature resulted identifying potential barriers to the implementation of process governance in organisations. According to the applied methodology, in the next stage of the research process, the identified barriers were reviewed and classified (phase 2). The following step of the research (phase 3) involved the integration and grouping of the collected data using the PG core elements identified in the earlier step. The research process was concluded with the synthesis of the obtained analysis results (phase 4). The results of the study were the basis for the final conclusions and recommendations.

The suitability of such an approach is confirmed by work related to the identification of BPM success factors (Gabryelczyk, 2018), a social pattern of business process (Schoormann et al., 2019), and corporate governance (Bawazir et al., 2021).

3. Barriers to the implementation of process governance — results and discussion

The potential barriers to implementing the governance process result from the cross-sectional analysis of the domain literature. According to the adopted methodology, identified barriers were verified, structured, and then mapped to the defined PG core elements. Tables 4–7 present a synthesis of the results of the conducted research in relation to each of the core elements.

One significant problem related to the lack of or ineffective process governance mechanisms is the failure to achieve the assumed goals of BPM implementation. The analysis of the identified PG barriers shows their polarisation around the issue of perception and the use of formalised methodologies related to the execution and integration of tasks within the whole Business Process Management Life-Cycle (Table 4). In this context, the passive transfer of BPM methodologies is a significant problem to process governance consistency. As Kelemen and Kostera (2002) pointed out, the lack of their internalisation may lead, under certain conditions, to the failure of the undertaken BPM initiatives. Kerpedzhiev et al. (2021) also pointed out that failure to consider the context of the use of BPM methods and tools can negatively affect the implementation of tasks derived

Tab. 3. Overview of the research process

Phase	CFA phase	Objective of the phase as per CFA
1	Collecting, mapping and reading literature referring to the research area	Mapping the spectrum of multidisciplinary literature regarding the business process governance Studying and categorising selected papers
2	Identification and definition of potential barriers to the process governance implementation	Identification and understanding the background of potential barriers of BPM implementation and governance
3	Integration of potential barriers to the process governance implementation	Integration and grouping together potential barriers to implementation of process governance
4	Synthesis	Synthesis barriers to implementation of process governance

Source: Elaborated by the author based on Jabareen, 2009.

from the BPM Life Cycle. The unfamiliarity with or incomplete understanding of BPM methodologies and standards can result in inconsistent process governance in planning and organising BPM initiatives undertaken by the organisation. As noted by Bandara et al. (2009), the lack of knowledge and correct application of BPM methodologies and standards are among the significant barriers to process management success. The need for standardisation of BPM methodologies is also emphasised by Scheer and Klueckmann (2009) in the context of coordinating the work of individual process teams in an organisation. The lack of standards means that content can be interpreted differently, leading to decisions based on incorrect data. Considering the specificity of PG barriers in the area of methodology and process management standards (Table 4), their appearance may be due to the low level of necessary knowledge and skills of process stakeholders in this area. Deficiencies in BPM and process governance competencies may affect the quality of identifying customer needs, critical success factors, defining enterprise architecture and process architecture.

An adequate and consistent approach to documenting business processes is also an important PG barrier. The results of empirical studies indicate that, on the one hand, their documentation and modelling is a relatively well-known and applied practice among companies implementing BPM (Gazova et al., 2016; Paschek et al., 2018), while, on the other hand, inconsistencies of process documentation/models are a barrier to effective process management frequently reported by researchers (McCormack et al., 2009; Glavan et al., 2015). The non-compliance of processes with documentation reduces the value they create from both internal and external customer perspectives (Hashmi et al., 2018). Inconsistencies in process documentation can significantly affect how well it is understood and accepted by process stakeholders. As a result, this leads to a mismatch in the way processes are performed and degrades the effectiveness and efficiency of their management and the communication of process participants (Jurczuk, 2019). This problem is considered more extensively by researchers in the context of the process culture of organisations (Schmiedel et al., 2013; Štemberger et al., 2018).

A major challenge for the operation of PG mechanisms is also the standardisation of processes and their compliance with external regulations and standards. The dilemma between the need to formalise processes and the need to maintain their flexibility and ability to innovate is highlighted (Schäfermeyer et al., 2012; Schmiedel & Vom Brocke, 2015; Wurm & Mendling, 2020). On the one hand, a tighter governance mechanism brings a more formalised processes documentation and training (Wurm

Tab. 4. Barriers to implementing process governance mechanisms — methodology and BPM standards

Core element	Governance barriers	Reference (chosen)
Methodology and BPM standards	• non-compliance with enterprise policies and external regulatory standards • insufficient or no understanding of BPM methodology (including process modelling notations) • inconsistent framework and methodology usage • "unavailability" of the methodology due to limitations of the organisation's resources (human, technical, financial) • lack of full, required compliance with external standards that determine the functioning of the organisation • under-implementation of methodologies and standards to support governance (i.e., P3M3, PMI PBA, BABOK, CMMI, BPMM-OMG) • omission of strategic goals and objectives from the BPM lifecycle • inconsistent, non-compliant process architecture • no identification of key cross-departmental processes in the organisation • inconsistency between the various types of process documentation • non-compliance of process documentation with the requirements of their stakeholders, IT developers (including Robotic Process Automation, RPA) • variation in the tools, standards, and methodologies used by different groups around similar BPM activities • inconsistency of business solutions and IT support (software, systems)	Kelemen & Kostera, 2002 Richardson, 2006 Bhat & Fernandez, 2007 Bandara et al., 2009 DeBruin, 2009 Ko et al., 2009 McCormack et al., 2009 Scheer & Klueckmann, 2009 Santana et al., 2011 Schäfermeyer et al., 2012 Schmiedel et al., 2013 Rosemann & Vom Brocke, 2015 Hove et al., 2015 Glavan et al., 2015 Gazova et al., 2016 Hashmi et al., 2018 Paschek et al., 2018 Štemberger et al., 2018 Jurczuk, 2019 Wurm & Mendling, 2020 Kerpedzhiev et al., 2021

& Mendling, 2020), while on the other hand, the formalisation of processes may limit their flexibility and creativity and innovation of employees (Tregear, 2015). Kerpedzhiev et al. (2021) considered BPM capabilities in the context of digital development and indicated a barrier to the development of governance mechanisms, i.e., an underestimation of the role of standards and guidelines for data management.

Establishing process governance mechanisms for process performance is a multidimensional problem and requires considering aspects related to both strategic and operational management as well as human resources, organisational behaviour or information systems (Franco-Santos et al., 2007; Sangwa & Sangwan, 2018). Process performance should be an integral part of corporate performance evaluation. In general, governance barriers related to measurement and performance may arise from an organisation's inability to adapt and apply a comprehensive process management methodology and a low level of process maturity and culture (Van Loy & Devos, 2019; Schmiedel et al., 2020). The analysis of identified barriers to process governance (Table 5) showed that they revolve around two main aspects: design and measurement and reporting and information flows.

A key issue from the perspective of the occurrence of potential barriers to process governance mechanisms is to ensure that process measurement and monitoring is comprehensive, and that objectives and performance indicators are consistent (Franco-Santos et al., 2007; Eckerson, 2009; Enslin et al., 2017; Kirchmer, 2017). This should be an integral part of enterprise governance (Hove et al., 2015; Dominguez et al., 2019). It is noted that the usability of the measurement system is influenced by the quality of the evaluation criteria of the process measures themselves and their information potential, and the quality of the data captured (Khosravi, 2016). As with the previous PG core element, a significant barrier to measurement and performance is the low level of process competence of employees and an organisation's process culture that is not aligned with the circumstances (Schmiedel et al., 2013; Jurczuk, 2019). The lack of a well-developed process culture of an organisation may affect the attitudes of process stakeholders in identifying and responding to problems in processes and the reliability of information and data supporting process governance. A derivative of competence gaps and data quality may be the misinterpretation of metrics as well as measurement outputs. This may lead to unjustified adjustment activities resulting in unnecessary changes in the way processes are performed. Moreover, their adjustment mechanism based on inconsistent metrics and unreliable and incomplete information may lead to discrepancies in the way processes are performed and organised. This is usually associated with a lack of critical analysis of the documentation in force in the enterprise prior to the introduction of changes to processes, which are assumed to lead to a reduction in their time and cost (Kohlbacher & Gruenwald, 2011; Enslin et al., 2017). As a result, it may cause deregulation of processes and their implementation according to the own preferences of their performers and not according to the established rules.

PG barriers related to measurement and performance may also result from information overload and insufficient support of IT tools in the design and use of the process monitoring system, including visualisation of process performance evaluation results (Valenca et al., 2013; Rahimi et al., 2016; Dominguez et al., 2019). The consequence of such a state is the inconsistency of information that forms the basis of managerial decisions related to the current and future way of process execution and, consequently, the functioning of the organisation (Jurczuk, 2019). This constitutes a critical barrier to the proper functioning of governance process mechanisms.

Roles and responsibilities, according to many researchers (Spanyi, 2010; Doebeli et al., 2011; Hammer, 2015; Rosemann & Vom Brocke, 2010), are a key element in activating process governance mechanisms in an organisation. As Hammer (2015) emphasised, the sustainable institutionalisation of BPM requires an appropriate division of responsibilities that ensure a holistic view of the relationships and impacts of business processes. Furthermore, it is important to ensure that the introduced division of roles and responsibilities does not turn into a new generation of horizontal silos (Hammer, 2015).

A review of ongoing research in this area has shown that the main constraints to the PG functioning include the lack of a process owner (Kohlbacher & Gruenwald, 2011; Danilova, 2018; Hrabal & Tuĉek, 2018) and the deficiency of or inadequately shared responsibility (Spanyi, 2010; Hammer, 2015; Rosemann & Vom Brocke, 2010). Discussions of the barriers to the functioning of process governance in relation to the key role of the process owner in BPM emphasise that these arise from the lack of real decision-making authority (Vom Brocke et al., 2014; Danilova, 2018; Hrabal & Tuĉek, 2018).

The effectiveness of PG mechanisms also depends on the place of the process owner in the hierarchy of

Tab. 5. Barriers to implementing process governance mechanisms — measurement and performance

Core element	Governance barriers	Reference (chosen)
Measurement and performance	• not recognizing the requirements of process stakeholders • poor or lack of linkage between BPM goals and the goals of business units/company • undefined or ambiguous overarching organisational goals and corresponding Key Performance Indicators (KPIs) • lack of vertical and horizontal integrity of process measurement systems • lack of clear, effective rules and mechanisms to identify areas, processes requiring improvement (risks, weaknesses) • lack of information on the monitoring of a strategy, business drivers • non-systematic measurement activities • lack of feeding back mechanism into BPM planning stages • misunderstanding of process evaluation results non-appropriate business processes performance review mechanisms • ineffective or lack of reporting, process knowledge management system, including acquisition, interpretation and enforcement of audit information • misinformation on process monitoring provided by stakeholders • lack of information on how objectives/business drivers are achieved • non-sufficient IT support • information overload • lack of precise rules for filtering and information flow • non effective reward system	Franco-Santos et al., 2007 Eckerson, 2009 Schmiedel et al., 2014 Hove et al., 2015 Hernaus et al., 2016 Rahimi et al., 2016 van der Aalst et al., 2016 Sangwa & Sangwan, 2018 Dominguez et al., 2019 Van Loy & Devos, 2019 Schmiedel et al., 2020

Tab. 6. Barriers to implementing process governance mechanisms — roles and responsibilities

Core element	Governance barriers	Reference (chosen)
Roles and responsibilities	• undefined or inadequate division of tasks, responsibilities, and the decision-making hierarchy in relation to the organisational structure and process architecture (all its levels) • lack of empowerment • weak position or no appointment of process owners • failure to define the scope of responsibilities and authority of process owners • lack of exchange of information regarding the reallocation of resources, redefinition of process roles, and responsibilities of process performers • failure to establish structures and principles for cross-departmental (functional) leadership and process coordination, including responsibility for improving and managing the organisation's key processes • lack of rules and best practices for communicating the organisation's strategy and business objectives	Rosemann & de Bruin, 2005 Spanyi, 2010 Doebeli et al., 2011 Kohlbacher & Gruenwald, 2011 Valenca et al., 2013 Nurdiani et al., 2014 Hamer, 2015 Reijers et al., 2015 Hernaus et al., 2016 Syed et al., 2016 Kirchmer, 2017 Hrabal & Tuĉek, 2018 Danilova, 2018 Klun & Trkman, 2018 Bruccoleri et al., 2019 Kratzer et al., 2019

the organisation (Markus & Jacobson, 2015; Hrabal et al., 2020) and their leadership experience (Kohlbacher & Gruenwald, 2011; Danilova 2018). The effectiveness of PG mechanisms may be affected by the issue of centralising or decentralising responsibilities of process ownership roles (Hrabal et al., 2020).

To avoid the basic barrier of process governance, which is the conflict of decision-making powers, it is recommended to create a new position in the organisational structure for the process owner independent of vertical divisions of responsibility (Markus & Jacobson, 2015, Hernaus et al., 2016). Moreover, the functioning of PG mechanisms may be limited by problems of resource competition or resource mismatch.

Therefore, issues of defining responsibility should be considered with the allocation of resources needed for BPM projects (Nurdiani et al., 2014; Jurczuk, 2019). However, as emphasised (Hammer, 2007; Hernaus et al., 2016), the position of the process owner should be defined and reviewed as the process maturity level of the organisation changes.

The analysis of PG barriers related to roles and responsibilities has also shown that their underlying cause is the lack of an empowered process culture in the organisation, especially in terms of employee attitudes and behaviours, leadership or communication, and teamwork ability (Santos & Alves, 2015; Schmiedel & Vom Brocke, 2015). Potential constraints may result from the difficulty of performers to adapt to process-oriented work styles and principles, siloed employee mentality leading to the limited focus on cross-functional processes, lack of focus on systematic improvement and innovation, and lack of BPM communication strategies (Rosemann & de Bruin, 2005; Klun & Trkman, 2018). The process governance mechanisms are also adversely affected by the inability to work and make decisions collectively (Spanyi, 2003; Alibabaei et al., 2009). This problem is explored in the context of the "Abilene Paradox" (Bruccoleri et al., 2019). The occurring constraints in sharing and executing responsibilities are also linked to the lack of appropriate skills in methodologies supporting BPM implementation (Hove et al., 2015; Jurczuk, 2019). The lack of adequate methodological support may negatively affect the consistency of proceedings, knowledge transfer, consistency of documentation, and, thus, the behaviour and attitudes of process stakeholders and, as a result, process governance mechanisms.

Another barrier to the implementation of PG mechanisms is related to leadership problems. On the one hand, its quality reflects the willingness of the BPM leader to lead and take real responsibility for business processes and, on the other hand, the extent to which the necessary leadership skills are applied in business practice (Syed et al., 2016; Wipulanusat et al., 2017; Bruccoleri et al., 2019). Occurring barriers to this underlying background are usually related to the lack of or insufficient support of BPM initiatives undertaken by the company's governing body. It can also be linked to the lack of a multilevel communication system to ensure the consistency of the information needs network and the integrity of information sources (zur Muehlen & Ho, 2006; Jurczuk, 2019). As Funke & Reha (2019) and Kratzer et al. (2019) highlighted, a barrier to BPM implementation may be the lack of a people-oriented leadership style. Leadership issues also arise in the context of knowledge transfer and discrepancies in requirements and behaviours in subordinate-supervisor relationships (Syed et al., 2016; Kirchmer et al., 2015). In the era of digital technologies and prevailing digitalisation and automation of business processes (Kirchmer, 2017; Kratzer et al., 2019; Kerpedzhiev et al., 2021), it is also worth paying attention to leadership barriers in the context of implementing technology changes in the organisation. This problem was recognised by Appelbaum et al. (1998), pointing to the legitimacy of changing the optics of the leader from technocratic to interpretive. Problems with sharing and executing responsibilities are also linked to the lack of appropriate skills in methodologies supporting BPM implementation (Hove et al., 2015; Jurczuk, 2019). The lack of adequate methodological support may negatively affect the consistency of proceedings, knowledge transfer, consistency of documentation, and, thus, the behaviour and attitudes of process stakeholders and, as a result, process governance mechanisms.

An important constraint for process governance mechanisms is the non-existent or inappropriately functioning BPM bodies, including the Centre of Excellence and process teams. In conjunction with the formally separated process roles (process owner, BPM manager), these constitute the basis for establishing governance bodies in the organisation (Jesus et al., 2018; Van Looy & Devos, 2019). The identified barriers related to this core element are included in Table 7.

As Rosemann (2010) points out, organisations usually establish BPM Centres of Excellence only as their process maturity increases. This is a consequence of the process-driven development of the organisation (Hammer, 2015). Failure to establish a BPM CoE may be due to unwillingness to break the existing structure of authority's influence, fear of loss of power of individual functional units resulting from the implementation of a process approach to management (Jurczuk, 2019).

When analysing the barriers of process governance, it is worth noting the importance of the CoE for the success of BPM. Indeed, the main tasks of the Centres of Excellence include, as mentioned above, supporting the implementation and coordination of BPM projects, knowledge transfer and providing support in the field of BPM methodologies, technique, tools and strategy alignment and establishing a process-oriented culture in the organisation (Richardson, 2006; Bitkowska, 2018). The establishment of a BPM centre is primarily intended to eliminate obstacles associated with cross-departmental interaction, collaboration and, of course, communication with external/internal process participants. This is particularly important in the case of interdepartmental business process initiatives, which, due to the lack of a coordinating unit, often get bogged down in interdepartmental politics, disputes and misunderstandings

Table 7. Barriers to implementing process governance mechanisms — cooperation bodies

Core element	Governance barriers	Reference (chosen)
Governance bodies and cooperation	• lack of BPM Centres of Excellence (or BPM Competence Centres or Business Processes Office) • position of BPM Centres in the organisation's structure is not adjusted to the requirements/maturity level • lack of adequate communication with managers regarding process implementation • low integration • traditional hierarchical thinking • non-formalised structure and position of process team and cross-departmental teams • lack of effective communication between teams/groups of process participants • lack of a common language of communication and effective communication between process stakeholders • failure to establish rules and a level of formalisation of relations with external partners • failure to establish rules and a level of formalisation of relations with internal process customers • lack of knowledge transfer - lack of understanding of the idea and principles of process management and process orientation at individual levels of the organisation	Spanyi, 2003 Richardson, 2006 Korhonen, 2007 Alibabaei et al., 2009 Scheer & Klueckmann, 2009 Rosemann, 2010 Santana et al., 2011 Niehaves et al., 2012 Tumbas et al., 2013 Valenca et al., 2013 Hamer, 2015 Khosravi, 2016 Syed et al., 2016 Kirchmer, 2017 Bitkowska, 2018 Czarnecki, 2018 Jesus et al., 2018 Thennakoon et al., 2018 Van Loy & Devos, 2019 Jurczuk, 2019 Harmon & Garcia, 2020

(Richardson, 2006). However, the findings of Harmon & Garcia (2020) show that companies cite the lack of coordination of interdepartmental process changes and insufficient senior management support among the main obstacles to BPM implementation. The language of BPM experts, which is too hermetic, or the lack of a communication system to ensure the flow of information and to build trust and motivation, may also be a significant limitation to the PG functioning (Bitkowska, 2018; Van Looy & Devos, 2019). These barriers may appear in the organisation precisely because of the lack of governance bodies, i.e., process owners, BPM leaders or BPM CoE. The failure of the BPM CoE to carry out its assigned tasks in terms of training and workshops may also be a source of process governance problems (Korhonen, 2007; Santana et al., 2011; Thennakoon et al., 2018). Overlooking proper staff preparation for changes in the way of working and too much focus on meeting external customer expectations may lead to competence gaps, which may cause resistance to change or misapplication of BPM support methodologies (Table 7).

The success of BPM is also determined by process teams (the Steering Process Committee, Process/Project Teams) which, in addition to the BPM CoE, constitute an important pillar of governance bodies. The main challenges of their functioning include the selection of the teams' membership and the way they are empowered, as well as the ability of their members to work as a team (Santana et al., 2011; Niehaves et al., 2012; Tumbas et al., 2013; Czarnecki, 2018). Santana et al. (2011) indicated that emerging barriers to BPM governance might be due to insufficient support of process team members by external consultants working with them. On the other hand, Czarnecki (2018) and Niehaves et al. (2012) indicated that process teams should also include people from outside the organisation. Moreover, researchers show that high team turnover (Valenca et al., 2013), often resulting from hiring staff from outsourcing companies (Santana et al., 2011), also has a negative impact on the functioning of PG mechanisms. When designing the structure of teams, one should also consider the possibility of certain conflicts related to their structure. Their substrates may be different attitudes of team members, competition between them for resources, and conflicts arising from service dependencies (Chong, 2007; Valenca et al., 2013; Tumbas et al., 2013; Khosravi, 2016). This is usually related to employees and managers belonging simultaneously to interdepartmental process teams and to relevant departments in the organisation. Emerging barriers related to the work of process teams may also result from the geographical dispersion of their members (Espinosa & Boh, 2009; Thennakoon et al., 2018), poor integration, and the lack of informal meetings (Santana et al., 2011; Tumbas et al., 2013). The occurrence of PG constraints, in this case, may be due to problems in understanding task dependencies or cognitive coordination (Espinosa & Boh, 2009).

The functioning of governance mechanisms is also adversely affected by a lack of trust and fear of expressing opinions and by BPM leaders being too interventionist in decision-making or not involving customers and suppliers in process teams. A potential source of problems in implementing and governing BPM initiatives may be the lack of job satisfaction monitoring in governance bodies (Alibabaei et al., 2009; Syed et al., 2016; Jurczuk, 2019).

Conclusions

This paper reviews parts of the domain literature on Business Process Management to identify potential barriers of process governance mechanisms. The analysis and synthesis of the collected research data allow me to state that they are structured around four areas: culture, competencies, structures, and IT. Most process governance obstacles polarise around the competence gaps of the process stakeholders and the immaturity of the process culture of the enterprise. This is a problem resulting from both the availability of human resources and the perception of BPM projects as secondary (Doyle & Seymour 2020). Competency and cultural barriers are mainly related to methodological errors and attitudes and behaviours of process stakeholders. Eliminating PG barriers from methodologies and standards is possible by ensuring consistency in the BPM tools, standards, and methods used by different teams in similar BPM activities (Bhat & Fernandez, 2007).

Another group of constraints to process governance arises from the existing structure of the organisation. They are mainly related to the fear of losing the authority of the representatives of the functional areas when the management bodies are constituted. An important challenge in establishing process governance is also a coherent, sustainable division of roles and responsibilities that prevents ad hoc actions and the creation of new silo structures (Vom Brocke et al., 2014; Hammer, 2015). In addition, the occurrence of constraints in the functioning of governing bodies may be due to the weak position of BPM centres of excellence and/or their failure to fulfil their knowledge transfer and communication tasks. Inconsistencies in PG also result from the failure of governing bodies to properly coordinate BPM initiatives at both operational and strategic levels. The PG limitations are relatively rarely associated with IT. They mainly refer to the lack of support of BPM systems in the decision-making process. It is also indicated that the development of technologies supporting BPM, including process intelligence, process mining, will cause the necessity of continuous adjustment and improvement of process governance mechanisms preventing the occurrence of constraints in their functioning.

The barriers to process governance mechanisms presented in the paper may contribute to a fuller understanding and thus to an insight into the challenges related to the BPM implementation. This is particularly important in the light of the increasing interest of organisations in the process approach to management. Thanks to the comprehensive approach to the identification of potential process governance barriers, the presented research results may contribute to the understanding of the reasons for failures in the implementation of BPM initiatives in organisations. Furthermore, the conducted synthesis of barriers to process governance can contribute to the development of a theoretical framework for Business Process Management.

Due to the changing circumstances of contemporary organisations, the mechanisms of process governance need to evolve, as does Business Process Management (Kerpedzhiev et al., 2021). Social, technology-driven changes in business realities will cause traditional governance mechanisms to become inadequate. The key challenge facing business leaders is, therefore, the ability to adapt to new market requirements and the expectations of process stakeholders. The complexity and multidimensionality of process governance aspects in the context of ongoing changes indicate the need for further research in this area. In the context of the observed changes in the way companies operate due to the ongoing pandemic situation, an interesting issue could be the analysis of the impact of remote working, virtualisation of teams and digital transformation on the mechanisms and instruments of process governance. Future research on distinct aspects of process governance would make an extremely valuable and comprehensive contribution to the body of knowledge on Business Process Management.

Limitations

Due to the character of the conducted research, the primary limitation of the presented results is the lack of empirical verification. Collecting the opinions of experts and BPM leaders responsible for implementing such initiatives in enterprises would allow the validation of the indicated barriers to the functioning of process governance mechanisms. The certain shortcoming of the presented synthesis is connected with the collection of literature referring to the research area. It would be worthwhile to apply a more formalised approach using criterion-based selection and rigorous critical evaluation for this purpose.

Acknowledgements

The publication of the article for the 11th International Conference on Engineering, Project and Production Management — EPPM2021 was financed in the framework of contract No. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

The research is carried out within the project "The FoF-Designer: Digital Design Skills for Factories of the Future (DigiFoF)", No. 601089-EPP-1-2018-1-RO-EPPKA2-KA.

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Volume 13 • Issue 4 • 2021

sciendo

received: 4 August 2021
accepted: 30 November 2021

pages: 39-56

Managing inter-departmental project delivery to enhance customer satisfaction

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A B S T R A C T
The National Department of Public Works and Infrastructure (NDPWI), an agency for infrastructure development in South Africa, provides accommodation and other infrastructure to various public service departments. Each department communicates its infrastructure requirements with the NDPWI. However, there are usually time lags between project briefing and the actual delivery of the infrastructure. Therefore, this article aims to explore the causes of delays and offer solutions to enhance customer satisfaction. The case study method of qualitative research was adopted. Data were collected from the NDPWI regional offices in Bloemfontein, Cape Town and Kimberley, and the professional service department at the head office in Pretoria, among purposively selected participants not below the deputy director level. The Delphi technique was used as an instrument for data collection and complemented during a focus group session. The findings revealed that the major factors contributing to delays included poor planning by the project execution team (PET), ineffective project monitoring and overcentralisation of the decision-making process. The findings, conclusions and recommendations of this research provide useful information for organisational restructuring, the training and continuous retraining of project personnel, especially the project managers. These steps hold the potential for ameliorating the negative effects of delay in the execution of construction projects by the NDPWI.

K E Y W O R D S
customer satisfaction, delays, infrastructure, participants, project execution team

10.2478/emj-2021-0030

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Introduction

Infrastructure developments involve the active participation of different government departments, with each playing specific and specialised roles. The client (department requiring the infrastructure), in conjunction with other relevant governmental units, scout for suitable land for their proposed infrastructure development. The town-planning services of the city where the development will occur, conduct the geotechnical investigations of the site, provide

Cosa, S., Ogbeifun, E., & Pretorius J. H. C. (2021). Managing inter-departmental project delivery to enhance customer satisfaction. *Engineering Management in Production and Services, 13*(4), 39-56. doi: 10.2478/emj-2021-0030

municipal services, and issue a site clearance certificate as a form of approval so that the project can advance to the planning phase. With this approval, the client approaches the National Department of Public Works and Infrastructure (NDPWI) with their project briefs, strategic goals, and infrastructure requirements, which facilitate the development of the preliminary design and rudimentary estimate. This enables the client to register the project with the National Treasury for funding. If satisfactory, the client receives the document referred to as a "planning instruction" from the National Treasury, authorising the client to commence the project. At this point, the NDPWI appoints a PM to coordinate the project from that point to completion. Furthermore, all relevant consultants (depending on the infrastructure type) are appointed and expected to translate the project briefs, finalise the preliminary design into a final design and produce the tender documents. The procurement unit coordinates the procurement process leading to awarding the contract to the chosen contractor(s). The NDPWI, in collaboration with the consultants, supervises and manages the project development processes until the completed project is delivered to the client.

The NDPWI, South Africa, receives its mandate from the arliament to provide accommodation (buildings) and other infrastructure to various public departments (clients). The NDPWI receives a request from its clients, translates the request to the development of suitable project briefs and the design of the suggested infrastructure. The department moderates the procurement process and oversees the execution of the construction project in consultation with the client. The main clients of the NDPWI include the South African Police Service (SAPS), Department of Defence (DOD), Department of Justice and Constitutional Development (DOJ & CD), Department of Correctional Services (DCS) and the Department of Home Affairs (DHA).

The NDPWI implements projects through twelve regional offices across the country, coordinated by the central Project Management Office at the head office in Pretoria. This research focused on three regional offices, namely, in Bloemfontein, Cape Town, and Kimberley. The choice of these three regional offices is largely due to economy, time, and proximity to the researcher, who is a staff member of the NDPWI and a resident in the Kimberley regional office. Similarly, SAPS and DOD are used as samples for this study, focusing on project requests registered with the NDPWI between 2016 and 2020 for illustration. Although many projects were registered in each regional office, only two such projects from the SAPS and DOD and their execution status in December

Tab. 1. Sample of selected projects received between 2014 and 2016 (the NDPWI project record in regional offices)

S/No	Infrastructure request	Client	Date when planning instruction was issued	Execution status in Dec. 2020
A: Bloemfontein Regional Office				
1	Bloemfontein, De Brug Mobilisation Centre, Area Support Base: Infrastructure upgrade	DOD	10/03/2014	Planning stage
2	Thabong, Bloemfontein East, Training College: Infrastructure upgrade	SAPS	21/12/2015	Planning stage
B: Cape Town Regional Office				
1	Saldanha, Military Base: Construction of Sick Bay Facility	DOD	15/01/2014	Construction stage
2	Cape Town, Wynberg Area Support Base: Western Cape: Officers Mess: Infrastructure upgrade	DOD	17/03/2014	Construction stage
C: Kimberley Regional Office				
1	Jan Kempdorp, 93 AMMO Depot: Infrastructure upgrade	DOD	15/05/2014	Construction stage
2	Kimberley Police Station: Infrastructure upgrade	SAPS	05/10/2016	Complete

2020 are shown in Table 1. Of the six projects, two are still at the planning/design stage, three are at the construction stage, and one has been completed.

Public construction projects that exceed their contract period and allocated budget have been a source of concern for clients (Solomon et al., 2017). The method(s) of executing any infrastructure project has overarching effects on the project success or delay. A construction delay can be referred to as a failure to attain the work's completion within the agreed contract period (Durdyev & Hosseini, 2019). The sources of delays can be grouped under the following causes, namely, "project, practices, participants and procurement", known as the 4Ps (Ansah & Sorooshian, 2018, p. 68). Interestingly, delays from project-related factors, practices, participants, and procurement have significant links to the project execution team (PET) members. Therefore, it is imperative to explore the role of PET members in the delay of execution of construction projects by the NDPWI.

In a nutshell, although clients register their requests for infrastructure development early with the NDPWI, the projects are not delivered on time, resulting in infrastructure deficits for the clients, delayed execution of planned programmes, delays in the execution of assigned national development programmes and low levels of customer satisfaction. This paper is an excerpt from a larger research effort that focused on exploring the factors responsible for the delays and suggested a concrete approach on how to ameliorate them. The paper starts with the literature review, which explores the factors responsible for delays in construction projects and the suggested approaches to solving them. It progresses to discuss the adopted research strategy, the multiple-site case study using mixed methods for data collection and analysis. This is followed by the section on the research findings, and the associated discussions against best practices gleaned from the literature. The concluding section provides the conclusions and recommendations. The recommendations include solutions to the factors responsible for delays and identifying areas for further research.

1. Literature review

This section examined the influence of PET members as possible factors responsible for delays in the execution of construction projects. In the context of this paper, PET members mean the client or project representatives, consultants and contractors. Also, the section focuses on the project manager's (PM) role as a client representative or independent entity. It provides information on how to ameliorate the adverse delay effects in the execution of construction projects and gives an overview of project and project stakeholders.

A project can be defined as a temporary endeavour to create a unique product, service, or result (Liu, 2020). The objective of any project is to be executed within specified constraints, commonly referred to as the "iron triangle" of time, cost and quality (Bodea & Purnus, 2016). According to Ahsan (2018), the five common life stages required to complete the project implementation cycle from needs analysis to full utilisation are "project identification, preparation, appraisal and approval, implementation and evaluation". The American Institute of Architects states that the success of a project delivery method depends on cost, quality, time, safety and how the project meets its intended purpose (Mosly, 2016). Project management involves planning, organising, coordinating, leading, and controlling resources to accomplish the project objective (Mosly, 2016; Hurta et al., 2017). Methods for the infrastructure project execution have overarching effects on the project success or delay. Construction delay can be referred to as a failure to complete works within the agreed contract period due to a deviation from the original plan (Gunduz & Abu Hassan, 2017; Alsuliman, 2019; Jigeesh & Rao, 2015). There is a tendency to use more effort to address a deviation rather than review the original plan (Durdyev & Hosseini, 2019). Therefore, all construction project stakeholders (PET members) need to avoid a deviation by consistently and cooperatively reviewing operational plans. As a PET member, the role of the client is crucial in ameliorating the adverse effects of delay.

Clients, owners, or project sponsors are common terms used to describe individuals, firms or corporate organisations that initiate infrastructure development projects and engage professionals to assist in different execution stages. Construction project clients can be divided into six categories, namely, "contact clients, intermediate clients, primary clients, unwitting clients, indirect clients and ultimate clients" (Cosa, 2020, p. 25). In the context of this research, the primary client is most relevant. Primary clients are individuals, groups of individuals or corporate organisations that own the project and who will pay for the services rendered during the different project phases (Cosa, 2020). To achieve the project objectives, the primary client must provide comprehensive or near-comprehensive briefs to PET members, and PET members must continuously check with the client to confirm or clarify areas of possible discrepancy (Franco & Nielsen, 2018). It is important to note that whoever is representing the client in the PET team must possess adequate knowledge of the project and be senior enough to take representative decisions on behalf of the client, where necessary. This is necessary to reduce the incidence of delays. Common sources of client-related delays include (Ansah & Sorooshian, 2018) but are not limited to the following:

- Frequent changes in the project scope and specification.
- Change in the leadership that results in requirement changes.
- Adoption of imported ideas without due consideration of the technical implications for construction.
- Disregard for operation and maintenance implications.
- Slow response to enquiries from PET members.
- Slow approvals and sign-off at different stages.
- Lack of prompt payments for services rendered.

Therefore, a timely and pragmatic client response is necessary to reduce the adverse effects of delay on the execution of construction projects. Another key stakeholder in the PET team is the Project Manager (PM).

The PM is the single point of reference for achieving project objectives. It is normal practice in the construction industry that the PM is appointed early in the project to provide key management decisions throughout the project life cycle. Depending on the infrastructure type, client preference or procurement system, the PM may be an independent individual or organisation or the lead infrastructure consultant also acting as the PM or a suitably trained and competent in-house professional. PMs are expected to have the necessary technical knowledge, expertise and competence. PMs must demonstrate a variety of competencies that can enhance effective multi-organisational teamwork and communication towards achieving successful project results (Nijhuis et al., 2018). In a typical infrastructure development project, a majority of the problems encountered during the construction phase may have arisen from the actions or inactions during the design phase. Therefore, the PM's technical and managerial competencies have significant impacts on the success of the project (Pourrashidi et al., 2017; Kuchta et al., 2017).

The growing complexity of infrastructure projects has led to the increased employment of specialists in different knowledge areas and contributors to the design.

This requires the effective integration of the knowledge and expertise of the PET members and other associated team members (Nijhuis et al., 2018). Unfortunately, in some building projects, the architects with dominant personalities do not readily accept contributions from other professionals. They can be outright disrespectful to the PM, especially if the PM is not a professional from the engineering or the built environment industry. This wrangling among PET members contributes significantly to delays in project execution (Nijhuis et al., 2018). Therefore, irrespective of the professional background, it is imperative that the PM possesses management competence in leadership, stakeholder management, team development, planning, effective communication, decision-making, cultural awareness and problem-solving. The PM should be analytical, flexible but firm, encourage teamwork and practise effective delegation (Zadeh et al., 2016).

Therefore, in appointing the PM, the client's organisation should ensure that a prospective PM possesses cognate technical capabilities, professional competencies in people skills, team management and project-related capabilities and is proactive. The PM usually serves as an interface between the client and consultants on the one hand and the contractor and consultants on the other hand.

In an infrastructure project, consultants help to translate the client project briefs for the realisation of the proposed infrastructure by developing appropriate work drawings and coordinating the execution of the project. The infrastructure dictates the composition of the relevant professional consultant team. In practice, consultants emerge from different specialist backgrounds but gradually integrate into an interdependent, collaborative, multi-disciplinary project-based environment, challenging each team member to demonstrate proficiency in project management skills alongside their technical roles in the project. Research efforts by Nijhuis et al. (2018) and Rao (2016) identified the following common sources of delay in the execution of construction projects that can be traced to the role and activities of the consultants:

- Lack of experience.
- Slow development and production of relevant work drawings or their amendments, addressing discrepancies in project documents and specifications.
- Poor communication and coordination with fellow consultants, the client, and contractors.

- Delays in the effective management of scope change and producing the related amended drawings.
- Inability to conduct effective project inspections, tests, and produce periodic functional reports.
- Frequent changes in the design during construction.
- Late instructions or owner requirements misunderstood by consultants.

Another source of delays from the consultants is the overreliance on the use of design software without adequate adaptations to produce relevant construction details (Rao, 2016). The resulting drawings impair the productivity of the contractors and cause avoidable delays.

Furthermore, the consultants should be proficient in technical roles, team relationships and human resources management to reduce the incidence of delays. The contractor is another critical stakeholder whose activities have overarching effects on the progress of a construction project.

Contractors are important members of the PET. They translate project drawings into the physical edifice to meet the expectation of the client. Their actions or inactions during the project execution periods have significant impacts on achieving project objectives or create avoidable delays. The PM, consultants, and their on-site representatives should follow the contract and work together in different phases of the construction process to reduce the incidence of delays.

In practice, some contractors may intentionally submit low tender figures and unrealistic project execution programmes, all in a bid to win the contract. When this group of contractors assumes responsibility on-site, they begin to raise issues that constitute a variation, which ultimately causes delays, leading to time and cost overruns at the expense of the client (Durdyev & Hosseini, 2019). The panacea for this group of contractors is to adopt the practice of awarding contracts to the most responsible bid and not the lowest bidder (Gambo et al., 2016). Several sources of contractor-related delays identified by Gambo et al. (2016), Durdyev & Hosseini (2019) and Rao (2016) are summarised as follows:

- Difficulties in securing additional finance for the execution of the project.
- Poor site management of own staff and subcontractors.
- Poor planning and scheduling.
- Unprofessional construction methods leading to rework due to errors during construction.
- Poor safety practices on site.

Many capital construction projects are awarded to main contractors, but they rely on subcontractors or specialist contractors for the actual execution. The main contractors adopt this practice to reduce their overhead, operating costs, maximise profit and efficient delivery of the project (Tan et al., 2017). In many instances, this approach has positively impacted project delivery. Unfortunately, many of the main contractors focus more on maximising the profit rather than building long-term relationships with subcontractors, which could facilitate improved performance. Other negative attitudes of main contractors that impair cordial relationships with subcontractors, observed by the authors include:

- Main contractors' authoritative attitudes.
- Delayed payment to subcontractors based on the clause "paid when paid".
- Lack of trust between main contractors and subcontractors.
- Subtle transfer of the project risks to the subcontractor.
- At best, subcontractors are "seen and not heard", usually neglected during decision-making processes.
- The main contractor views the suggestions from the subcontractor from the point of cost rather than added value.

Expanding further on relationship difficulties between the main contractor and subcontractors, especially around payment for services rendered, Tan et al. (2017) observed that "Unfortunately, efforts at getting main contractors to deal fairly with their chain of subcontractors have mainly been unsuccessful. Irrespective of the fact that standard contracts stipulate periods within which subcontractors should get paid, such specified periods are repeatedly ignored, with subcontractors often stretched to the limits before getting paid." These negative attitudes demoralise the subcontractors, stifle innovation, reduce productivity, ultimately causing delays and inhibiting improvements in the efficacy of the project delivery process (Pal et al., 2017; Tan et al., 2017). Having discussed the possible causes of delay, it is imperative to explore how to ameliorate construction project delays.

The preceding subsections identified potential factors responsible for delays in the execution of a typical construction project. The literature suggests that the majority of these factors can be ameliorated by and through the office of the PM. In practice, the PM is the project leader and coordinator of all associated responsibilities for achieving the project objectives. However, PMs will not achieve the project objectives without the necessary competencies, such as knowledge, skills and attitude, which are the tools, techniques and practices needed to manage projects. PMs should have the ability to distinguish tools to be used from the project management toolkit to manage and evaluate certain projects after considering their characteristics (Zadeh et al., 2016).

The PM should bear in mind that project success should exceed the "iron triangle" to include client and stakeholder satisfaction, which can be managed effectively through the contextual use of the performance management principle. In management literature, performance measurement is seen as a forerunner to performance management because management follows measurement (Saunila, 2017). Performance management uses the information from performance measurement to effect the necessary changes in an organisation's operational systems, processes and culture. Performance management allows for a symbiotic relationship between leaders and members of the PET by helping to set realistic performance goals. Fillion et al. (2017) suggest that organisations (notably, the PM) should have the ability to cope with rapid changes in construction projects, and the PET members should be capable of responding to the ever-changing demands of customers and global markets. This requires continuous learning together. "Learning organisations are organisations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (Fillion et al., 2017, p. 76). This culture of team learning is central to ameliorating the negative effects of the factors responsible for the delays in the execution of construction projects.

The procurement systems adopted for the execution of a construction project have a significant impact on the performance of the project manager. The three common procurement systems used in the execution of construction projects are the bid-and-build (DBB), design-and-build (DB) and the relationship-based (RB) (Ogbeifun et al., 2018). In the traditional procurement system, the competitive bid method is used for the selection of the PET members (Yap & Skitmore, 2018). In most cases, the lowest price is used as the criterion for selecting the winner instead of competence, proven previous experience and balanced pricing (Gambo et al., 2016; Deep et al., 2017). If the PM is an independent individual or organisation with an observable weakness, such as being younger and having less professional experience, some consultants on the team may exploit the weakness and make the administration of the project difficult. Alternatively, if the lead consultant in the project also acts as the PM, they might become authoritative, acting as "the judge in their own case" when addressing the shortcomings resulting from the professional lapses of the organisation (Pourrashidi et al., 2017; Durdyev & Hosseini, 2019). In the design and build (DB) procurement system, the two common approaches and a variant, identified by Baal and Outridge (2020), are:

- Pure DB: both the design and construction team are within the same organisation, commonly referred to as a "consortium". The variant in this approach is where different organisations (consultants and contractors) conglomerate to form a consortium, using the instrument of a memorandum of understanding (MOU).
- Partially integrated DB: the consortium invites other consultants or contractor(s) to execute specific or specialised functions within the project.

The method for selecting the PET members in a DB procurement system significantly influences the role and effectiveness of the PM. If the PM is the lead consultant in the DB consortium, they may behave as a counterpart in the traditional system, "the judge in their own case". On the other hand, if the PM is a client's representative or an independent individual or organisation and not a professional resourced as the lead or other team consultants, the tendency is to undermine the authority of the PM. Conversely, the relationship-based procurement method encourages the symbiotic relationship between the client organisation and the PET in a win-win relationship. Some of the instruments used include Project Partnering (PP), Joint Ventures (JV), Alliance Contracting, Framework Contract (FMC), Early Contractor Involvement (ECI), and Integrated Project Delivery (IPD) (AC) (Aaltonen & Turkulainen, 2018). The objectives of this system are to encourage the PET members to proactively identify risks and seek the best way(s) to address them before they affect the project (Aaltonen & Turkulainen, 2018). The client and the executing team jointly set measurable Key Performance Indicators (KPIs) and target timelines. The "purposively" selected PET develops a mutual agreement which encourages the collective sharing of risks and benefits, including the clause for "no blame/no dispute" in their agreement, and harnesses the resources for the project based on the expertise of team members (Aaltonen & Turkulainen, 2018; Ogbeifun et al., 2018). The system has a thin dividing line between the PM and other

PET members. Irrespective of the PM, the structure of the relationship-based procurement system can make project management easier for the PM.

In addition to the PM's technical ability, professional competencies, and the adopted procurement system, the client can help the PM execute functions effectively. This can be done publicly by oral and written communications, identifying and asserting the authority of the PM. The client will deliberately refuse any unofficial communications, except through the PM. Thus, other PET members will relate to the PM effectively and reduce the negative effects of delays.

Literature confirms that different stakeholders in the construction industry, notably the project manager, contribute significantly to the delays in the execution of infrastructure projects. Therefore, this research explores the capacity and capabilities of PMs within the NDPWI, the role of senior management in enhancing PMs' ability to ameliorate construction delays and achieve customer satisfaction.

2. Research method

The case study was used as a qualitative research method (Mukhtar et al., 2020) for dealing with specific issues. It allows intense observation, provides opportunities to study various aspects, puts each part in relation to the environment where it operates and tasks the creativity of the researcher to provide "voice to the voiceless" (Braun and Clarke, 2016). This research focused on exploring the factors responsible for the delay in the execution of construction projects by the NDPWI as its specific operational issue. The data for this study were obtained from three regional NDPWI offices (multiple sites) in Cape Town, Bloemfontein, and Kimberley, as well as the headquarters. The data were collected in two stages from pre-qualified, purposively selected participants. The process of data collection is explained in subsections 2.2 and 2.3.

2.1. Population and sample

The population for this research includes all the staff of the NDPWI responsible for infrastructure development in South Africa. However, due to resource and time constraints, the sample of participants was limited to the Kimberley, Bloemfontein, and Cape Town regional offices of the NDPWI, as well as the Professional Services Department at the headquarters in Pretoria. The target sample was 28 participants from the Construction Management, Professional Services, Finance and Supply Chain Management (SCM) Units. The participants were officials at the level of Chief Director, Director and Deputy Director who had spent at least five years in the relevant departments. Initially, 22 personnel accepted the invitation to participate in the research. Five of them were disqualified because four did not complete the information on personal demographics, and one had been in the office for less than five years. The 17 participants who met the pre-qualification criteria continued in the remaining phase of the research exercise. The demographics of the participants are summarised in Table 2.

2.2. Data collection

Two instruments were used for data collection, namely, the Delphi technique and the focus group (FG) session. The first phase of data collection using the Delphi technique sought to identify the factors responsible for the delay in executing the infrastructure projects on behalf of the clients of the NDPWI. The second phase of data collection was aimed at discussing the impact of the factors identified in the first

Tab. 2. Summary of participants' demographics

Position	Qualification			Experience			Gender		Total
	Post-graduate	1st degree	Diploma	6–10	11–20	20+	Male	Female	
Chief Director	2	-	-	1	1	-	1	1	2
Director	1	2	1	1	1	2	1	3	4
Deputy Director	1	3	2	2	3	1	3	3	6
Chief Architect	2	-	-	-	-	2	1	1	2
Chief Engineer	1	-	-	-	-	1	1		1
Architect	1	-	-	-	-	1	1		1
Engineer	-	1	-	-	-	1	1		1

phase and proffering suitable solutions. These data were collected through the FG session.

The Delphi technique, a "hybrid" of quantitative and qualitative methods, was used for data collection and analysis, and the results were complemented with a focus group (FG) session (Ogbeifun et al., 2016; Ogbeifun et al., 2017). The Delphi technique has many variants, the two most common being the classical and the modified classical Delphi. The difference between the two variants is that in the classical Delphi, participants generate the prospective solutions to the research question in the first round of the exercise, which is usually a qualitative response. In the modified classical Delphi, participants are provided with generic solutions in round one. After the first round of the classical Delphi, the subsequent rounds of data collection run the same course as in the modified classical Delphi and the data collected are treated through a quantitative approach. The classical Delphi technique was used in this study.

The participants of a typical Delphi exercise are commonly referred to as the panel of experts or highly knowledgeable persons in the research subject (Szpilko, 2020). They can be few or as many as possible. They are "purposively, rather than randomly" selected after careful pre-qualification. The geographical location of participants is no hindrance to effective participation in a Delphi exercise (Belton et al., 2019). No participant can be traced to his or her contribution; they can express themselves freely without group pressure or pressure from persons with dominant personality traits (Ogbeifun et al., 2017). The exercise goes through several rounds of data collection, which allow participants to adjust their responses, and the results are refined in these successive rounds of data collection. The research coordinator serves as an unbiased umpire who collates, iterates, and circulates feedback to participants without interference in the process. Depending on the sample size, extensive statistical analysis may be necessary, or the basic computation of the statistical mean and sometimes accompanied with standard deviation (SD) can be used to evaluate consensus. Consensus or equilibrium of opinion is attained when participants no longer change their opinion or the process has attained 51–80 % agreement on the items in the final list (Belton et al., 2019).

In the first round of the Delphi exercise, the 17 participants who met the pre-qualification criteria were requested to suggest between three and five reasons they observed as causes of delays in the execution of construction projects by the NDPWI (classical Delphi). After the synthesis of responses from the participants, 106 generic suggestions were listed. The suggestions were whittled down to 89 factors by eliminating the duplication of factors. The list of 89 suggestions was circulated to participants in Round 2, requesting them to score the factors on a five-point Likert scale.

The scores were allocated in terms of importance with 1 denoting not important and 5 denoting extremely important, (1 = "not important", 2 = "important", 3 = "moderately important", 4 = "very important", 5 = "extremely important"). It was agreed that after the analysis, only factors with a score of 3.0 and above would be taken to subsequent Rounds. One participant did not return his response due to workload, and 16 participants submitted responses in Round 2. The exercise went through three rounds of data collection and analysis before achieving equilibrium in Round 3, and 36 factors were identified to be responsible for the delays in the execution of construction projects by the NDPWI. The outcome of the Delphi exercise was taken to the FG session for ratification. The details of the executed Delphi process, analysis and the results are presented in the section on findings and discussion.

2.3. Focus group session

An FG session is a qualitative method of data collection, rarely used as a stand-alone approach but preferably employed in conjunction with other methods (Varga-Atkins et al., 2017). Compared to a one-on-one interview, an FG session is more cost-effective (Varga-Atkins et al., 2017). The size of a typical FG session is between 4 and 12 participants (Reefke & Sundaram, 2017; Sierra-Varela et al., 2017). It is possible that in a group larger than 12, many ideas may be generated, but it may become difficult to manage, especially with dominant characters in the group (Reefke & Sundaram 2017; Sierra-Varela et al., 2017). When an FG session is used as a complementary tool to other research efforts, first, the FG session reviews, adopts or adapts the conclusions from the previous research exercise (Reefke & Sundaram, 2017; Strasser, 2017). The FG session evaluates the conclusion, developing practical solutions to the problems identified in the previous research effort (Ogbeifun et al., 2016). In this research, the FG session confirmed the 36 factors developed as reasons responsible for the delays in the execution of construction projects by the NDPWI. They analysed the associated problems and proffered solutions. The synthesis of the solutions led to the development of suitable themes, which are discussed in the findings and discussion section.

2.4. Validity and reliability

The reliability and validity of any research are influenced by the quality of data, the source of data and the analysis method. In this research, the participants who had contributed the data were key stakeholders in the NDPWI involved in infrastructure development. None of the participants was below the deputy director level; they had at least five years of work experience and possessed a blend of educational qualifications, including postgraduate degrees, a bachelor's degree and a diploma. The gender balance of participants was ensured as there were nine males and eight females. This composition provided a high degree of reliability to the data collected. As a tool for data collection, the Delphi technique added to the reliability of the data because the participants' opinions were anonymous and obtained without pressure (Ogbeifun et al., 2017). The result of the Delphi exercise was ratified by the FG session (Ogbeifun et al., 2016). The practice of using different instruments for data collection, akin to the principle of triangulation, helps to improve the reliability and validity of data and the entire research process (Maslach et al., 2018).

3. Findings and discussion

The two methods or instruments used for data collection are presented in this section together with the results.

3.1. Outcome of the Delphi exercise

The Delphi exercise went through three rounds of data collection and analysis before it achieved equilibrium. The first round was a qualitative response, where participants provided 106 possible reasons for delays in the execution of approved infrastructure projects by the NDPWI. The initial 106 factors were reduced to 89 and circulated to the participants in Round 2. The participants were invited to rate the factors using the five-point Likert scale, and the statistical mean approach was used to analyse consensus. After the analysis, 84 factors met the requirement of the benchmark of 3.0 and above. Due to similarities in the terminology, the 84 factors were further refined to 36 factors. The 36 factors were recirculated to the participants in Round 3. After the analysis, the 36 factors were retained. At this point, the process had attained equilibrium because participants did not change their opinion, and the exercise was terminated. A careful study of the results showed that most factors responsible for the delays were due to the operations of in-house personnel, policies, and practices of the NDPWI, as shown in Table 3. Therefore, the participants for the FG session were limited to the strategic leaders from the three regional offices.

The FG session had eight participants, including two Chief Directors, one Director and five Deputy Directors. This figure is within the acceptable limit of 4 to 12 participants recommended by literature (Reefke & Sundaram 2017; Sierra-Varela et al., 2017). The FG session was conducted through the video conferencing system, which lasted for four hours.

The 36 factors were circulated to the members of the FG session. Their first assignment was to confirm, amend or refute the 36 factors (Reefke & Sundaram, 2017; Strasser, 2017). All members agreed that the 36 factors aptly represented the causes of delays. Table 4 is an excerpt from the 24 factors contributed by the NDPWI, relating to PM competencies, composed during the Delphi exercise and confirmed in the FG session.

Each factor was discussed, identifying the root causes of the problems, and panel members offered solutions, which facilitated the development of suitable themes. For example, the factors relating to project-management competencies, the discussions on factors 1 and 2 in Table 4 and the synthesis of information that led to identifying suitable themes are used to illustrate the outcome of the FG process. Table 5 provides the discussion on factors 1 and 2 from Table 5,

Tab. 3. Classification of factors

Classification of results					
Clusters	NDPWI	Contractor	Consultant	Other	Total
Number of factors	25	5	3	3	36
Percentage representation	69.5 %	13.9 %	8.3 %	8.3 %	100 %

Tab. 4. Summary of factors related to PM competencies

S/No	Factors	Suitable theme
16	The lack of work ethic by PMs within the NDPWI — the lack of motivation/poor morale and no sense of responsibility towards the achievement of goals as a collective	PM Competencies
21	Incompetent PMs — the lack of leadership and understanding of internal processes in the department, poor planning, monitoring and poor management of various contracts in the project	
27	Insufficient progress monitoring on-site and contractor reporting not delivering to PM.	
31	The lack of work ethic among PMs within the NDPWI — sometimes incorrect estimation of time and costs	
33	Failure to accomplish the Visit Programme Plan and poor monitoring of execution programme by the PM	
36	NDPWI Engineering and Architectural teams notified late by the PM regarding their involvement in active projects	

Tab. 5. FG discussions on factors 1 and 2

<table>
<tr><td>16</td><td>The lack of work ethic by PMs within the NDPWI — the lack of motivation/poor morale and no sense of responsibility towards the achievement of goals as a collective team</td></tr>
<tr><td colspan="2"><u>Analysis:</u>
• PMs are not recognised for their effort and good performance
• Poor management of resources and work by Senior Managers
• Allocation of duties is inconsistent to boost the morale of under-utilised officials, leaving some PMs over-utilised and others under-utilised
• Management does not enforce the correlation between goods and services and the expenditure on sites
• Poor management of incoming Planning Instructions by the Head of Projects leading to capacity problems in the regions whereas staff who had left is not replaced</td></tr>
<tr><td colspan="2"><u>Solutions:</u>
• The NDPWI must demand high-performance standards and value from PMs
• The NDPWI Senior Management must enforce consequence management
• Continuous training and development for PMs to improve skills and boost morale
• Enhance teamwork culture and improve communication
<u>Theme:</u>
• PM competencies</td></tr>
<tr><td>31</td><td>The lack of work ethic by PMs within the NDPWI — sometimes they provide an incorrect estimation of time and costs.</td></tr>
<tr><td colspan="2"><u>Analysis:</u>
• There is no accountability and responsibility for PMs and consultants
• PMs are not effectively managing projects from inception until closure
• There is a lack of performance management of PMs by heads of PMs and a lack of performance management of the head of projects by regional managers
• Regional managers do not play an oversight role in the management of projects and during the monthly reporting sessions of the project-management schedule</td></tr>
<tr><td colspan="2"><u>Solutions:</u>
• Appoint PMs who have at least a Bachelor's degree (including proficiencies in project management, acquired through postgraduate studies or continuous professional development) and 10 years of experience
• PMs must be professionally registered with relevant professional bodies, having a minimum of 6 years post professional registration
• Senior management must enforce consequence management if PMs do not implement contract management
<u>Theme:</u>
• PM competencies</td></tr>
</table>

Tab. 6. Themes and associated clusters

S/No	Themes	Associated cluster
1	Effective client-management structure	Service provider (NDPWI) related
2	Project-management competencies	
3	Leadership	
4	Systems thinking	
5	Consultant competencies	Consultant related
6	Contractor competencies	Contractor related
7	Teamwork	All the stakeholders

showing the analysis, the solutions proffered by the participants and the developed theme.

A similar approach was adopted in the discussion of 36 factors, which led to the development of the following themes:

1. Effective client-management structure.
2. Project-management competencies.
3. Leadership.
4. Systems thinking.
5. Consultant competencies.
6. Contractor competencies.
7. Teamwork.

The themes were classified into four clusters, as shown in Table 6.

3.2. Discussion of findings

In this section, the discussion of the research findings will be limited to the themes associated with the factors contributed by the service provider (the NDPWI), namely, effective client-management structure, project-management competencies, leadership and systems thinking. This is because the service provider contributed the highest number of factors responsible for the delays in the execution of the client's construction projects.

3.2.1. Effective client-management structure

There are five models of organisational structure commonly referred to in the literature on organisational structuring, namely "the simple model, the bureaucratic model, the professional model, the adhocratic model, and the divisional model" (Janićijević, 2017, p. 7). The simple model is commonly practised in small firms, led by single individuals who tend to be autocratic leaders, and the bureaucratic model occurs in large companies and public administration departments. Employee participation in decision-making is extremely low in the bureaucratic model. Professionals play a key role in the professional model and the adhocracy model. The fifth — the divisional — model is complex, as it consists of two or more levels of authority. The NDPWI management structure is best described under the bureaucratic model, which is highly formalised with centralised models of administration involving the "top-down-bottom-up" approach.

Based on the FG session, employees and professionals are experiencing loss of autonomy, innovation and are limited to controlled participation in decision-making processes (Janićijević, 2017). That is why even senior managers do not see themselves fit to take firm and timely technical decisions during project execution. They are compelled to go through the established hierarchy, which is time-consuming. This leads to a sense of the "lack of urgency" among government officials. Furthermore, FG members believed that the structure strips significant authority from the PM, resulting in general project management delays and reporting defaulting contractors for an appropriate sanction.

3.2.2. Project-management competencies

Project-management competencies may be divided into three separate elements, such as knowledge, performance and personnel. A successful PM must have the knowledge and insight of technical project features, relationships between team members and project elements (Sharma, 2017). Competency can be defined as skills, attitudes, knowledge and personal characteristics that can be improved with experience, education and training (Oun, 2016). This challenges the PM to adapt the ten Project Management Institute (PMI) knowledge areas, which include "project integration, scope, time, cost, quality, human resource, communication, risk, stakeholder management, and procurement management" (Oun, 2016, p. 31). The implication of the negative factors attributed to the delays in the execution of construction projects by the PM becomes clearer when related to the relevant PMI knowledge areas, which are as follow:

- Project integration and human resources. To achieve project integration and the effective use of available human resources in any project, the PM should actively involve all project stakeholders, both internal and external team members. In this research, the late involvement of the in-house technical team (engineers and architects) contributes to the delays in the execution of construction projects. The factor suggesting the PM's "lack of motivation/poor morale and no sense of responsibility towards the achievement of goals" can also be attributed to the lack of early involvement of other relevant team members.
- Communication. As a build-up on (a), PMs lack the skill of and practise in effective communication. This is evident in their lack of understanding of internal processes, communication with senior management, monitoring and evaluation, developing suitable periodic reports as well as the effective coordination of PET members.
- Scope, time, cost and quality. The Delphi exercise identified the PM as "lacking work ethics … sometimes they provide an incorrect estimation of time and costs". A low competence level in these areas has significant effects on scope change management, the quality of the construction process and, in turn, influences the timely execution of the overall project.

Furthermore, concerted efforts should be made to ameliorate the negative effects of the factors responsible for project delays. This challenges the PM, the coordinator of the PET members and client representative, to imbibe the culture of team learning and contextual use of the concept of performance management (Saunila, 2017; Fillion et al., 2017). Therefore, it is imperative that PMs should undergo periodic training to improve their project-management skills and coordination abilities.

3.2.3. Leadership

Management and leadership literature offers several definitions of the term leadership. The postulations of reference (Davis, 2018) on leadership are being considered here as: a matter of personality, inducing compliance, the exercise of influence, particular behaviours, a form of persuasion, a power relation, an instrument to achieve goals, an effect of interaction, a differentiated role, initiation of structure, and as many combinations of these definitions. These definitions suggest that organisational leaders must acknowledge that a system can only function effectively if its subsystems are fully functional, and employees can support the change if they have been made aware of the changes (Sharma, 2017).

The findings from this research revealed that the factors responsible for the delays in the execution of construction projects, contributed by the leadership style and structure of the NDPWI, can be classified into three groups, namely, process centralisation, performance measurement and performance management.

The practice of process centralisation implies the religious observance of the "top-down-bottom-up" concept of leadership, where the centre exerts control over the operation of the whole organisation. This leadership style does not encourage innovation but produces mere mechanical followership. This research revealed the following factors as evidence of the negative influence of processes over-centralisation:

- Indecision by the NDPWI Management.
- Poor planning by the NDPWI Senior Management.
- Government Officials in constant fear of severe consequences and punishment by Senior Management for taking wrong decisions.

The over-centralisation of the decision-making process inhibits innovation, creates room for indecision, poor planning, and fear among subordinates. However, the "top-down-bottom-up" concept of leadership can be flexible if it allows for inclusive, participatory leadership (Chan et al., 2016); but in an over-centralised system, instructions are communicated from top to lower levels. Response and suggestions are communicated from lower to higher levels. Until approval is received from the senior management, the officers at lower levels cannot act, which in turn causes delay. The leadership style of the persons occupying control positions within the NDPWI structure, at the different levels, determine whether the structure tends towards a strictly bureaucratic model or a suitable modification that allows for a reasonable measure of autonomy and innovations (Chan et al., 2016). Proactive leadership suggests a blend in using two leadership tools of performance measurement and performance management.

In management literature, performance measurement is seen as a forerunner to performance management because management follows measurement after suitable assessments (Mahdi et al., 2020). There are many definitions of Performance Measurement

(PM), but we refer to two in this research that describe PM as "the process of quantifying the efficiency and effectiveness of an action" (Ogbeifun, 2018). The Oak Ridge Associated Universities provided a simplistic but practical definition: "Performance measures quantitatively tell us something about our products, services and the processes that produced them; they are a tool to help us understand, manage, and improve what our organisations do" (www.orau.gov). The common features in these definitions are that:

- PM operates with a defined set of measurable indicators of production or work process;
- The indicators are designed to achieve the goals of the organisation;
- The feedback from periodic observations (assessments) are used to improve the production or work process (management).
- The application of the principles and PM practice will enable the NDPWI:
- To determine issues that are critical for the achievement of its infrastructure development goals.
- To determine issues that are critical for the successful delivery of the infrastructure and achieve customer satisfaction.

Though there are many benefits to adopting performance measures, it should be noted that "performance measurement is only a tool, whereas performance improvement is the goal" (Rodriguez-Labajos et al., 2016). Therefore, in the design of an appropriate performance measuring system, first, identify the characteristic content and structure of the performance measure and the suitable model to drive the implementation. The driving force behind the concept of performance measurement hinges on the timeless adage "you can't manage what you can't measure" and "what gets measured gets done" (Shohet & Nobili, 2017).

There are several tools or models available for the measurement of the performance of the whole or part of the organisations' operations (Ogbeifun, 2018). A few of them will be mentioned here, such as total quality management (TQM), and the balanced scorecard (BSC) (Okwiri et al., 2018), the business excellence model (BEM), the Capability Maturity Model (CMM), the key performance indicators (KPI) (Rodriguez-Labajos et al., 2016), the just-in-time (JIT) model (Gomes & Yasin, 2017; Knol et al., 2018), and Six Sigma (Rosa & Broday, 2018). The objectives of each model are to improve on the current performance to achieve the goals of the organisation (Ogbeifun et al., 2016). Each model has unique variables for measuring performance and standard units for the assessment of that performance (Ogbeifun, 2016a). The Balanced Scorecard (BSC) has assumed a prominent position as a tool for performance measurement and management (Rodriguez-Labajos et al., 2016). However, the complexities of data collection, proficiency in statistical analysis and translating the general concept to concrete contextual action have limited the use of BSC for performance measurement (Ogbeifun et al., 2016a).

The quality of results from using any performance measurement tool depends on the development of personally effective individuals committed to a common vision and an emphasis on customer needs (Ogbeifun et al., 2016). This concept of developing personally effective individuals to be committed to the vision of customer satisfaction is crucial because service providers may work as a team or as individuals. Until the individual imbibes the culture of working with the view of customers' satisfaction, having customer satisfaction as a goal may end up as a mere policy statement. Although the implementation of any performance measure may yield immediate, visible improvement, the goal is not a quick fix of things but to develop relationships and processes capable of generating and sustaining quality improvement now and in the future (Ogbeifun et al., 2016). It is an exercise that requires a commitment to succeed and road maps for more effective management (Ogbeifun et al., 2016). Furthermore, other factors that would affect the results include the level of competence, capacity and capabilities of the operating personnel, quality of data and commitment to their analysis.

The objectives of performance measurement will not be achieved without adequate and periodic assessments of actual performance (Ogbeifun, 2018). Performance assessment compares performance results against the expectations of the measuring system in operation (Ogbeifun et al., 2016). The assessments should be timely, accurate and relevant. The exercise should be undertaken in ways easily understood by the actors using the performance measuring system being evaluated (Ogbeifun et al., 2016). The differences in measurements are harnessed in coordinated feedback, and this, in turn, is used to develop suitable strategies for improved performance (Ogbeifun, 2018). Although several performance measurements have been conducted, or their tools utilised, they are not often followed by an effective analysis of results or honest attempts at the improved performance (Ogbeifun et al., 2016). The performance assessment records obtained from the feedback information should be subjected to further investigation. Effective analysis of feedback facilitates the identification of the magnitude and source of variance. Feedback can be obtained using the instrument of an individual or group interview, a response to a questionnaire, a focus group session or through the Delphi technique (Ogbeifun et al., 2016). The analysis of the inputs from relevant stakeholders during the feedback exercise should be followed by focus group sessions (Varga-Atkins et al., 2017).

Reflecting on the analysis of findings in Table1 1, and an average of five years after registering a request for infrastructure development with the NDPWI, only one project is completed, three at the different stages of construction and two are still at the planning or design stage. If the leadership of the NDPWI had a performance measurement system in place and performance measures were assessed periodically, the management would have asked relevant questions, identified debilitating problems, and addressed them. Consequently, the department was not responsive to customer needs because the leadership did not seem to be mindful of factors leading to customer satisfaction. In this regard, if the NDPWI should achieve customer satisfaction, the department would have to embrace the three components of performance measurement, performance assessment and performance management.

Performance management uses the information from performance measurement to affect the necessary changes in the operational systems, processes, and culture of an organisation. Performance management allows for a symbiotic relationship between leaders at the strategic and tactical levels in an organisation by helping to set realistic performance goals. The process enables the tactical level leaders to allocate and prioritise resources for achieving the set goals within the stipulated time frame (Lee & Mouritsen, 2018; Janićijević, 2017; Shao et al., 2017). In the NDPWI organisational structure, the PM is accountable to other senior managers, who oversee their performance and report to others in the higher levels of leadership. The findings from the Delphi exercise and the focus group session revealed that the supervising managers were slow-moving in the performance of their functions, as shown in these factors:

- Poor performance management by PMs, which is not reported by Senior Managers.
- Insufficient monitoring and reporting of contractors who do report to Senior Management.

The performance management process requires demanding progress reports from subordinates, progressive reviews, confirmation or change of current policy or programme directions (Lee & Mouritsen, 2018). The performance results emanating from the performance measurement tool is shared with all relevant units of the organisation progressively in a collaborative effort of pursuing, achieving, and excelling in the set goals (Janićijević, 2017). Consequently, the contextual application of the suggestion from performance assessment through performance management facilitates progressive performance improvement in any organisation (Shao et al., 2017).

Therefore, the performance management challenges senior management of the NDPWI to set, monitor and evaluate the performance of the PM in every project to ensure that productions are in accordance with the project schedule. Otherwise, proactive measures should be taken to ameliorate delays. According to Shaw (2018), PMs are responsible for planning, organising, coordinating, controlling and directing the execution of the project. The PM demonstrates their skill and competence level in the quality of activities showing the construction process, otherwise known as "Work Breakdown Structure". These activities are represented in the timeline, using the most convenient project or construction management tools, such as Gantt Charts, the Project Evaluation Review Technique (PERT), and the Critical Path Method (CPM). Successful projects are characterised by execution within the given project timeline (Bodea & Purnus, 2016). The quality of the periodic reports from the PM, performance in terms of time, cost and quality will inform senior managers on the areas of continuous training of the NDPWI PMs, which must be consistent with the recommendation by the Project Management Institute.

3.2.4. Systems thinking

A learning organisation is characterised by five fundamental disciplines, such as systems thinking, personal proficiency, mental models, shared vision, and team learning. All five disciplines must be developed together. Systems thinking is regarded as the first discipline and a cornerstone of the other disciplines, interlinking them to function as a unit. Systems thinking and other disciplines are joined through a mind shift from seeing parts to seeing wholes (Fillion et al., 2017). According to the FG session, the NDPWI directorates are working in silos with extensive delays caused by the supply chain management (SCM) processes. Although the NDPWI has a mandate from the Parliament to provide accommodation and infrastructure to other departments, the implementation of these projects is achieved with the high cost and time overruns due to bureaucracy, conflicting policies, and an overcentralised administration. FG participants observed that the NDPWI is overregulated, resulting in prescripts that are not user-friendly, constant changes and the lack of understanding of supply chain management (SCM) processes by officials, bid committees, consultants, and contractors.

Fillion et al. (2017) suggested that organisations and governments should have the ability to cope with rapid changes and frontline staff capable of responding to the ever-changing demands of customers and global markets. "Learning organisations are organisations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (Fillion et al., 2017, p. 76). For any change to take place, people must be motivated to assist in making the change a reality. Personal proficiency assists in focusing strengths on achieving a successful result for the organisation. The NDPWI managers should provide enabling conditions for people to develop their skills and integrate them into the execution of their given task to achieve the goals of the department. Through open lines of communication, the staff can share the vision of an organisation and integrate a sense of involvement.

Granted that the NDPWI has the mandate of the government to develop infrastructure, the benefiting departments need the infrastructure for the performance of governance for the benefit of the citizens. Nevertheless, the citing and execution of such infrastructure initially or permanently alter the host community's lifestyle. Therefore, it is necessary to build a collaborative relationship with the host community to win their support and buy into the project. Achieving this requires "thinking outside the box" and not overt reliance on the government's authority. The FG session suggested that the NDPWI should engage the collaborative efforts of non-governmental organisations (NGOs) and other government departments to improve on the relationship-building efforts and support from the project host communities, to facilitate smooth project execution.

Team learning is developed from inside the organisation through a dialogue between staff members, and it is buttressed by systemic thinking, a shared vision, and personal proficiency (Fillion et al., 2017). The NDPWI can respond on time to its clients if it implements the five core disciplines of a learning organisation.

Conclusions

The research aimed to explore the factors responsible for the delays in the execution of construction projects registered with the NDPWI by its client and suggest a concrete approach to their amelioration. As shown in Table 1, a sample was made of six projects registered with the NDPWI from the three regional offices between 2016 and 2020. As of December 2020, two of the projects are still at the planning/design stage, three are in the construction stage and one has been completed. Although the sizes of the projects were not identified, there is no doubt that the slow pace of execution has negative effects on the relationship between the clients and the NDPWI. Therefore, this research was justified, focusing on identifying the possible factors responsible for the slow pace of project delivery and proffering suitable solutions.

The factors responsible for the delays in construction project execution are effective client-management structure, project-management competencies, leadership, and systems thinking. They are classified as in-house constraints. The others are consultant and contractor competencies; these two are classified as external constraints. The third cluster of factors is teamwork, which embraces all stakeholders in the construction project. Therefore, the first objective of this research has been achieved; the factors responsible for the delays have been identified, encapsulated in the themes, and classified. The second objective was to proffer solutions on how to ameliorate the negative effects of these delay factors. As a panacea to the problems identified, this research recommends that:

- The NDPWI should adopt a semi-decentralised management structure, encouraging the delegation of authority, semi-autonomy, and innovation in the regional offices.
- The training and retraining of PMs should be given prominence to improve their competency level.
- The PMs should be empowered to perform project coordination and enforce the penalty and reward clause in contractual conditions.
- Senior management should adopt the contextual use of the concept of performance management, demanding timely progress reports from the PMs, and holding them accountable for lapses in the execution.

Furthermore, since this research was conducted in three out of the twelve regional offices, this research should be extended to all the regional offices of the NDPWI to obtain a nationwide picture. By doing so, it will be possible to effectively generalise the factors causing the delays in the execution of construction projects by the NDPWI and proffer long-term solutions.

Acknowledgements

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Volume 13 • Issue 4 • 2021

Engineering Management in Production and Services

received: 5 August 2021
accepted: 30 November 2021

pages: 57-71

Determination of black spots by using accident equivalent number and upper control limit on rural roads of Thailand

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ABSTRACT
The Department of Rural Roads (DRR) is one of the highway authorities in Thailand responsible for over 48 000 kilometres of rural roads and highway networks. One of its responsibilities is to provide better road safety management. In road safety procedures, black spots are usually identified by observing the frequency of accidents at a particular road section. This research aims to develop a model that includes levels of accident severity in the black spot identification process. The classification of severity levels includes fatalities, serious injuries, minor injuries, and damaged property only. The Analytic Hierarchy Process (AHP) is employed to derive the weight of each severity level. The identification model is developed using Equivalent Accident Number (EAN) and Upper Control Limit (UCL). The data applied in the model are obtained from the road accident investigation of DRR. Five roads — Nakhon Ratchasima 3052, Chonburi 1032, Nonthaburi 3021, Samutprakarn 2001 and Chiangmai 3029 — have been selected based on the top frequency accident recorded in the last three years. Based on the results of black spots identified in the study, most accidents occurred from frontal and rear-ended impacts due to exceeded speed limits. The article discusses recommendations.

KEY WORDS
black spot, equivalent accident number, road safety, rural roads

10.2478/emj-2021-0031

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Introduction

The number of road traffic fatalities worldwide continues to rise and has reached 1.35 million in 2016 (World Health Organization, 2018). Globally, this indicates nearly 3 700 traffic fatalities every day, despite road safety procedures used in many countries. In low- and middle-income countries, the leading cause of traffic fatalities is road traffic crashes. In Thailand, traffic fatalities and injuries are still a major public health problem accounted for by road acci-

Treeranurat, W., & Suanmali, S. (2021). Determination of black spots by using accident equivalent number and upper control limit on rural roads of Thailand. *Engineering Management in Production and Services, 13*(4), 57-71. doi: 10.2478/emj-2021-0031

Tab. 1. Number of road traffic accidents, fatalities and injuries in Thailand

Year	Number of Occurrences			
	Accidents	Fatalities	Injuries	Serious Injuries
2018	345 234	10 526	394 588	2 091
2019	375 964	10 836	430 788	2 066
2020	432 647	9 282	432 647	1 786

Source: (Thai RSC - Road Accidents Data Center for Road Safety Culture, 2020).

dents. In 2016, Thailand ranked 8th among the countries worldwide with the highest number of road traffic fatalities from accidents, with 32.7 deaths for 100 000 population per year. The numbers have remained virtually constant over the last ten years. The statistical data (Table 1) retrieved from the Road Accident Data Center for Road Safety Culture (ThaiRSC) consists of the number of accidents, fatalities and injuries in Thailand. The data collected from provinces of the country represent the increasing trend in the number of accidents and victims from 2018 to 2020.

The Department of Rural Roads (DRR) under the Ministry of Transportation (MOT) of Thailand is one of the highway authorities that develop and enhance road safety on rural roads and networks and reduce accidents and the number of victims. Road safety measures under the DRR include proactive and reactive measures to identify, reduce and improve road safety. Proactive measures focus on assessing road risk spots by using the Star Rating System (SRS) — one of the tools offered by the International Road Assessment Programme (IRAP). This tool requires many resources and systems to be integrated, which leads to high investments in many dimensions. For instance, road attributes must be collected, such as lane width, the number of lanes, skid resistance, median type etc. In addition, crash types are categorised and used as an important component to identify the road safety level; however, this is a preventive measure used by the DRR to inspect the road safety level. On the other hand, a traditional or reactive measure is based on road accident and crash frequency data. It aims to inspect road safety levels, i.e., identify black spots, without utilising road attributes and other available parameters.

A black spot is a road section with a high risk of a vehicle accident. The identification method considers an accident as a counted statistic record. Unlike a proactive measure, a reactive measure requires little resources and investments. According to the ORSA (2017), the identification of a black spot location used by the DRR relies on the frequency of accidents as a parameter. Nevertheless, other collected parameters from accident sites, such as traffic volume, type of crash and road characteristics, have not been included in the identification process.

The reactive measure of identifying a black spot uses only the number of accidents and historical accident data (ORSA, 2017). With additional information collected from accident sites, the DRR has more valuable data and can develop a better system to identify black spots. One important collected parameter is the accident severity level. This parameter is related to the value of life and the economic value and has not been utilised as a parameter in the black spot identification. Hence, this research emphasised the development of an alternative method that includes the severity levels to identify black spots on rural roads and the network. The developed method was applied to five selected road networks, i.e., roads with a relatively high frequency of accidents. The accident data were collected by the highway authorities of the DRR from 2016–2018. This dataset consists of accident locations, the number of accidents and the severity levels, including victims involved. The parameters of interest or the severity levels are classified as fatalities and minor or major injuries.

1. Literature review

The literature review focusses on reviewing the road safety evaluation method and its background information as well as the previous case study to support this research.

1.1. Black spot definition and identification in European and other countries

The hazardous, dangerous, or accident-prone locations are referred to as a black spot, which is a road section with a higher accident risk compared to others (ORSA, 2017; Kowtanapanich, 2007). In European countries, the black spot definition differs in many aspects. According to some authors (Elvik, 2007; Sorensen, 2007), the black spot definitions and identification in eight European countries are reviewed based on theoretical and best practice terms. Theoretical terms classify the black spot definition into numerical, statistical, and model-based (Elvik, 2007). The numerical definition is based on the accident number, accident rate and the combination of accident number and rate. The statistical definition is based on the critical value of accident number and the critical value of accident rate. In addition, the model-based definition relies on the empirical Bayes and dispersion value. The extended work was made to produce the best practice guidelines (Sorensen, 2007) based on previous theoretical terms (Elvik, 2007), which contain the identification principles and methods for those eight countries.

The identification principles can be divided into accident-based and accident-unbased. The accident-based principle includes other than model-based identification, which uses such parameters as the number of accidents, frequency and the rate of accidents. The model-based identification includes category analysis and accident-specific identification. The category analysis divided the set of an accident, road characteristics and traffic data into the pre-defined category to calculate the average number of accidents. The value of the average number of accidents will be used to compare with the expected number of accidents from a specific model, such as regression analysis or the empirical Bayes.

For the accident-unbased principle, quantitative and qualitative methods are used. These two methods focus on using road information, for instance, road geometry, surrounding environment, driving speed etc., instead of accident data. The summary of criteria to define a black spot, the identification principle, and the method used in eight European countries and Thailand are shown in Table 2.

Based on the above (Elvik, 2007), there is no recognised standard definition of a black spot. Still, in general, it could be determined as a site with a higher expected number of accidents than another site similar in terms of local risk factors. The number of accidents is the main parameter for traditional identification approaches in most reviewed cases. This is due to the independence of this parameter, which can be collected easily through an investigation without calculations or predictions. The suggested period for identification is a range between 3 and 5 years (Nguyen et al., 2016). The road analysis will focus on road sections determined based on the sliding window method, which allows dividing a road into sections to find the number of accidents in each. Based on reviews, the common sliding window can be between 100 – 1000 meters.

However, developing countries, specifically Southeast Asia, have data availability limitations. Hence, researchers have proposed multiple approaches to identifying black spots in this region. In Vietnam(Nguyen et al., 2013), the criteria used for black spot identification is the number of accidents on a particular road and the damage severity. The severity levels are divided into three cases: two fatal accidents, three or more accidents and one fatal, and four or more accidents but no injury. The Black Spot Management (BSM) approach (Taneerananon et al., 2013) uses accident data to determine the blackspot site within a road network, which is a road section with poor safety performance, and classifies the road infrastructure as a black spot. This study includes a prioritised index by ranking blackspot sites using the safety potential in accident costs. The focused parameters in the study are the traffic volume, the accident severity and the accident cost rate.

In Myanmar (Mon, 2016), the combination of accident frequencies, the accident rate and the rate of quality control have been applied as the black spot identification procedure. The prioritisation or the black spot ranking is defined as the Danger Index (DI), and a site with the smallest DI is considered the most dangerous black spot. The required parameters in this research are mainly focused on the number of accidents, the accident rate and traffic volume.

Several authors (e.g. Susilo, 2016; Susilo et al., 2018; Halim & Saing, 2018; Leuhery & Hamkah, 2020) stated that Indonesia adopted the Equivalent Accident Number (EAN) method that determines the black spot location using the Weighted Accident Numbers (WAN) and the Upper Control Limit (UCL) as identification and ranking methods. The identification methods use such parameters as the number of accidents, accident severity levels. Such methods are used by many researchers in various areas of Indonesia. In addition, these methods do not require much investment and resources to prioritise black spots.

In Thailand, according to the ORSA (2017), previous research included various methods to determine black spots; for instance, the number of accidents method focusing on a location to identify the safety performance, the accident rate method that uses the number of accidents divided by the vehicle exposure to find the rate or their combination. The parameters and the number of accidents required for the accident number method have been summarised in research (Leelakajonjit & Iamtrakul, 2013). The traffic volume and the number of accidents are required for the accident rate method. The model-based identification requires all mentioned parameters. According to the ORSA (2017), the DRR employs the number of accidents method for the black spot identification defining a black spot as a location or

Tab. 2. Black spot identification principle, method and criteria in eight European countries

Country	Identification Principle	Identification and Method	Criteria to define as Black spot	Sliding Window (Meter)	Identification Period (Year)
Austria	Combination of Specific and Model Based	• Accident type • Accident rate	• ≥3 similar injury accidents within 3 years • A relative coefficient (Rk) ≥ 0.8	250	3
Denmark	Combination of Model Based and Not Model Based	• Poisson distribution • Accident number	• 4 accidents within 5 years	Fix length equal to mean value of mean number of accidents	5
Belgium	Not Model Based	• Accident number	• 5 similar types of accidents within 1 year • ≥ 5 injury accidents or ≥3 serious injury accidents within 3 years	100	1 or 3
Germany	Combination of Specific and not Model Based	• Accident type • Accident number	• 5 similar types of accidents within 1 year • 5 injury accidents within 3 years • 3 serious injury accidents within 3 years	-	1 or 3
Hungary	Not Model Based	• Accident number • Accident rate	• ≥ 4 accidents within 3 years (Outside built-up area) • ≥ 4 accidents within 3 years (Inside built-up area)	100 or 1000	3
Norway	Not Model Based	• Accident number	• ≥ 4 injury accidents within 5 years	100	5
Portugal	Not Model Based and Model Based	• Accident number • Empirical Bayes	• ≥ 5 accidents within 1 years on 200-meter location and severity indicator ≥20	200	1 or 5
Switzerland	Not Model Based and Model Based	• Accident number • Traditional model	• Threshold value of accident number and injury accident number	-	2

site with a straight or curved road section or an intersection area with more than three accidents in three years. Based on research, the sliding window is 100 meters.

In Thai DRR, only the number of accidents is used as a parameter to identify black spots, but not the models employed by previously mentioned European countries. This is due to limited survey data of rural roads from the past years. The available parameters are only the number of accidents and the accident severity level related to the victims. Thus, the lack of other parameters is the reason for this study to propose an identification method. The review of Indonesian research studies (e.g. Susilo et al., 2018; Halim & Saing, 2018; Leuhery & Hamkah, 2020) showed that EAN and UCL methods were supported by the department of transportation in Indonesia. The methods include such parameters as the number of accidents and accident severity levels. The result of black spot locations can be obtained using the EAN and UCL methods without requiring additional investment or resources. The combination of the number of accidents and severity levels has not yet been implemented in black spot identification. Hence, rather than focusing on the number of accidents only, the black spot identification model developed in this study emphasises the inclusion of accident severity levels. The developed model is expected to provide accurate black spots for the DRR and prioritise them for better road safety management for road users.

1.2. Equivalent Accident Number (EAN)

The EAN is known as a numeric economic scale to weigh the degree of accidents. The degree of accidents is then classified according to severity levels: Death (D), Serious or Severe Injury (SI), Minor Injury (MI) and Damaged Property Only (DPO). The accident numbers in each severity level then multiplied by the EAN value will become the Weighted Accident Numbers (WAN). The high value of WAN indicates that the road section must be fixed, or maintenance is the top priority compared to the lower WAN value for other road sections. The WAN is used to prioritise the black spot locations. Rather than focus on the number of accidents as in the past, this method involves the life value of road users as a concerned parameter for identifying a black spot location. The weight for the EAN can be different due to the methodology used; the recommended EAN values from previous research are summarised in Table 3.

The WAN is the sum of the weighting value for a selected road, which can be seen in Equation 1 below.

Tab. 3. Equivalent accident number from previous research

Method	Equivalent Accident Number			
	Death (D)	Serious Injury (SI)	Minor Injury (MI)	Damaged Property Only (DPO)
Research and Development Centre	12	3	3	1
	(Engineering Committee for Standardization of Transportation Infrastructure, 2004)			
Land Transportation	12	6	3	1
	(Soemitro & Bahat, 2005)			
Indonesian Police	10	5	1	1
	(Direktorat Jenderal Perhubungan Darat, 2007)			
Accident Point Weightage (APW)	6	3	0.8	0.2
	(Wedasana, 2011)			
Average of Rationalisation	10	4.25	2.33	1
	(Sugiyanto, Fadli, & Santi, 2017)			

$$WAN = EAN_D \times D + EAN_{SI} \times SI + + EAN_{MI} \times MI + EAN_{DPO} \times DPO \quad (1)$$

where:
WAN — Weight Accident Number,
EAN_x — Weight of each Degree of Accident; x = {D, SI, MI, DPO},
D — Number of Deaths,
SI — Number of Serious Injuries,
MI — Number of Minor Injuries,
DPO — Number of Damaged Property Only equal to Number of Accidents.

1.3. Upper Control Limit (UCL)

To determine black spot location in this study using the statistical quality control chart, which is the Upper Control Limit (UCL) as shown in Equation 2.

Compared with the EAN, the road section that contains the WAN higher than the value of the UCL is defined as a black spot. Based on research (Sugiyanto et al., 2017), the value of probability factor (ψ) is the probability that the accident rate is large enough so that the accident is not a random event, as shown in Table 4. The most selected value of ψ is 95 % significance or 1.645 and 99.5 % significance or 2.576.

$$UCL = \lambda + \psi x \sqrt{(\frac{\lambda}{m} + \frac{0.829}{m} + (\frac{1}{2} \times m))} \quad (2)$$

where:
λ — Average Accident Score,
ψ — Probability Factor,
m — Accident score in each section.

Tab. 4. Probability factor

Probability	0.005	0.0075	0.05	0.075	0.10
ψ	2.576	1.960	1.645	1.440	1.282

2. Research methods

The structure and systematic activities were carried out with stages according to the scientific research. After obtaining the accident data, including accident severity levels, from the past three years recoded by the DRR, the weight of each severity level was determined using the analytic hierarchy process (AHP). Then, the EAN and UCL methods are applied to identify the black spots.

2.1. Accident data

The secondary data used in this study were retrieved by the Road Accident Investigation (RAI) team in the Department of Rural Roads, Thailand. The data consisted of road accidents on rural roads around the country during 2016 – 2018, including the accident numbers and accident severity levels. 1 472 roads had 4 781 accidents that resulted in 1 595 deaths (D), 1 533 serious injuries (SI), 1 653 minor injuries (MI) and the damaged property only (DPO).

2.2. Severity level and their weights

The severity levels of accidents can be divided into three categories: (1) death or fatal injury (D), (2) serious or major injury (SI), (3) minor or slight injury (MI). An accident without any injured victims is called an accident with material or property loss only or damaged property only (DPO). The death or fatal injury refers to accidents with fatalities on the spot or from an injury sustained with 30 days of the accident. An accident with a serious or major injury refers to a serious injury suffered by victims and in need of hospitalisation for over 30 days. A slight or minor injury requires first aid on-site or hospitalisation of fewer than 30 days.

To obtain the weight for the severity levels, the AHP is employed. It is one of the decision-making tools to deal with multi-criteria problems (Kim et al., 1999). By applying this method, the components of the decision-making problem are digested into a hierarchy of a top objective or goal, criteria, and sub-criteria layers. Then, the experts conduct a simple pairwise comparison by using a 9-point intensity among aspects in the structure, as shown in Table 5. The objective of this AHP is to find the significance of each severity level (weight) that affects the identification of a black spot. The severity level in each group is considered as a criterion that must be compared. To illustrate further, an expert must compare a pair of severity levels, for instance, whether death or a serious injury has more impact in determining the road section as a black spot using the intensity level. According to Kim et al. (1999), the process of determining the weight includes forming a team of experts and assigning a pairwise comparison to the severity levels. A pairwise comparison matrix is then constructed by assigning a relative score for each pairwise comparison based on the numerical 9-point intensity levels. Then, the relative weight from each expert is evaluated, and the level of importance is obtained through normalisation. The calculation of the consistency ratio is also done to validate the results. Finally, the relative weight from the expert judgements is obtained by applying the geometric mean for all relative weights received from each expert.

The questionnaire survey was carried out at the Department of Rural Roads (DRR), Thailand, with a selection of experts who currently hold or previously held a leadership or management role in the areas of the black spot improvement or road safety audit. They must have experience in road safety audits or management for at least five years. They represent the road safety audit team. A total of 11 experts participated in the in-depth interview and responded to the AHP pairwise comparison. Based on research (Batagarawa et al., 2015), the number of experts was sufficient for the analysis. All definitions, such as

Tab. 5. 9-point intensity level

Intensity Level	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extremely strong importance

severity and intensity levels, were clearly explained to experts. They were given the same set of questionnaire surveys during the interview session.

2.3. Data preparation

For the black spot identification, the roads were selected for the analysis based on the number of accidents, i.e., no less than ten accidents (Halim, 2018). Out of 54 roads with more than one accident, five roads were selected as they had the top five number of accidents. In this research, five roads were selected for the black spot identification: Nakhon Ratchasima 3052 (NRM 3052), Chonburi 1032 (CBR 1032), Nonthaburi 3021 (NBR 3021), Samut Prakarn 2001(SPK 2001) and Chiangmai 3029 (CM 3029). The black spot identification process suggested using accident data for 3 – 5 years (Elvik, 2007). Each road was then divided into sections of 100 meters in length, and the number of accidents in each section was calculated. There were 41, 80, 41, 61, and 159 road sections with at least one accident for NRM 3052, CBR 1032, NBR 3021, SPK 2001, and CM 3029, respectively. In addition, the types of accidents,

Tab. 6. Number of accidents according to types and causes of an accident

Road	Types of Accident							Causes of Accident					
	RR	HP	FT & RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
NRM 3052	14	4	15	0	0	15	3	5	3	20	7	13	9
NBR 3021	22	0	22	5	0	31	13	2	2	43	38	4	4
CBR 1032	13	3	29	4	1	5	11	2	1	28	27	5	4
SPK 2001	15	1	144	101	8	3	3	1	0	0	270	4	0
CM 3029	9	0	219	7	0	89	19	43	16	13	203	60	4
Total	73	8	433	113	9	143	49	53	22	104	545	86	21

Tab. 7. Length, road properties and total number of accidents

Road	Length (Kilometres)	Road Properties	Total Number of Accidents (2016-2018)
NRM 3052	69.543	• 2 Lanes of straight sections • 3- and 4-Way Intersections • Simple, compound and broken back curvature • Residential area	51
NBR 3021	31.102	• 10 Lanes of straight sections • 3-way Intersection with a traffic light • Simple curvature • Residential Area	93
CBR 1032	12.492	• 2 Lanes of straight sections • 3-way Intersection without a traffic light • Simple and broken back curvature • Residential and industrial area	66
SPK 2001	13.53	• 6 Lanes of straight sections • 3-way Intersection without a traffic light • Simple and broken back curvature • Residential and industrial area	275
CM 3029	26.108	• 6 Lanes of straight sections • 3-way Intersection with a traffic light • Simple and compound curvature • Residential area	343
Total			828

including Run-off-Road (RR), Head-On (HO), Frontal & Rear-End (FT&RE), Intersection & Access Point (INT&AP), Cross-Road (CR), Obstacle (OC) and Otherwise (OTW), and the causes of accidents including Drunkenness (DKN), Drowsiness (DSN), Recklessness (RLN), Violate Traffic Rule (VR), Cross-Cut (CC), Otherwise (OTW)) are summarised in Table 6. The length, road properties and the total number of accidents are demonstrated in Table 7. The example of a road divided based on the sliding-window method is shown in Table 8.

2.4. Black spot identification in selected roads

Before applying EAN and UCL methods, the AHP results from 11 experts have led to weights for each severity level. It is referred to as EANx in Equation 1. Frequencies of accidents and severity levels for each road section (100 meters in length) were tallied. Then, the WAN value for each section was determined as indicated in Equation 1. The average accident (λ) for each road was calculated as the total WAN values divided by the total number of sections with accidents. The UCL value for each road section was determined according to Equation 2. The last step was to compare WAN and UCL values within the same road section. If the WAN value exceeded the UCL, a black spot was identified.

3. Research results

3.1. Prioritisation of criteria using AHP

The collected data from 11 experts were analysed using the AHP mentioned in section 2.2. The consistency ratio was less than 0.1, which indicated that it was acceptable to use (Kim et al., 1999). The summary of the results is shown in Table 9. Then, to determine the relative weight of each severity, the geometric mean was applied. The relative weight results were 0.57 or 57 for death (D), 0.28 or 28 for serious injury (SI), 0.01 or 10 for minor injury (MI), and 0.05 or 5 for damaged property only (DPO), as indicated in Table 9. The experts prioritised between two severity levels and determined a score for each comparison using their scale. Experts evaluated which severity

Tab. 8. Example of road sections for NRM 3052

Road Section Number	Frequency			
	D	SI	MI	DPO
1	1	0	0	1
2	0	0	1	1
3	0	0	1	1
4	0	0	0	1
5	0	0	1	1
6	0	0	1	1
7	0	0	1	1
8	0	0	1	2
9	0	1	1	2
10	0	0	1	2
11	0	0	0	1
12	0	0	2	1
13	0	0	1	1
14	0	0	1	1
15	0	0	2	2
16	0	0	2	1
17	0	0	1	1
18	0	0	1	1
19	1	0	0	1
20	0	1	0	1
21	0	0	1	1

Road Section Number	Frequency			
	D	SI	MI	DPO
22	0	1	0	1
23	0	0	0	1
24	0	0	2	1
25	2	1	1	5
26	0	0	1	1
27	0	0	1	1
28	0	0	2	1
29	0	0	1	1
30	0	0	1	1
31	0	0	3	1
32	0	1	0	1
33	0	1	0	1
34	0	1	1	2
35	0	1	1	1
36	0	0	1	1
37	1	0	0	1
38	0	0	1	1
39	1	0	0	1
40	0	0	1	1
41	0	3	5	2

Tab. 9. Relative weight based on expert decisions

Expert	D	SI	MI	DPO
1	0.60	0.21	0.14	0.06
2	0.57	0.28	0.09	0.05
3	0.59	0.27	0.10	0.05
4	0.48	0.36	0.10	0.06
5	0.62	0.21	0.12	0.05
6	0.59	0.25	0.10	0.06
7	0.47	0.40	0.09	0.04
8	0.56	0.29	0.09	0.06
9	0.56	0.33	0.06	0.05
10	0.63	0.23	0.10	0.04
11	0.60	0.26	0.10	0.04
Relative Weight	0.57	0.28	0.10	0.05

level dominated over another in each comparison by determining the consequences and responsibilities that the highway authorities must bear in the case of accidents. The relative weight from experts demonstrated that the most important factor was the number of deaths from an accident. A high number of deaths from an accident implies some potential road safety standard problems. The weights obtained from the AHP identify the black spot location as equivalent accident number (EAN) values.

3.2. Black spot identification using the EAN and the UCL

The weight accident number (WAN) for each road section was calculated, where the equivalent accident numbers (EAN) were 57, 28, 10 and 5 for death or fatal injury (D), serious or major injury (SI), slight or minor injury (MI), and damaged property only (DPO), respectively. The sum of WAN values was determined for each road and used to calculate the average value accident (λ) by divining the WAN sum by the number of road sections with at least one accident, as summarised in Table 10.

The results of black spot locations are determined when the WAN value exceeds the UCL, arranging from the highest to the lowest WAN or severity values, as summarised in Tables 11, 12, 13, 14 and 15. In addition, Fig. 1 demonstrates the calculated WAN and UCL values for all road sections.

For further analysis, accidents at each black spot were investigated. The types and causes of accidents at each black spot were summarised in Tables 11 to 15.

Tab. 10. Total WAN value, the number of road sections and the average value accident

Road	Total WAN	Number of Road Sections	Average Value Accident (λ)
NRM 3052	1315	41	32.07
NBR 3021	2029	80	25.36
CBR 1032	1661	41	40.51
SPK 2001	4514	61	74.00
CM 3029	9194	159	57.46

As the study aimed to establish a black spot identification method for the DRR that included severity levels in addition to the number of accidents, the developed method used the existing severity data collected from the DRR road accident investigation team. Having different severity levels, black spots can be identified and prioritised by looking at the WAN. Larger WAN values indicate that a high priority should be placed on such locations. The highway authorities from the DRR participated in this study. The judgement of experts from the civil engineering group with experience in highway road safety audits pointed out that an accident involving deaths was the most significant parameter in identifying black spots. Based on the analysis, NMR 3052 has eight road sections with WAN values higher than the upper control limit boundaries; hence, they are classified as black spots. While the roads NBR 3021, CBR1032, SPK 2001 and CM 3029 have 25, 11, 15, and 49 black spots, respectively. The EAN and UCL methods were successful in identifying black spots and their rank based on the derivation from severity levels and accident frequencies.

From further investigation, the majority of accidents at black spots were frontal and rear-ended accidents due to exceeded speed limits. The surrounding areas of the selected roads were mostly residential. Road safety equipment should be installed to reduce accidents. For instance, rumble strips and additional speed-limit signs for road users.

Conclusions

In the past, the traditional approach focused on reducing the number of accidents by focusing only on accident frequencies at a particular road section. Identifying black spots by involving only frequencies of accidents at a particular road section may not be enough as it does not include severity levels, such as death or serious injury. Also, the focus should be on

Tab. 11. Eight black spot locations on NRM 3052

ROAD SECTION NUMBER	FREQUENCY				WAN	UCL	TYPES OF ACCIDENT							CAUSES OF ACCIDENT					
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
25	2	1	1	5	177	56.33			3			2				2	3		
41	0	3	5	2	144	53.96		1				1		1			1		
1	1	0	0	1	62	46.53			1										1
19	1	0	0	1	62	46.53	1									1			
37	1	0	0	1	62	46.53							1					1	
39	1	0	0	1	62	46.53	1										1		
9	0	1	1	2	48	44.87	2							1			1		
34	0	1	1	2	48	44.87			2							1	1		
						TOTAL	4	1	6	0	0	3	1	2	0	4	7	1	1

Tab. 12. Fifteen black spot locations in NBR 3021

ROAD SECTION NUMBER	FREQUENCY				WAN	UCL	TYPES OF ACCIDENT							CAUSES OF ACCIDENT					
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
28	2	2	1	1	185	50.15						1				1			
31	1	1	3	2	125	45.76						1					1		
46	1	1	1	1	100	43.62						1					1		
68	1	1	0	1	90	42.69	1									1			
25	1	0	2	1	82	41.92			1					1					
48	0	2	2	1	81	41.82						1				1			
50	1	0	1	2	77	41.41	1									1			
55	1	0	0	2	67	40.35	1									1			
47	1	0	0	1	62	39.8							1				1		
58	1	0	0	1	62	39.8	1									1			
34	0	2	0	1	61	39.68						1					1		
40	0	1	1	3	53	38.74						1				1			
38	0	0	4	2	50	38.37						1				1			
39	0	0	4	1	45	37.73						1					1		
67	0	0	3	2	40	37.06	1									1			
						Total	5	0	1	0	0	8	1	1	0	9	5	0	0

Tab. 13. Eleven black spot locations in CBR 1032

ROAD SECTION NUMBER	FREQUENCY				WAN	UCL	TYPES OF ACCIDENT							CAUSES OF ACCIDENT						
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
1	0	5	0	2	150	62.86			2							1		1	
14	1	3	0	1	146	62.56		1								1			
29	1	1	0	3	100	58.8			1			1	1			2	1		
6	0	1	5	4	98	58.62			3		1	1				1	2	1	1
17	0	1	4	5	93	58.16	2		2				1	1		1	1	1	1
23	0	1	4	4	88	57.69	1		2			1				2	2		
18	1	0	1	2	77	56.6		1					1	1			1		
37	0	1	3	3	73	56.19			1				2			1	2		
12	1	0	0	1	62	55						1					1		
40	1	0	0	1	62	55			1							1			
7	0	0	4	3	55	54.2	1					1	1				1	1	
						Total	4	2	12	0	1	5	6	2	0	10	11	4	2

Tab. 14. Fifteen black spot locations in SPK 2001

ROAD SECTION NUMBER	FREQUENCY				WAN	UCL	TYPES OF ACCIDENT							CAUSES OF ACCIDENT						
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
32	1	0	23	25	412	110.98	1		8	15			1				25		
29	0	0	27	26	400	110.44	2		10	13	1						26		
11	0	0	21	21	315	106.35	1		15	4	1						21		
14	0	0	14	15	215	100.75	1		7	5	1						15		
17	0	0	14	15	215	100.75			1	14							15		
39	0	0	16	9	205	100.12	1		4	4							9		
12	0	0	13	14	200	99.8	1		8	2	1		1				13	1	
15	0	0	12	15	195	99.48			10	2	2						14		
36	0	0	11	9	155	96.74	1		6	2							9		
40	1	1	3	5	140	95.63		1	1	3							4	1	
55	0	0	9	10	140	95.63	1		3	6							10		
54	2	0	0	2	124	94.38			2								1	1	
59	2	0	0	1	119	93.97			1								1		
16	1	0	2	5	102	92.52			2		1	2					5		
5	1	1	1	1	100	92.35							1				1		
						Total	9	1	78	70	6	2	3	0	0	0	169	3	0

Tab. 15. Forty-nine black spot locations in CM 3029

Road Section Number	Frequency				WAN	UCL	Types of Accident							Causes of Accident					
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
65	2	3	15	9	393	93.57			8				1	1			2	6	
151	0	0	18	18	270	87.39			7	1							7	1	
17	0	2	16	10	266	87.17			6	1		1				2	2	6	
31	1	0	8	4	157	80.28			4								4		
152	2	0	3	2	154	80.06			2					1			1		
117	1	2	3	2	153	79.99			1			1		1			1		
145	0	1	10	5	153	79.99			5								4		
15	1	1	4	3	140	79.01			3								3		
33	0	3	3	5	139	78.93			5								3	2	
48	2	0	1	2	134	78.54			1			1					2		
24	0	0	11	4	130	78.23	1		3								4		
49	1	0	5	4	127	77.99			4							1	5		
20	0	2	5	4	126	77.9			4								2	2	
83	0	1	6	7	123	77.66			2			2					4		
71	0	0	9	6	120	77.41			6									5	
144	0	1	7	4	118	77.25			3				1				2	2	
133	1	0	3	5	112	76.74						5			2		3		
8	1	1	1	2	105	76.12	1						1	1			1		
23	0	0	8	5	105	76.12			2	1		2		1			4		
42	0	0	9	3	105	76.12			2				1				3		
139	1	1	1	2	105	76.12			1			1					2		
114	0	1	6	3	103	75.95			3						3				
14	0	1	5	4	98	75.49	1		3						2		2		
36	0	1	5	4	98	75.49			2			2					1	3	
121	1	0	3	2	97	75.4			1			1		1			1		
128	1	0	3	2	97	75.4			1			1						2	
119	0	1	5	3	93	75.03			3								2	1	
135	0	1	5	3	93	75.03			3					1	1		1		
11	1	0	2	3	92	74.93						2	1	1			2		
9	0	2	2	3	91	74.84	1					1	1	1	2				
72	0	0	7	4	90	74.74			3			1					3	1	
10	0	1	4	4	88	74.55			1			3		1	1		1		
19	1	0	2	2	87	74.45			2								2		
40	0	0	7	3	85	74.25			3					2			1		
46	0	0	6	5	85	74.25			2			3		2			2	1	
104	0	1	4	3	83	74.05				2		1		1			2		
52	1	0	2	1	82	73.95			1					1					
70	0	0	6	4	80	73.75			3			1		1			2		1
103	0	0	6	4	80	73.75			4					2		1	1		

Road Section Number	Frequency				WAN	UCL	Types of Accident							Causes of Accident						
	D	SI	MI	DPO			RR	HO	FT& RE	INT & AP	CR	OC	OTW	DKN	DSN	RLN	VR	CC	OTW
7	0	1	4	2	78	73.55			1			1					1	1	
62	0	1	4	2	78	73.55			1			1					1	1	
75	0	1	4	2	78	73.55			1	1				1			1		
154	0	1	4	2	78	73.55			1				1				2		
54	1	0	1	2	77	73.44			1			1		1			1		
73	1	0	1	2	77	73.44			1			1					2		
112	1	0	1	2	77	73.44			1			1		1			1		
126	0	0	6	3	75	73.23			3					1				2	
137	0	0	7	1	75	73.23			1								1		
158	0	0	6	3	75	73.23			2				1				2	1	
						Total	4	0	117	6	0	34	8	23	11	4	90	37	1

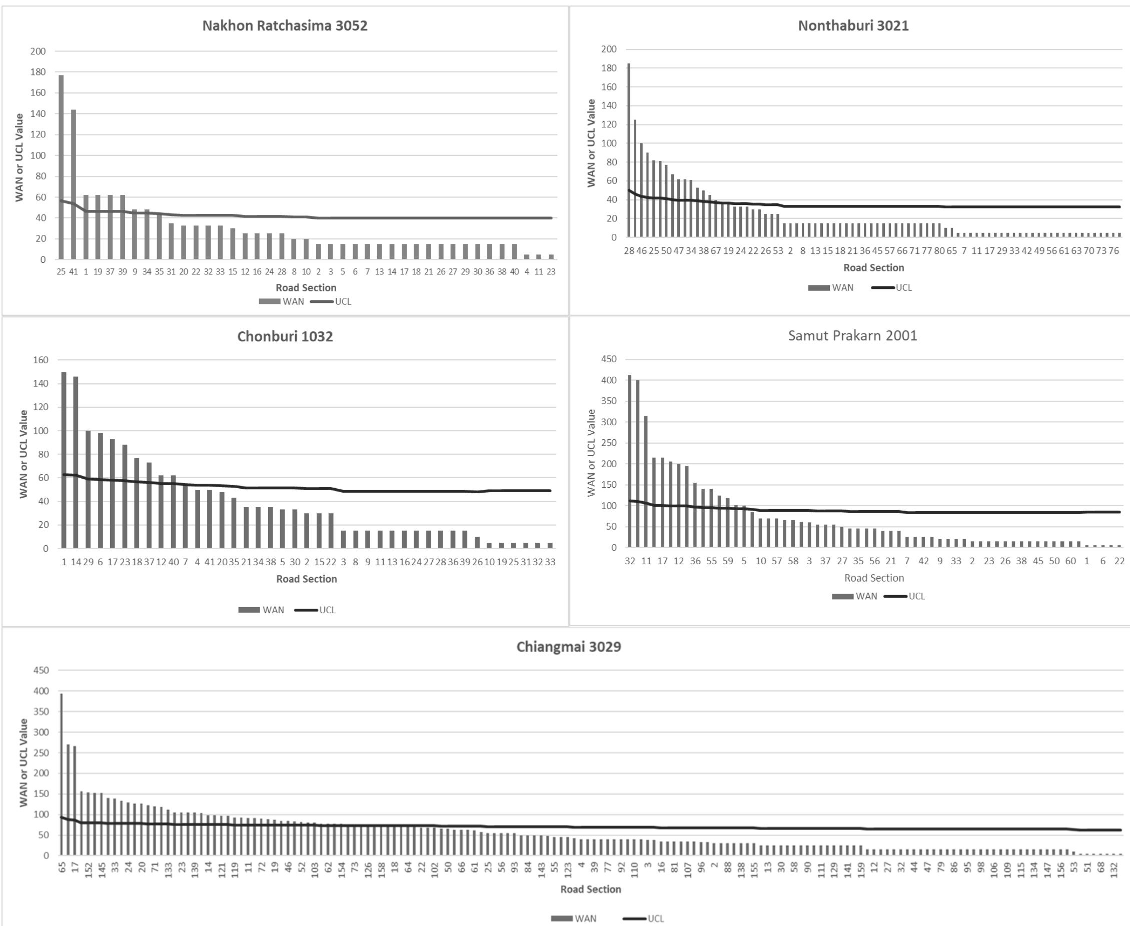

Fig. 1. Black spot identification with UCL boundaries on all sampled roads

a road section with accidents resulting in injuries or fatalities. Hence, the developed method that includes different severity levels should give the highway authorities a better perspective of black spots. For instance, in the case of road section 25 on SPK 3021, the number of accidents in the past three years was four, with two minor injuries recorded. However, based on the traditional accident frequency approach, the section is considered a black spot since the frequency is above three. Once severity levels are considered, the result of this developed model yields the EAN value of less than the UCL. Hence, using this research method, such a section is not a black spot even though it had more than three accidents. On the other hand, two accidents occurred in road section 54 on SPK 3021 in the past three years. This road section is not considered a black spot when using a traditional approach. However, these accidents resulted in two deaths. Thereby, when using the EAN approach and considering the severity levels in the calculation, the EAN is much greater than the UCL. As a result, it is a black spot, and has a high priority to be fixed or reworked to make sure it can maintain the standard of road safety. The most critical black spots are those listed based on WAN values. Once the critical or true black spot is identified, the DRR can prioritise the road for safety improvement. With accurate identification of black spots, effective road safety plans and budgets can be organised. Once safety measures are applied to black spots, road users can travel safer, and the number of injuries or fatalities are expected to decrease. This implies that in socioeconomic terms, the cost of an accident based on fatalities, for instance, cost of productivity loss or human cost and property damage cost, will also decrease.

The identification and prioritisation by using the EAN on rural roads of Thailand are applicable to use, and the generated results are acceptable. The proposed model does not require many additional parameters or investments. The added parameters can be obtained easily by requiring such detailed records of accidents with their classification of severity levels.

The limitation of this study is that the weight was obtained based on the decision of experts in Thailand. In addition, the weight for damaged property only is rather low when compared to other parameters; this infers that the experts believe that the influence of the property damage is relatively low. In addition, accident types and causes in the secondary data only provided four types of severity levels. If other organisations have different databases and severity levels, the black spot identification process for each organisation can be adjusted by adding or removing the parameters mentioned in this research.

Acknowledgements

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Volume 13 • Issue 4 • 2021

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 10 August 2021
accepted: 5 December 2021

pages: 72-78

Industry 4.0 — policy-based approaches to efficient implementation in SMEs

Joanna Łabędzka

ABSTRACT

Industry 4.0 (I4.0), driven by the need to access real-time insights and information across the manufacturing process, creates a disruptive impact on industries. Large-scale machine-to-machine communication, virtual reality (VR), the Internet of Things (IoT), simulation technologies and network management are integrated for increased automation, machine learning, self-controlled social and technical systems (Smart Factories). The uptake of advanced manufacturing solutions represents a challenge for businesses and SMEs in particular. SMEs possess neither the organisational capability nor financial resources to systematically investigate the potential and risks of introducing Industry 4.0. However, the so-called Fourth Industrial Revolution is a matter of technology and cooperation between European regions to share knowledge concerning alternative regional and national approaches to reinforcing the I4.0 uptake. Therefore, this paper primarily aims to analyse practical experience on how European policies related to the European Regional Development Fund (ERDF) can unlock the full potential of Industry 4.0 and overcome the fragmentation of Industry 4.0 solutions. Case studies of successful transfer of I4.0 to SMEs in Europe and supporting regional policy instruments presented in the paper could inspire and enable the potential of digitalisation by dealing with main challenges hampering their diffusion into the business ecosystem.

KEY WORDS
Industry 4.0, digital transformation, SMEs, structural funds, policy instruments

10.2478/emj-2021-0032

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Introduction

The transformation of industrial production is a new economic paradigm in which material wealth is not delivered perforce at the expense of growing environmental risks, ecological scarcities and social disparities (United Nations Environment Programme, 2011). Industry 4.0 might offer an enormous chance to align the sustainable development goals with the ongoing digital transformation in industrial development (Beier et al., 2020). It is expected that

Łabędzka, J. (2021). Industry 4.0 — policy-based approaches to efficient implementation in SMEs. *Engineering Management in Production and Services, 13*(4), 72-78. doi: 10.2478/emj-2021-0032

the development of Industry 4.0 will contribute to tackling global challenges by achieving better resource- and energy efficiency and strengthening the competitiveness of high-income countries (Rauch et al., 2018).

The core principles of I4.0 are modularisation, self-regulation, and digital integration across business functions and within and beyond the organisational boundaries (Prause, 2019) based on the Internet of Things (IoT) (Atzori, Iera, & Morabito, 2010) and cyber-physical systems (Khaitan & McCalley, 2015).

With the advent of newer developments, including artificial intelligence, 3D printing and robotics, yet more profound changes are anticipated in the years and decades to come (Ramalingham et al., 2017).

Companies across the globe are digitally transforming as they are challenged to improve processes and develop new capabilities and business models. Large companies are anticipating the changes arising from the digital revolution in the production and value creation process more easily, while small and medium-sized enterprises (SMEs) are struggling to embrace the Industry 4.0 revolution (Azevedo & Almeida, 2021).

Only 17 % of SMEs have successfully integrated digital technologies into their businesses, compared to 54 % of large companies (Digital Innovation Hubs Working Group, 2018). And yet, the successful implementation of an industrial revolution has to occur not only in large enterprises but in SMEs in particular (Sommer, 2015).

However, the transformation of the European manufacturing business towards I4.0 is not only a matter of technology but also a matter of cooperation between regions to share knowledge concerning policy instruments at the regional and national level to assist this process, especially in small and medium enterprises. Several different types of constraints can affect this process in SMEs and should be considered.

The paper's author wishes to present inspiring good practice on policy instruments supporting the transfer of digital development in SMEs that is critical to achieving the competitiveness and vision of accelerating sustainability and building a green economy. The research presented in the paper intends to analyse experience on how policy related to Structural Funds can unlock the potential of Industry 4.0 in SMEs and answer the key question: What are effective policy instruments to reinforce the Industry 4.0 uptake in SMEs?

1. Literature review

Small and medium-sized enterprises are the foundation of the growing economy. The European Commission considers SMEs and entrepreneurship essential in ensuring economic growth, innovation, job creation, and social integration in the EU (Papadopoulos et al., 2020; European Commission, 2021). SMEs create two out of three jobs, generate 50 % of the EU's GDP and play a crucial role in adding value in every economic sector (Borowicz, 2021).

Given that SMEs are a major driver of the European economy, accounting for most firms and creating large shares of employment and value-added, the digital transformation is a matter of their market position (European SME Survey, 2019). SMEs in Europe risk their future in the case of failure to embrace digitalisation, as more than one in two SMEs are concerned that they may lose competitiveness if they do not adopt new digital technologies (Azevedo & Almeida, 2021).

The digital revolution is still a challenge to SMEs as they are regarded as less well-prepared for the new technologies and standardisation problems and may face particular barriers in implementing I4.0.

Researchers have indicated several barriers that could constrain SMEs in the adoption of innovations, including I4.0 solutions, for example, the lack of awareness concerning digital capabilities, cybersecurity issues, limited financial resources, inflexibility to change, strategic aspects, technological intensity, aversion to innovation, unclear I4.0 implementation details, insufficient or lacking capacity to test industrial solutions, including limited access to facilities (Horvath & Szabo, 2019; Saunila, 2020; Prause, 2019; Alcacer & Cruz-Machado, 2019; Galati & Bigliardi, 2019; Marchuk, 2021; Jovanovski et al., 2019).

Another reason for SMEs to likely refrain from implementing I4.0 technologies is related to new production and product development technologies and has a competence-based explanation (Yu & Schweisfurth, 2020; Ingaldi & Ulewicz, 2020). Some decision-makers renounce digital transition simply because they do not understand how it can be incorporated into the business (Azevedo & Almeida, 2021).

The lack of support and guidance from the best practices in adopting new technologies in SMEs was also one of the main barriers. Traditional SMEs are often uncertain in their choice of digital business strategy, have problems tapping into large extensive data repositories available to larger companies and shy away from advanced AI-based tools and applications (EU's SME Strategy for a sustainable and digital Europe Communication, 2020). SMEs' access to information must be improved to stimulate the transfer of technology.

The role of the government as an enabler of SMEs in the implementation process cannot be ignored (Jovanovski et al., 2019). The importance of I4.0 transfer to SMEs has been recognised by the European Commission (EC) that has published numerous documents and studies on digitalisation (Davies, 2015; Probst et al., 2018; European Commission, 2018; European Commission, 2020). In addition, the EC has earmarked EUR 80 billion in the period 2014 – 2020 for research and innovation, including help for the development of key enabling technologies to encourage local, regional, and national governments to develop different financial and non-financial support for reindustrialisation and increasing the competitiveness of the EU (Borowicz, 2021).

Also, the European Regional Development Fund (ERDF), under the umbrella of the European Union programme Interreg Europe, co-funded the project entitled "Smart SMEs for Industry 4.0" (acronym SMARTY) to overcome the research gap and help regional and local governments across Europe to develop and deliver a better policy. The international research network is composed of EU regions: Tuscany (Italy), Flanders (Belgium), Lapland (Finland), Mazovia (Poland), Slovenia, Castilla y León (Spain), Catalonia (Spain), Leeds City Region (UK). The paper presents research realised within the SMARTY project focused on sharing solutions and policy learning on alternative approaches to successfully implementing Industry 4.0 in SMEs.

2. Methodology

The main research method used in the paper is a case study based on an investigation of the regional/national policy instruments that help to reinforce the Industry 4.0 adoption in small and medium manufacturing enterprises. The case study method was selected as its advantages overshadow the limitations of statistics-based research methods, such as surveys, interviews or experiments, and it is suitable for developing theories in design research (Teegavarapu et al., 2008).

The following steps were employed in the case study approach: (1) research justification, (2) the justification of the case study method, (3) criteria for selecting a case, (4) data collection, (5) case study analysis. A descriptive case study (Stake, 1995) was designed to answer the research question.

The cases were identified in the learning process within the SMARTY project in the following thematic domains: (1) clusters and clustering initiatives, (2) Digital Innovation Hubs (DIHs), and (3) Digitalisation for Green Transition and Sustainability. The presented investigation was relevant because it fosters knowledge-sharing about alternative measures to face the challenges and overcome obstacles that hamper SMEs' digital transformation.

The presented cases are based on the regional experiences on I4.0 transfer and were shared by their owners within international seminars to inspire other European regions and countries, so the interregional exchange of experience and transfer of knowledge can be applied in other regional and business systems. Each case was then reviewed and assessed by, among others, the representatives of those regions, entrepreneurs, stakeholders, I4.0 experts, career advisors, considering the following aspects: (a) the track record/results/impact/success of a case, (b) the potential of transferability, and (c) special interest/relevance for other regions. Cases with the highest ranking were selected for detailed description, confirmed as good practice of I4.0 transfer to SMEs and will be transferred to action plans and recommendations for public policies.

3. Research results

The first policy instrument is an example of a cluster-centred approach that plays a significant role as a driver of regional innovation and the ability to increase collaboration in the Industry 4.0 ecosystems. The Future Industry Platform (https://przemyslprzyszlosci.gov.pl) is a State Treasury Foundation established by the Polish Ministry of Entrepreneurship and Technology in response to the low level of knowledge and awareness of the SMEs regarding the potential of digital transformation, especially new technologies in production processes and modern business models. The platform financing is based on the annual subsidy established by the Ministry.

The low level of knowledge and awareness of SME management regarding the potential of advanced technologies is one of the main barriers to the implementation of I4.0; therefore, the platform was created to strengthen the competences of I4.0 employees of enterprises operating in Poland. To reach this objective, the platform offers training programmes and innovative ways to demonstrate and explain I4.0 technological solutions to entrepreneurs. Free of charge, thematic workshops are organised in all voivodeships in Poland to provide access (for managers and business owners) to basic knowledge concerning business models, change management at the strategic level and transfer of I4.0 solutions to production.

Creating knowledge and experience exchange processes that ensure access to the international community and experts in the field of digital transformation is one of the results achieved by the platform.

The digital transformation towards I4.0 is also a matter of cooperation and co-creation of new values; therefore, the platform creates a network of partner organisations to scale its activities, for example, Registered Training Organisations (RTOs), clusters, chambers of commerce, DIHs, and direct support for SMEs: training, consultancy, webinars, and expert studies.

To reinforce the uptake of digital transformation and implementation of digital products and services, in SMEs in particular, the platform also helps to introduce business models based on intelligent data analysis, automation, process virtualisation, and cybersecurity.

Interestingly, the Future Industry Platform designed an online self-assessment tool to assess the digital maturity of companies (available in Polish at the Future Industry Platform web page: https://przemyslprzyszlosci.gov.pl/) interested in digital transformation. The tool investigates the following key pillars of enterprise development towards Industry 4.0:

- Processes — scan questions refer to product life cycle integration, ecosystem integration, internal integration, and standardisation;
- Technologies — scan questions refer to connectivity, automation, autonomisation, and intelligent product; and,
- Organisation — scan questions refer to leadership, employees, strategy cooperation, and projects.

The main aim of the scan is to determine the real level of digital transformation of the company, identification of challenges and necessary changes (individual recommendations for a company are prepared after the scan completion) to align standards in the context of I4.0.

The case of the Future Industry Platform may be of interest to other regions because of its transferability potential to different levels of application: national, regional, and organisational. The platform also builds the awareness of the Industry 4.0 benefits for SMEs, stimulates the activities of individual enterprises towards digitisation and integrates business units, especially SMEs, that can positively boost their capacity to absorb I4.0 technologies. Moreover, the case presented strengths of the business sector by creating mechanisms for cooperation between different stakeholders like RTOs, educational institutions, technology providers and local governments by sharing knowledge and building trust in relationships between market entities involved in the digital transformation process.

Cluster initiatives, such as the Future Industry Platform, must be focused on establishing a robust and regenerating ecosystem that produces the innovation, talent, and economic opportunities that firms need to thrive. The focus is fostering innovation through the development of the ecosystem and supporting SMEs for restructuring, modernisation and knowledge acquisition.

The following case of the regional and national facilitation of I4.0 transfer to SMEs describes the EC's initiative, the Digital Innovation Hub (DIH). DIH is a regional-based platform that facilitates public-private partnerships to co-design policy initiatives resulting from co-participation and negotiation of spatially-bound oriented initiatives for digitising. DIHs may offer several public–private collaboration models to its business partners (SMEs, entrepreneurs, large corporations), for instance: piloting and co-design of new services (proof-of-concept work, prototyping), training and support (technical consultancy, commercialisation), visibility (networking to expand beyond local markets).

Catalonia's Digital Innovation Hub (DIH4CAT) is a non-profit regional ecosystem led by the Generalitat of Catalonia through the Department of Digital Policies and Public Administration and the Department of Business and Knowledge. The Hub integrates the main parties involved in the digital transformation process and fits perfectly into the Catalan landscape as Catalonia has become a major European innovation hub for digital and biomedical technology. As a result of coordination actions and specific growing instruments, over 1000 SMEs were technologically transformed between 2019 and 2021. Pro-digital actions in Catalonia included: mapping of technology capacities and sector technological needs, coordination actions to improve players' efficiency, mapping technology capacities and sector technological needs, and specific programmes to support SMEs in the digitalisation process.

The DIH4CAT connects seven strategic nodes:

- artificial intelligence (AI) — over 170 AI companies employing over 8 000 workers with a turnover of EUR 1 358 million.
- supercomputing — the main objective is to create a scientific infrastructure of excellence.
- cybersecurity — 356 companies specialising in cybersecurity in Catalonia employing over 6 000 workers with a turnover of EUR 808 million.
- smart connectivity — 38 companies specialising in smart connectivity, 150 workers in 5G technology jobs, 251 IoT companies with over 3 000 workers.
- additive manufacturing and 3D print — 118 specialised companies employing over 1 300 workers with a turnover of EUR 325 million.
- robotics and advanced manufacturing — 147 robotics companies, 391 circular economy companies with 70 419 workers; and,
- photonics — 60 laboratories and nine spin-off companies, Cluster SECPHO with more than ten partners.

Each node is coordinated by an RTO or a university and offers a complete portfolio of technology and business services concerning awareness and diagnosis, transformation plan, training, prototype and testing, and networking. The DIH4CAT is a one-stop shop that supports all services along the commercialisation process, from the concept of innovation, through prototyping, training to market expansion. Primary Catalonia's objective is to help SMEs become "digitised and connected, sustainable, and integrated". The Hub works as a dynamic community integrating stakeholders with capabilities in digital technologies and Industry 4.0 and improves their skills and knowledge through its regional and international interconnection with ecosystem actors.

The presented DIH4CAT helps foster the transition into Industry 4.0 and facilitates a new path development. Its ambition is not only to deliver user-friendly and targeted advice on sustainability and digitalisation but also to connect support structures so that every SME has advice nearby. The DIH4CAT creates the ecosystem and works closely with other DIHs and stakeholders to ensure a seamless support and advice service, including with national, regional and local authorities and support structures.

Digitalisation for Green Transition and Sustainability refers to the process of digitalising the economy in a long-lasting, green, and organic way. The next policy instrument highlights incentives for R&D projects for the productive reconversion within the circular economy that has been introduced in Italy by the Ministry of Economic Development (MISE). The initiative's main aim is to introduce innovative production processes and solutions for the green transition in accordance with the circular economy and the digitalisation process in support of the green economy objectives. As a result, R&D projects leading to more efficient and sustainable use of available resources are co-financed.

The budget available for this measure is EUR 140 million, of which EUR 100 million for the concession of subsidised loans and EUR 40 million in the form of direct contributions to the expenditure. The nominal percentage of the eligible costs for SMEs is 11 – 20 %, and 10 % for large companies. The projects eligible for subsidies must focus on industrial research and experimental development activities, aimed at the productive conversion of economic activities through the creation of new products, processes or services or to significant improvement of existing products, processes or services, through the development of the key enabling technologies, including, among others, ICT, advanced manufacturing and processing.

The main supported activities are as follow:

- product and process innovations based on the efficient use of resources and "zero waste" transformation considering circular economy standards or/and environmental compatibility (eco-compatible innovations).
- experimental design and prototyping of a technological model aiming to enforce the dual industrial pattern.
- innovative technological tools to increase the life span of products and the efficiency of the productive cycle.
- smart packaging experimentation through the utilisation of waste material.
- systems, tools and methodologies for the development of technologies for the supply, rational use and sanitation of water.
- systems for the selection of super-light material to enhance the recovery of and recycle small and light materials.

Submitted proposals are evaluated by the National Agency for Inward Investment and Economic Development (Invitalia), and the technical-scientific evaluation is made by the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and then recommended to the Ministry for financing. The incentives for R&D projects for the productive reconversion within the circular economy help companies invest and develop new environmentally-friendly products, services and processes using I4.0 technologies that respect green economy, green transition and sustainability concepts. The described initiative promotes the transition of the economic activities towards a circular economy-based model through the reconversion of the industrial productive activities with the support of the digitalisation process.

Conclusions

Small and medium-sized enterprises are a focal point in shaping enterprise policy in the European Union, and they do need support in becoming more competitive by improving their business processes, products and services using digital technology. The article presented digital transformation towards Industry 4.0 from a regional innovation system (RIS) and policy perspective to improve regional innovation. In the research process, the descriptive analysis focused on cases as examples of ERDF-based initiatives that support the Industry 4.0 transfer of businesses, SMEs in particular.

Examples of effective policy instruments reinforcing Industry 4.0 absorption by SMEs that have been already successfully implemented in European regions are Industry 4.0-oriented Platforms, Digital Innovation Hubs and incentives for R&D projects focused on green and digital transformation.

SMEs might feel threatened by Industry 4.0 and related technologies. Educational activities of the knowledge platforms, also DIHs, are crucial for businesses to respond to external changes and understand the benefits of such technologies. Companies are likely to reject new technologies without such knowledge since they fail to understand their potential and benefits. Therefore, it is important to develop the ERDF-based policy instruments to support entrepreneurs in the transition process and serve as a guide in the adjustment to the challenges of Industry 4.0, particularly in the area of staff training and the implementation of technological processes.

Digital Innovation Hubs are another instrument for boosting the uptake of I4.0 among SMEs by promoting multi-actor collaborative platforms and place-based collaboration alliances that respond to local/regional contextual specificities and demands.

Also, the regional and national support financed from structural funds for R&D projects is an effective way to help regions/countries invest in the green and digital transition through adopting innovative and sustainable solutions aimed at reconverting productive and industrial activities within the circular economy. The projects and financial aid can boost the economic development and competitiveness of companies, including SMEs, in need of investments and incentives for R&D activities.

It is significant to highlight successful cases of how specific policy instruments can help in boosting the digitalisation of SMEs and enable the transformation potential by dealing with main challenges hampering their diffusion, new technologies, products, services, or business models. The learning potential and inspirations embedded in presented interregional exchanges could result in the uptake of good practice by SMEs and policymakers aiming to speed up the diffusion of I4.0 technologies and thus enable the delivery of innovation within regional supply chains.

Acknowledgements

The results presented in this paper were reached with the help of funding from the European Regional Development Fund under the Interreg Europe programme (project acronym: SMARTY). The project mainly aims to improve the ability to implement policies supporting SME innovation projects that adapt Industry 4.0 solutions in line with regional strategies of intelligent specialisation.

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Volume 13 • Issue 4 • 2021

Engineering Management in Production and Services

received: 5 August 2021
accepted: 30 November 2021

pages: 79-94

Towards Industry 4.0: digital transformation of traditional safety shoes manufacturer in Thailand with a development of production tracking system

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A B S T R A C T
There are many digital transformation challenges going forward towards Industry 4.0 in Thailand, especially for the traditional manufacturing firms that have been operating without digital technologies. The paper presents a case study of a safety shoe manufacturer, CPL Group Public Company Limited, adopting digital technologies to transform its production system of 40 years. It presents a conceptual design for production tracking based on IoT technologies for productivity improvement. This research uses inductive case study research design by interviewing executives and participating in the digital tracking development project using IoT sensors and image processing. The findings show the key success factors of digital transformation in manufacturing, strategies required for development, and the conceptual design of the production tracking system.

K E Y W O R D S
digital transformation, manufacturing, IoT, production tracking, footwear industry

10.2478/emj-2021-0033

Introduction

Many firms have been moving toward digital transformation (DT), which refers to using new digital technologies to enable major business improvements (Fitzgerald et al., 2014). Industry 4.0 includes the digitalisation of the production concept, the integration of learning machines, communication objects, and autonomous robots to create new avenues of production (Valenduc & Vendramin, 2017). It consists of interoperability, virtualisation, flexibility, real-time

Intalar, N., Chumnumporn, K., Jeenanunta, Ch., & Tunpan, A. (2021). Towards Industry 4.0: digital transformation of traditional safety shoes manufacturer in Thailand with a development of production tracking system. *Engineering Management in Production and Services, 13*(4), 79-94. doi: 10.2478/emj-2021-0033

availability, automation, service orientation, and energy efficiency (Perales et al., 2018). Examples of Industry 4.0 technologies are Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data, Industry Automation, Artificial Intelligent (AI), Cloud Computing, Cybersecurity, Robotic Process Automation, Intelligent Robotics, and Human-Computer-Interaction (HCI) (Baena et al., 2017; Himang et al., 2020; Hofmann et al., 2019; Peruzzini et al., 2017; Siderska, 2020). These technologies aim to connect the physical and the virtual worlds with the intelligent flow of the workpieces machine-by-machine in a factory, in which machines communicate in real-time (Alcácer & Cruz-Machado, 2019). The flexible and collaborative system can upgrade the factory to be more intelligent and more adaptive, allowing to make the best decision when dealing with industrial problems (Peruzzini et al., 2017).

Industry 4.0 presents a challenge for the manufacturing industry to adopt digital technology and create more efficient and effective production processes. It is an extremely challenging process because a firm needs to formulate new strategies that align with its culture and workflow. Employees are mostly afraid of being replaced by robots or AI. A firm needs to gradually change people's mindsets to embrace technologies and the new working environment. Many firms have adopted new technologies to improve production processes, such as 3D printing, RFID, robots to track production, increase productivity, and reduce costs in the long term (Bertola & Teunissen, 2018). However, it is not easy to fully integrate digital technologies in the production process in a labour-intensive industry. The rapid digital transformation in manufacturing can cause problems, such as employee learning curve, resistance, and overwhelming data. Some firms invest in modern technologies, such as IoT, CPS, or human-computer interaction systems, just because they think digital transformation is investing in technologies. They did not know how to utilise and properly implement them fully. Manufacturing has a complex adaptive system that involves adaptive interaction between humans and machines (Jones et al., 2021; Miller, 2016).

This paper presents a case study of a safety shoe manufacturer in Thailand adopting modern digital technologies for production tracking and defect detection using IoT sensors and image processing. It presents the conceptual design and development of the production tracking system for the safety shoe products. The project aims to improve productivity, increase accuracy by providing real-time production processes, and identify bottleneck processes. Furthermore, this paper shows the key DT success factors of the factory. This paper contributes to the literature on digital transformation in the manufacturing industry by providing practical methods and guidelines for firms to adopt digital technologies and improve productivity.

1. Literature review

Automated machinery and digital and innovation technologies are important to the development of a Smart Factory. The digital transformation concept is widely discussed in different definitions (Issa et al., 2018; Jones et al., 2021; Mahmood et al., 2019). Vial (2019) developed a working definition of digital transformation as "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" (Vial, 2019, p. 118). Kutnjak et al. (2019) showed a literature review of digital transformation across industries, indicating that industries have implemented modern technologies to improve production and work processes, called a smart factory. Industry 4.0 technologies like CPS, IoT, AI, Big Data, Cloud Computing, and HCI enable seamless data integration, virtual reality, and an automation system (Himang et al., 2020; Peruzzini et al., 2017; Mokhtar et al., 2020; Siderska, 2020).

Kane et al. (2015) argued that digital transformation was not only about adding technology but also more about changing aspects of processes, culture, individual mindsets, and strategies. Paulk et al. (1993) developed the capability maturity model to assess and evaluate the development of software systems, projects, human resource management, and IT governance. Issa et al. (2018) defined four maturity levels. Level 1 has no Industry 4.0 or only ad-hoc, meaning that no person is responsible for Industry 4.0 or digital technologies. Level 2 is the departmental level, at which DT is being implemented on a departmental or shop floor level. However, the activities are not synchronised. Level 3 is the organisational level, meaning that DT is implemented in the whole organisation. All departments are involved in vision and digital strategy formulation. Level 4 is the inter-organisational level, meaning that DT is implemented with overall supply chain partners.

The main objectives of firms to adopt DT are efficiency, productivity, and integrating suppliers and customers in their value chain (Baird & Raghu, 2015). Implementing DT required digital strategies and alignment with the whole organisation (Hess et al., 2016; Kane et al., 2015). Therefore, DT is the adoption of digital technologies (combinations of information, computing, communication, and connectivity) to radical internal and external change processes and then evolving into an implicit transformation of the organisation, requiring a holistic approach (Schweer & Sahl, 2017). However, it is difficult to fully integrate digital technologies in the entire life cycle of products, especially for micro, small and medium enterprises (MSMEs).

Borangiu et al. (2019) stated that "the digital transformation of manufacturing envisaged by Industry 4.0 is based on the paradigm of 31 technological advances: (1) Instrumenting manufacturing resources (e.g., machines and robots), products (e.g., product carriers and subassemblies), and environment (e.g., workplaces and lighting); (2) Interconnecting orders, products/components/materials, and resources in a service-oriented approach using multiple communication technologies such as wireless, broadband Internet and mobile. (3) intelligent decision making in the manufacturing value chain based on ontologies and digital twins – digital models of manufacturing resources, processes and products extended in time, space and operating context, new controls based on ICT convergence in automation, robotics, machine vision, agent-based control, holonic organisation, data science, machine learning, and implementing frameworks: Multi-Agent Systems (MAS), Cloud services, and SOA, and novel management of complex manufacturing value chains (supply, production, delivery, after-sales services) in virtual factories" (Borangiu et al., 2019, p. 151-152).

There is no one right solution to conduct digital transformation. Many firms are ready to engage with digital transformation, but they are uncertain of how to change. A major barrier of digital transformation is the lack of an effective strategy, technology disruption, strategic alignment, data insufficiency and unreliability, high investment, inadequate knowledge and skill, and challenges in value-chain integration (Borangiu et al., 2019; Mahmood et al., 2019; Vogelsang et al., 2019; Gajdzik et al., 2021; Nwaiwu et al., 2020). Hence, many firms slowly adopted modern technologies step by step to synchronise the interaction between humans and machines and conduct trial-and-error exercises. Firms and employees need to find the root cause and propose solutions that fit their circumstances. They tend to use the widely used technologies like Radio Frequency Identification (RFID) for production tracking and production robots to optimise speed and precision (Bevilacqua et al., 2017; Chen & Tu, 2009; Ding et al., 2018). The main implementation objectives are to measure current performance in real-time and identify bottlenecks and losses in the operations (Stoldt et al., 2018). Ding et al. (2018) developed a prototype using RFID devices in each job-shops and a transportation vehicle to collect real-time production and transportation data in a printing machinery company. Data were processed to monitor production progress and states. Bevilacqua et al. (2017) proposed an optimisation process for the footwear production and reengineering the production planning using the IDEF0 approach and (RFID). However, it was the TO-BE map to introduce a new production scheduler and RFID technologies. The RFID provides a solution for logistical tracking of inventory or equipment (Bevilacqua et al., 2017). Chen and Tu (2009) showed the prototype of agent-based manufacturing control and coordination system. This system used ontology and RFID technology to monitor and control and track dynamic production flows of mass customisation manufacturing processes. Musikthong and Chutima (2020) presented a development plan of machinery and technologies to support digital transformation in organisations, such as manufacturing information, machinery integration, security track trace, and RFID system for production and inventory management systems.

The next step is data integration between tools, machines, and factory ICT systems, which involve data acquisition, connection, preparation, conversion, and analytics. The digitalisation of production systems requires the availability and connectivity of data and ICT systems. Many studies have proposed approaches to improve manufacturing systems using digital technologies. However, most of them cannot deal with real-time data that can be effectively analysed and used by web-based applications and services (Huang et al., 2009; Monostori et al., 2016).

CPS enables the horizontal and vertical integration of the end-to-end digital integration (Ding et al., 2018). CPPS includes the integration of computing technologies, ICT, and manufacturing science and technologies (Wright, 2014). It is characterised by intelligent and autonomous interactions among CPS objects and their environment using IoT, responsiveness to changes, and integration of physical resources (Atzori et al., 2010; Monostori et al., 2016). CPPS is connected within and across all levels of the production and logistics network. Its three main characteristics are intelligence, connectedness, and responsiveness (Monostori et al., 2016). CPPS has two main functional components: advanced connectivity to ensure real-time data acquisition and analytics and computational capabilities (Monostori et al., 2016). Previous studies have discuses CPS, IoT, and cyber-physical production systems (CPPS) (Dafflon et al., 2021; Monostori et al., 2016; Wright, 2014). Zhao et al. (2020) adopted collaborative tracking using IoT, edge computing technology, and supervised learning of genetic tracking methods to track and locate a material trolley in real-time at the air-conditioner manufacturer in China. Jagtap et al. (2019) adopted an automated and real-time system based on IoT concepts, image processing, and load cell technologies to measure the overall amount of waste and the reasons for waste generation in real-time in the potato processing industry in the United Kingdom.

A video camera captured images to identify the damaged, unusable potatoes. A digital load cell measured their weight. The Convolutional Neural Network (CNN) was applied to identify a potential reason for potato waste generation. The real-time data helped workers in the production, transportation, and processing of potatoes to identify various causes of waste generation.

Jagtap and Rahimifard (2019) presented the design and IoT application to monitor and capture food waste data in real-time in the ready-meal factory, the United Kingdom. Nemec et al. (2003) presented the automation of the shoe lasting process using a commercial lasting machine, a vision-guided last positioning machine, and an industrial robot to increase productivity and reliability of the production. However, they only focused on the lasting process.

Many factories are developing and enhancing their capabilities approaching Industry 4.0. They focus on the production tracking system as one of the Industry 4.0 activities; however, a study related to this issue is limited (Minoufekr, Driate, & Plapper, 2019; Zhong et al., 2013; Zhang & Sun, 2013). It improves productivity, monitors workflow, detects bottlenecks, and reduces production time. Physical objects can be tracked using sensor and RFID technologies (Minoufekr, Driate, & Plapper, 2019). Minoufekr, Driate, and Plapper (2019) showed the IoT and RFID solution for SME manufacturing to track the production chain. Each workstation was equipped with RFID scanners to record activities and the product flow. The system displayed a real-time status of the assembly line. The production efficiency increased from 62.63 % to 87.50 %. Several challenges arise while implementing the production tracking system. Zhong et al. (2013) proposed an RFID to monitor a real-time manufacturing execution system for mass customisation production. Nevertheless, it could not support the dynamic change of manufacturing processes. Zhang and Sun (2013) proposed the architecture of an RFID-enabled customised/personalised production based on multi-agents for CPPs, which consisted of five elements: manufacturing cloud, central node (workshop gateway), local wired/wireless network, shop-floor workstations and parts/materials. The local wired/wireless network connected the central node and workstations. RFID tags were mounted on (key) parts. Each station was equipped with RFID readers to read the identity from the tags. This system could track manufacturing objects and monitor the shop floor.

Shoe production is labour-intensive manufacturing. It requires skilled labour in many processes, such as inspection. The adoption of full automation in this industry is low (Nemec et al., 2003). There are several perspectives of research in the footwear industry, such as productivity improvement, sequencing problem, production planning, scheduling problem, automation of planning, production, and distribution processes (Calderón-Andrade et al., 2020; Castillo-Castañeda et al., 2021; Jimeno-Morenilla et al., 2021; Nemec et al., 2003; Sadeghi et al., 2021). Castillo-Castañeda et al. (2021) adopted the lean concept to increase productivity and reduce reprocessing. Sadeghi et al. (2021) presented an optimisation model for a mixed-model assembly line sequencing problem. Zangiacomi et al. (2004) applied a finite capacity scheduler integrated with new software based on the Analytical Hierarchy Process decision support system to solve a production planning and scheduling problem for mass customisation systems. Dang and Pham (2016) applied Discrete Event Simulation (DES) to design a footwear assembly line with uncertain task times and parallel workstations to maximise the performance of the assembly line. Tran et al. (2021) proposed a concept for a low-cost integrated automation system in footwear SMEs in Vietnam.

In Thailand, to the best knowledge of the authors, there is no case study of digital technologies implementation in the production line of a shoe factory. Extant research focused on footwear design strategies (Adulyanukosol & Silpcharu, 2020), which is not relevant to production tracking. Case studies about implementing IoT and image processing in production tracking are limited. Many firms are ready to invest in modern digital technologies with limited budgets but do not know how to start. This paper presents a production tracking system designed using IoT sensors and image processing to track the production process and count good and failed products at the safety shoe factory to demonstrate how to improve the production process. IoT sensors collect shop floor data, integrate it from several machines, and display it on the system monitor in real-time. Moreover, this paper discusses the key success factors that facilitate DT in the factory.

2. Research methods

This paper conducted qualitative research by using an inductive case study. The interview was conducted onsite, and the duration was approximately two hours. A site visit was organised to observe operations in the production line for three days. The team participated in designing and developing the digital tracking solution using IoT sensors and image processing to count the number of passed and defective finished goods. An open-ended interview was used to iteratively gather information and investigate how the firm utilised digital technologies to transform the production line to yield meaningful insight (Nowell et al., 2017). the interview involved the CEO of CPL Group Public Company Limited (hereafter referred to as CPL) and the CTO of Smart Sense Industrial Design Company Limited (hereafter — Smart Sense). Smart Sense is a consulting, engineering, and IoT system service provider and the partner for hardware design and support in this project. The interview focused on the progress of the digital tracking development project using IoT sensors and image processing.

3. Research results

3.1. Company profile

CPL is a major safety shoe manufacturer in Thailand under the "PANGOLIN" brand, the market leader in Thailand for over 25 years. On 27 January 1994, CPL registered the company with the capital of THB 180 million by Charoensin Family, Pan Oversea Cooperation, and Lien Dah Ltd. On 19 December 1994, the company transformed into a public company limited by listing on the Stock Exchange of Thailand named "CPL Group Public Company Limited".

CPL manufactures and distributes leather products, personal protective equipment and renders the tanning service. Its business consists of three main parts: 1. Finished Leather Business, 2. Tanning Service Business, and 3. Safety Shoes and PPE. This study focuses on safety shoe production. Its products have been used by many sectors of industries nationwide and exported to various countries. Examples of its customers are Thai Honda, Thai Toyota, Charoen Pokphand, Siam Cement Group, and PTT oil.

In 2001, CPL expanded the business by a joint venture with three companies in China involved in the tannery industry and shoe factories. The tannery named "C.P.L. International Company Limited" was opened in Guangzhou, China, to support customers' purchase orders in China. Currently, this factory was terminated, and it is in the process of business restructuring. Recently, a business discussion was initiated with a new potential investor in China.

In 2016, the company invested with a business partner in Hong Kong and established a company named "Integrated Leather Business Company Limited" that engages in the import and sales of leathers. The company held 40 % of total registered shares because the company saw the potential opportunities in the leather business and reduced the restrictions on the grade of leather that will be used in the production process.

The safety footwear accessory brand PANGOLIN was the first to receive certification according to the standard TIS. 523-2558, Standard Quality Management System ISO 9001: 2008 by Bureau Veritas. It has the highest market share in the safety shoes and safety equipment market in Thailand. There are three groups of safety shoe products: low, medium, and premium. The low group focuses only on durability. The medium group focuses on durability and comfort. The premium group uses higher material quality. It is more durable, comfortable and has beautiful shapes and many colours.

3.2. Production process

Fig. 1 shows the five main manufacturing process flows.

- Cutting process. This process uses manual cutting and semi-automation cutting machines to cut leather and material into different patterns for the upper. After that, operators conduct QC before sending it to the next process.

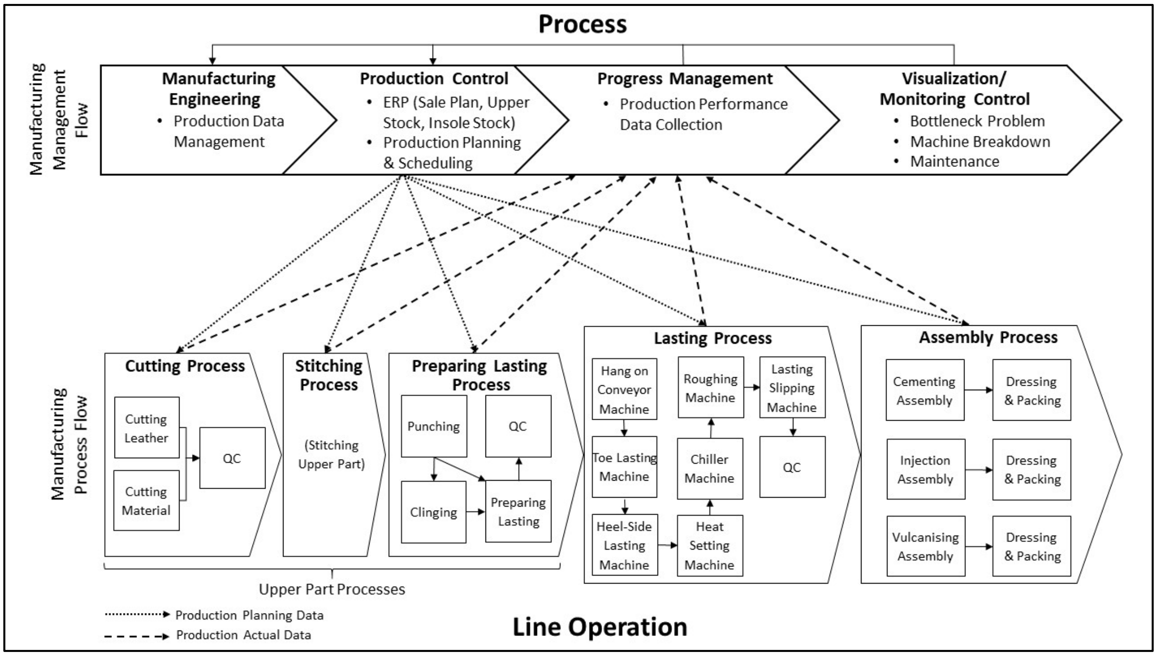

Fig. 1. Line operation for safety shoes

- Stitching process. Workers use a sewing machine or computerised sewing machine to stitch upper parts together according to a pattern.
- Preparing lasting process. Workers use machines for punching, clinging, and detail sewing to prepare upper parts for the lasting process (i.e., some detail sewing).
- Lasting process. This process uses a combination of manual, semi-automated, and automated machines. There are two types of upper: Stretching and Strobel, which are processed in parallel production. There are eight subprocesses in this workstation. Parts are hung on the conveyor machine to the lasting machine. After parts are fed into the machine, the shoe lasting machine glues the shoe upper and shoe last and sends to the toe lasting process for gluing. There are two toe lasting machines for the left and right sides. Then parts move to the heel-side lasting machine for gluing. There are two heel-side lasting machines for the left and right heel. Then it moves to the heat setting machine to apply high-temperature steam and hot air to mould the upper for controlled periods of time to destress and relieve the residual stress from the lasting process. Then it moves to the chilling machine. The chiller machine is used after tightening the shoe to stabilise the shoe material on the block with the sole glued to reduce the processing time of the workpiece on the shoe last. Cold temperature is used to stabilise leather and remove the excess moisture from the surface. Then, the parts move to the roughing machine and then to the lasting slipping machine. The last subprocess is the inspection. Inspectors conduct a quality check to ensure that the upper is appropriately sewn, the size of the upper is correct, the quarter tightening system is correct, materials for the lasting are suitable and compatible with the materials of the safety shoe.
- Assembly process. This process combines the upper with the insole. There are three assembly processes: cementing (one assembly line), injection (three assembly lines), and vulcanising (one assembly line). The cementing process has a conveyor and a semi-automated machine. The injection process uses the semi-automated machine and robot arms. The vulcanising process uses semi-automated machines. Each machine can produce only one side of the shoe. The outputs of each assembly line move through its conveyor to the dressing and packing processes. The dressing process is the final detail decoration and checks the quality of products before sending to the packing process. If the product has defects, QC staff will apply a mark to identify defective spots and separate them to another line. For the passed products, workers put Pass QC stickers on the box and pack them.

3.3. Problems in the current system

The current system has no digital production planning or scheduling. Managers use their experience to order production. They use a production order sheet to identify the total number of daily productions for each safety shoe model. Mostly, the total number of productions did not finish as planned. Sometimes when there is a surge in demand, the factory fails to meet customer needs.

The current system consists of manual, semi-automated, and automated machines. However, the majority of the system is manual machines that require worker interaction. Despite implementing machines and robots in the production line, the factory has not installed any IoT devices to collect data. Managers and employees do not have real-time production status data, temperature, and the number of passed and defective shoes. The plant manager and operators cannot see the real-time temperature at heat setting and chiller machines. Moreover, the machine status (on-off, breakdown, maintenance) cannot be tracked, leading to insufficient control management and cannot help managers identify bottlenecks in the system, especially in the lasting process with many sub-processes. When a machine is down or stops working, managers or operators do not get a system alert. Operators need to inform the manager when they see it happen, which slows down the production and affects production planning. In addition, the production capacity cannot be maximised.

Another issue is the production tracking at the lasting workstation. There is no record of a number of products in and out from the system. Operators have to record data manually, which causes data inaccuracy and difficulty in justifying the overall equipment effectiveness (OEE). The last issue is the lack of passed/defective product recording. In the current system, inspectors at the packing workstation need to check each shoe's defects in the box manually, separate defected from passed products, and count them box by box.

3.4. Design and development of production tracking system

This paper presents a conceptual design and development of the production tracking system by adopting the IoT sensors and video camera to track the production flow starting from the lasting process to the assembly process (Fig. 2). This system also includes real-time data display and monitoring control.

There are three types of IoT box prototypes: IoT box for temperature tracking, IoT box for machine status tracking, and IoT box as a gateway to connect the data from the shopfloor, cameras, and the software part. They were installed at the lasting, cementation, PU2003 injection, PU2001 injection, and vulcanising workstations to cover the critical areas. The IoT box was not installed at the PU1983 injection workstation because it produces special products that have low demand each year.

Before the digital transformation, managers and operators could not see the current temperature in the heat setting, chiller machine, and gluing process

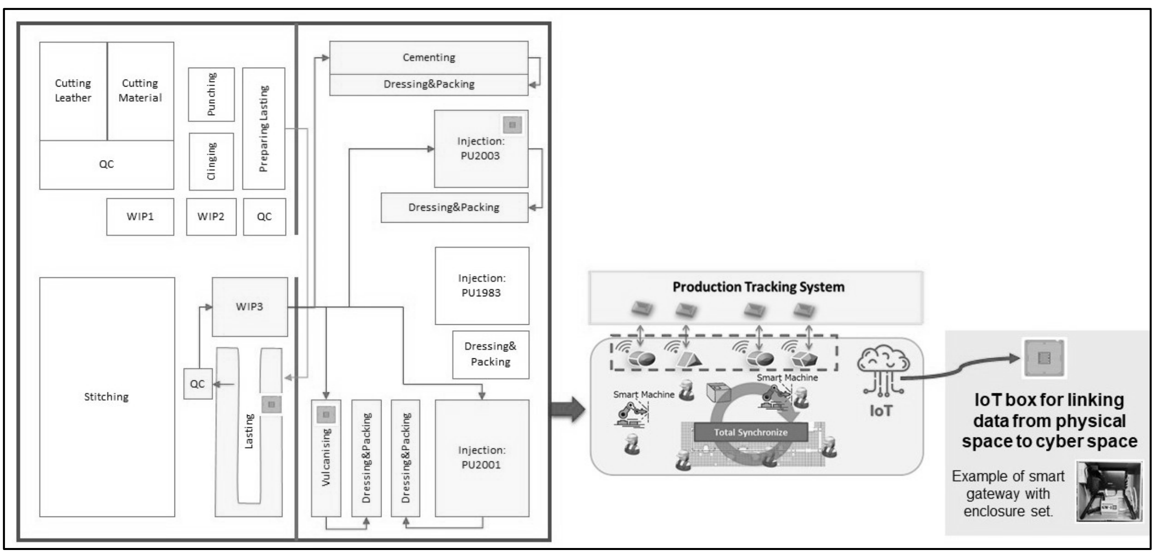

Fig. 2. Conceptual design of the production tracking system

at the lasting station. Therefore, six IoT temperature sensors were used at the lasting workstation to improve productivity and show the real-time temperature at each station (Fig. 3). Two sensors were installed at three stations: the heat setting, chillers machine, and the gluing process. Temperature control is important for these processes to produce a quality product.

The QR code is used to update product movement and status. The batch QR code contains the Batch ID, date of the job order, the station, the quantity for the lot, the pattern insole, the group, the SKU number, the shoe size, and the quantity. Operators move the WIP in batch (Fig. 4). Once the batch is ready, an operator scans the QR code for checking in and confirms the production number on the tablet screen. The system records the production time for each batch. Once the production process of each batch begins, the input buffers are divided into each basket by four pairs, consisting of two pairs of stretching and Strobel. The stretching group needs to go to vulcanising, the PU2001 injection process, and the cementing process. The Strobel group goes to the PU2003 injection process and cementing processes.

Fig. 5 shows the process before leaving the lasting station. A QC worker checks the product quality and then scans the job order card to count the passed product. The worker must confirm each batch's num-

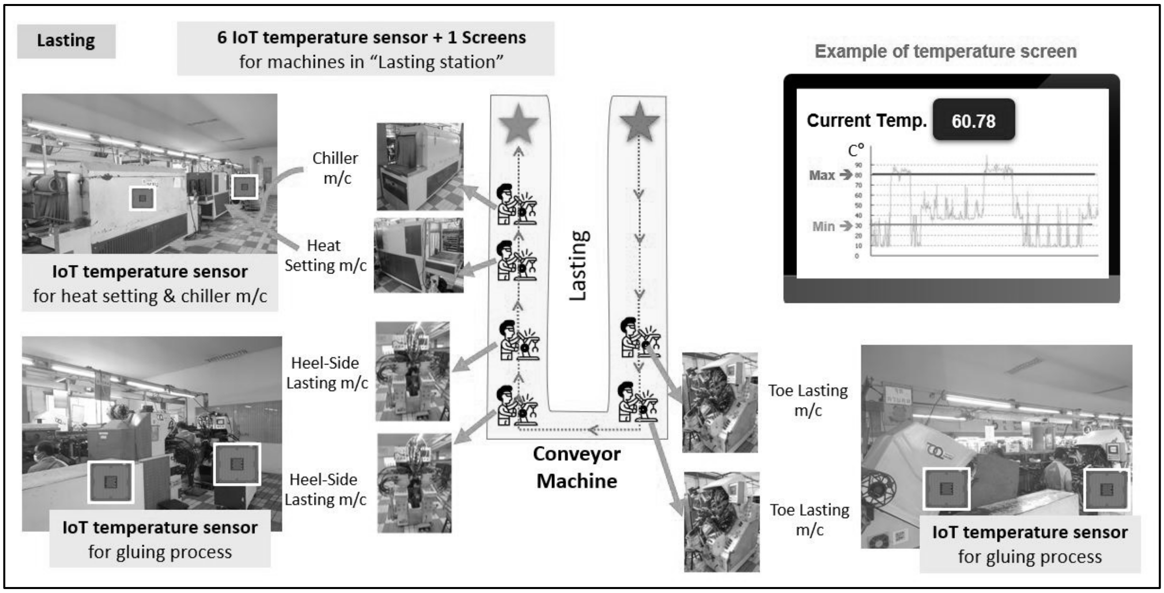

Fig. 3. Design concept of IoT sensor installation at the lasting station

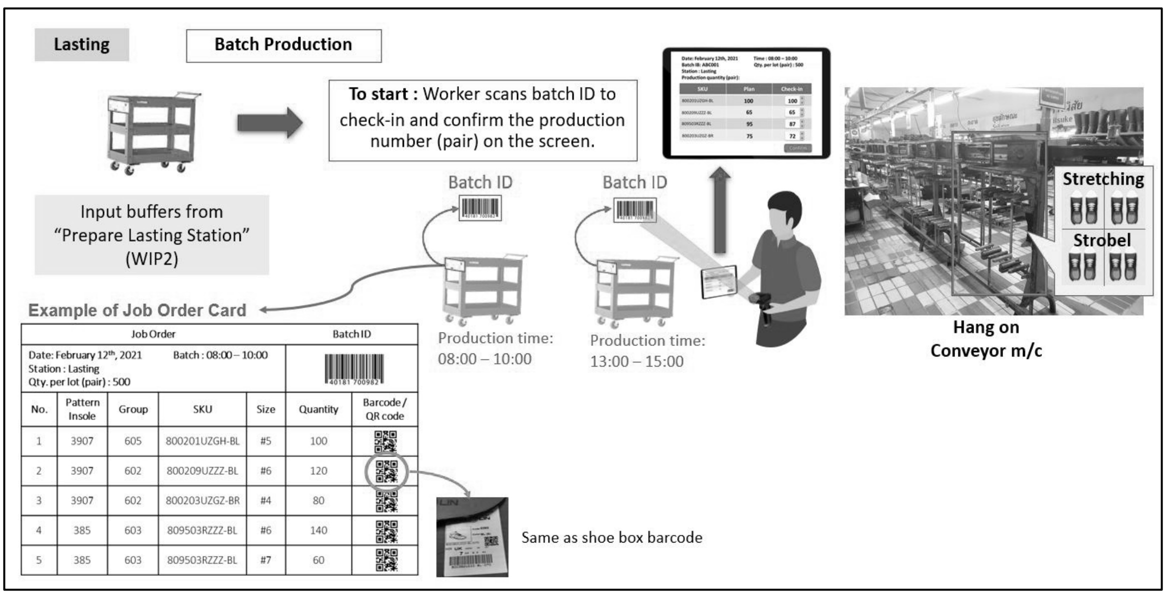

Fig. 4. Design work process at the lasting station by using the QR code and Kanban job order

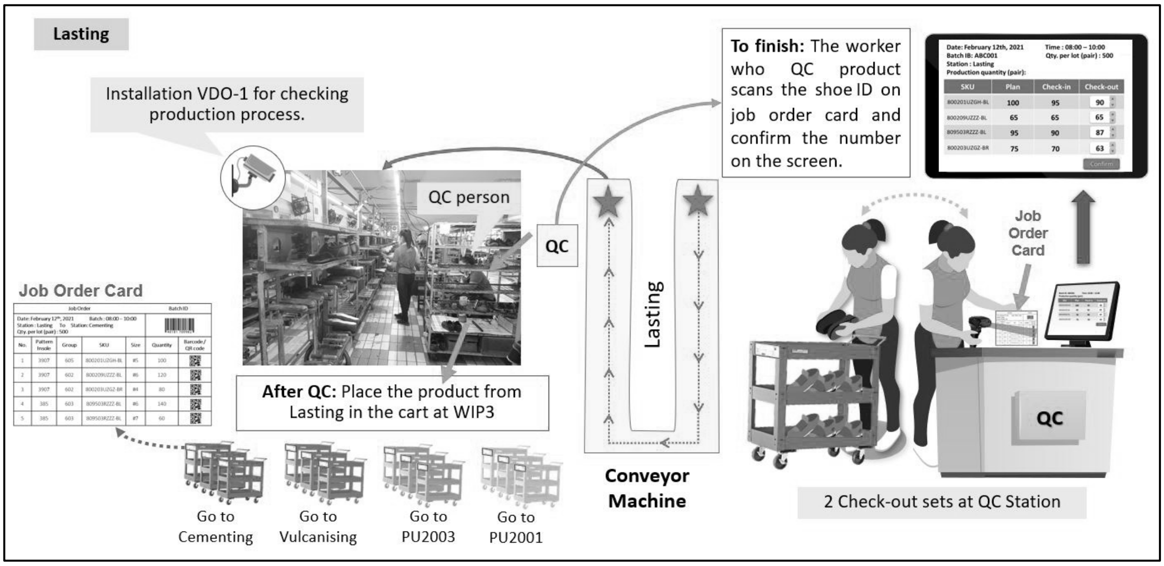

Fig. 5. Design work process of inspection at the lasting station

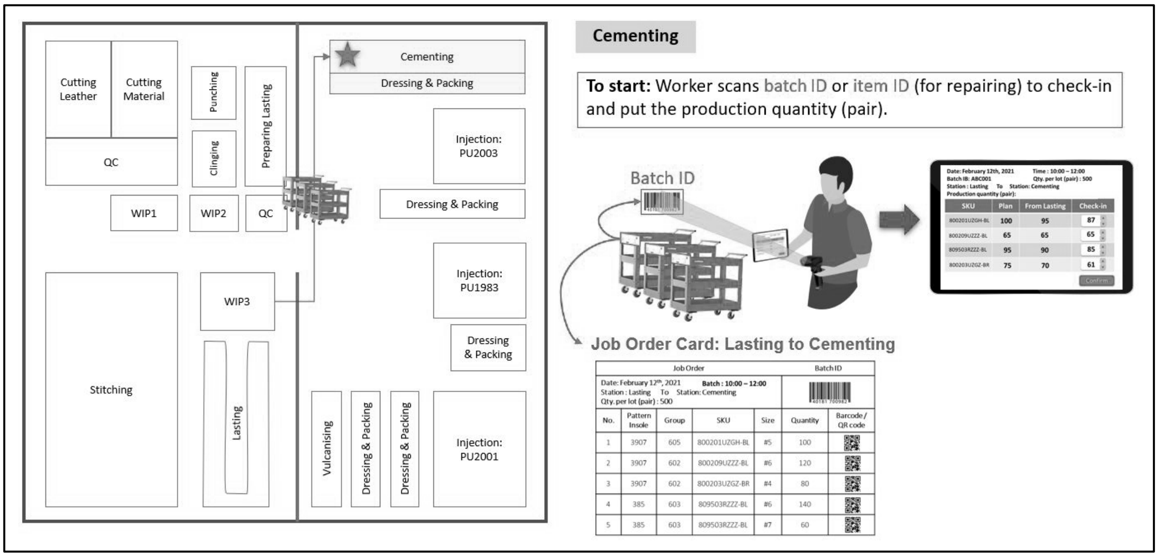

Fig. 6. Example of the production tracking system at the cementing process (check-in process)

ber of passed products before placing the passed product from a lasting station on the cart at the WIP3 station and waiting to be transferred to the assembly stations. There are four types of carts. The first cart goes to the cementing station. The second cart goes to the vulcanising station. The third cart goes to the PU2003 injection station, and the last one goes to the PU2001 injection station. A QC worker scans the QR code of each product on the job order card and confirms the total number on the computer. Then the job order card is attached to each cart. The cart is transferred to the next process. This process was observed over an installed video camera to monitor the production process.

There are four assembly stations in this production tracking system design scope: cementation, PU2003 injection, PU2001 injection, and vulcanisation. At the check-in point of each assembly station, an operator scans Batch ID or Item ID (for repairing) to receive this order and confirm the production quantity. At the vulcanising station, a video camera was installed for defect tracking (Fig. 7).

Two injection stations are involved in the production tracking system: PU2003 and PU2001. This station uses a 6-axis spray robot, 6-axis roughing robot robotics, and PU injection machines. An injection machine has 24 sub-machines. Each sub-machine can produce one side of the shoe. Thus, the QR code and the IoT sensor were used to update product movement and status. These IoT sensors were installed to detect and count incoming and outgoing products from the station. Additionally, the

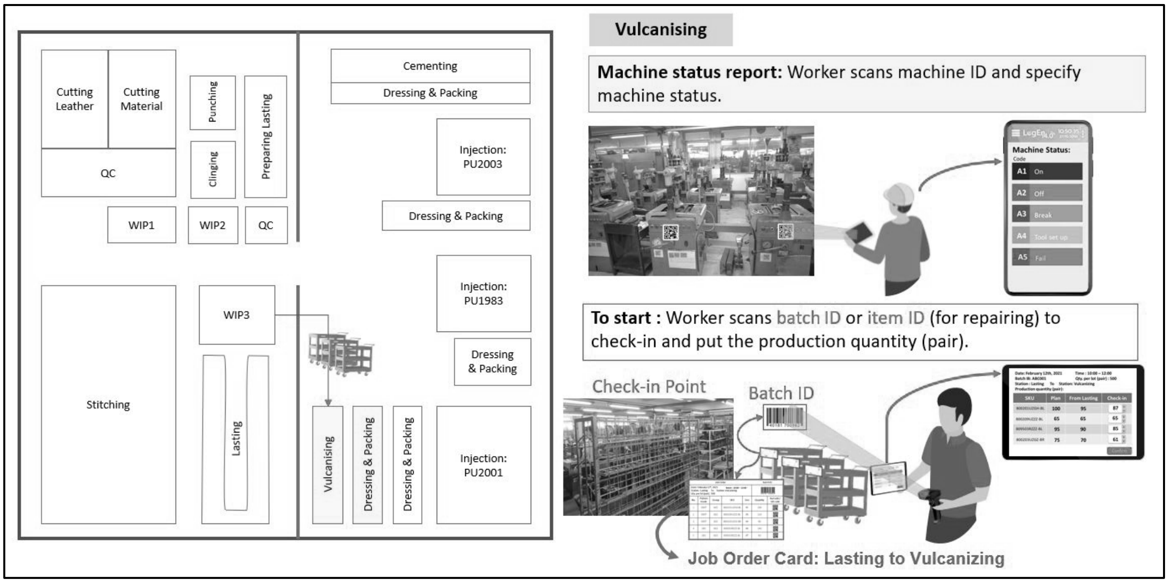

Fig. 7. Example of the production tracking system at the vulcanising process (check-in process)

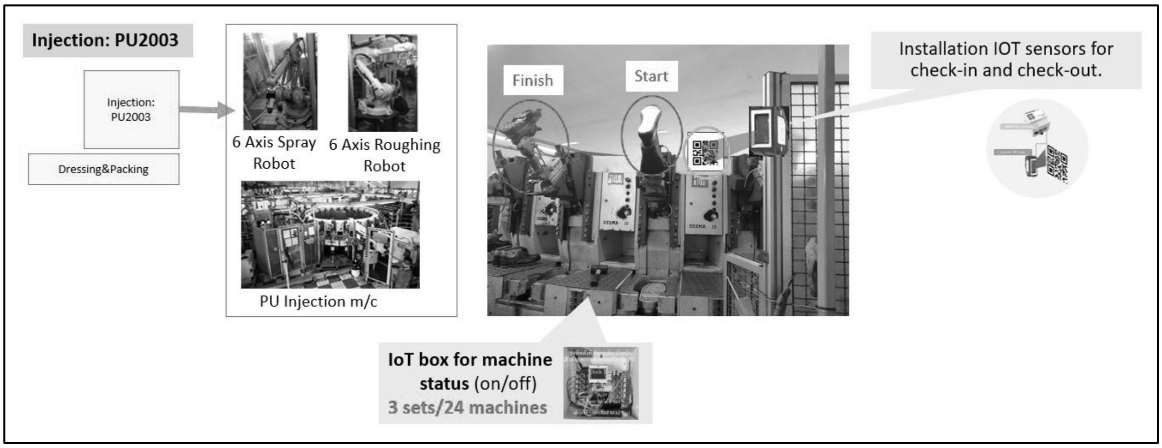

Fig. 8. Machine status tracking at the PU2003 injection process

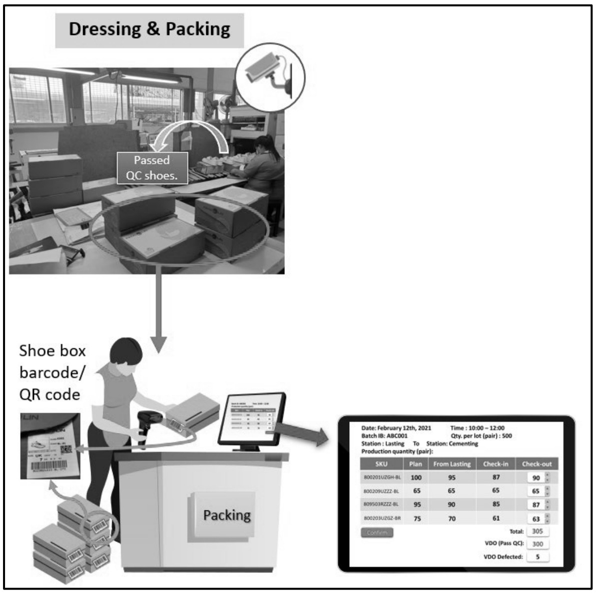

Fig. 9. Dressing and packing process

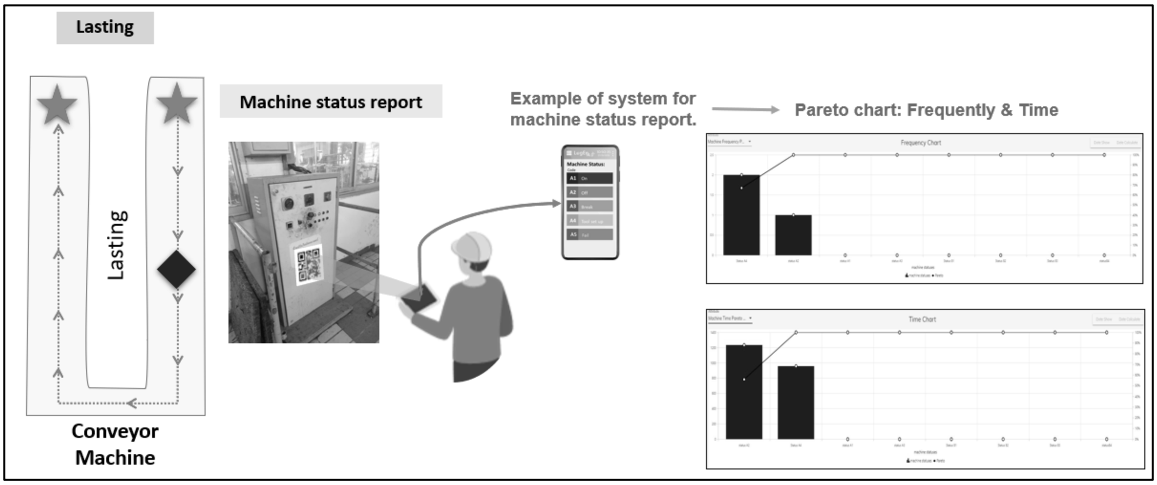

Fig. 10. Machine status manually reported system at the lasting process

three sets of IoT boxes were installed to automatically track the on-off status for 24 sub-machines. The same IoT set was installed for both PU2003 and PU2001 lines for the machine status tracking.

At the dressing and packing of each assembly station, one video camera was installed for defect tracking. Image processing was used to detect and count passed and failed products. The defects were speared for reproduction. A QC worker marks the passed sign spot-on product and sends it on the conveyor to the packing point. Then packing worker scans the QR code or the Barcode to record it into the system, then rechecks and confirms the productivity of each batch before sending it to the warehouse. All assembly stations have the same process for product check-in and check-out.

Machine status tracking is important for machine monitoring. A real-time machine status report was designed at the lasting station, injection, and vulcanising machines. IoT boxes collect the status of machines, such as on-off, breakdown, tooling changeovers, and maintenance. These data allow operators and managers to determine the machine's efficiency, condition-based maintenance, and detect the production problem in real-time.

From the above-described conceptual model, the solutions already implemented in the production processes are the installation of two sets of IoT temperature sensors at the lasting station. The team ensured that the devices were well-functioning and provided accurate temperature values. The four video cameras were installed at the beginning of the lasting process (one unit), at the lasting QC process (two units), and at the dressing and packing station (one unit).

This conceptual design and development of a production tracking system allow the factory to monitor the production process and performance in real-time. Moreover, it helps them to detect any breakdown, bottleneck in the processes and increase the overall efficiency.

4. Discussion of the results

4.1. Development of the production tracking system

Industry 4.0 poses a significant challenge for the manufacturing firms in Thailand, especially SMEs, as the capital and resources are limited. The case study demonstrated in the previous section provides an example of the digitalisation of the safety shoe factory. The CPL has mixed machine and human interaction systems for the production processes. The production data and machine status are collected manually on paper and stored in the form of electronic files. However, the data implementation and utilisation are limited as the firm cannot visualise data and analyse it to detect a problem in real-time. Consequently, the report is inaccurate. To solve these problems, CPL gradually adopted Industry 4.0 technology to improve the production process and productivity.

CPL collaborated with Smart Sense and the university research unit to design the production tracking system using QR codes, IoT sensors, and cameras to track and collect data from the production line. The system covers the lasting, cementing, injection, vulcanising, dressing, and packing stations. The system design includes both hardware and software aspects. The software consists of a web application that operators use to confirm the amount of input and output in each station and the image processing recount to confirm the productivity accuracy. Another part is a real-time machine temperature monitoring, cycle time visualisation, and alert system. The software collects data from manual input and retrieves data automatically from IoT sensors. For hardware design, the architecture was designed for IoT sensor installation at a feasible location to optimise performance and minimise total cost. Video cameras were installed for image processing, a hand-held scanner to scan QR codes, and tablets and monitors to display real-time data. The prototype system is under development at CPL.

In terms of process improvement, the factory has learned that the development of the production tracking system allows their employees to improve their workflow and realise the bottleneck of the current processes. Moreover, they learned how to change the adjustable layout, working position, and environment to improve the efficiency of image processing and increase accuracy.

4.2. Key success factors of digital transformation

As already mentioned, the implementation of digital technologies requires modern technologies, strategies, and support from management. The key success factors of this project are as follow.

1. CPL used a top-down approach to initiate digital transformation in the organisation. The company owner imposed digital strategies and created a collaborative environment to encourage employees to collaborate on projects with external experts and academics to create a knowledge and technology transfer network. This approach is in line with Vogelsang et al. (2019), who suggested that "DT as many projects cannot be executed without other companies from the network" (Vogelsang et al., 2019, p. 132). The top management approved and provided funding to support the production tracking system.

2. Since this is the first DT project in the company, the absorptive capability of employees is low. Most employees do not know how to implement digital technologies in a production line. Smart Sense and the academic team filled this gap by providing knowledge, know-how, and technologies and managing the whole project. The team created an intensive session with production line operators to investigate the root cause of the problem on the shopfloor and visited the shop floor to observe the actual operation. Once pain points and bottlenecks were identified, it was easy to convince employees that digital technologies could help them to improve productivity. The team trained employees to understand and use IoT sensors.

3. After understanding pain points and how DT could improve overall production processes, employees embraced the transformation quickly. Once they understood the project's usability, they voluntarily expressed ideas and proposed solutions from their perspective. During the system installation and development, employees provided feedback on the system's software user interface design and architecture design.

4. The pilot project helped to realise and see the whole issues of operations. The tracking system allowed detecting issues related to employee ergonomics, movement, workflow, and bottlenecks in the production processes. With the numerical and visual evidence, the plant manager solved the production at the right pain points and created a better workflow. Furthermore, the plant manager proposed adjusting the working environment on the shop floor to enhance the efficiency of the production tracking system. For example, create zoning in the conveyor to separate passed and defective shoes, create a dividing line in the defective shoe areas to enhance the detection efficiency (Fig. 11). Fig. 12 shows before and after adjustment by installing transparent partition at the lasting to prevent the camera from counting the shoes on the back shelf, which can mislead the image processing detection.

5. According to the definition of the capability maturity model developed by Issa et al. (2018), CPL has developed level three of the capability maturity readiness to embrace digital technologies. It had a vision and mission, assigned a team responsible for DT, formulated well-defined processes and support systems. DT was used to solve production problems on the shop floor level. Departments were involved in defining and imposing digital strategies. CPL adopted 5S and several ISO standards to maintain and continually improve its performance and quality.

It provided in-house training to employees about warehouse management and related topics to improve productivity. The company also implemented enterprise resource planning (ERP) software and adopted robotics in some production processes. Employees also collect data manually to identify the OEE. Therefore, they gained an initial readiness for digital transformation.

Fig. 11. Before (left) and after (right) adjusting on the conveyor

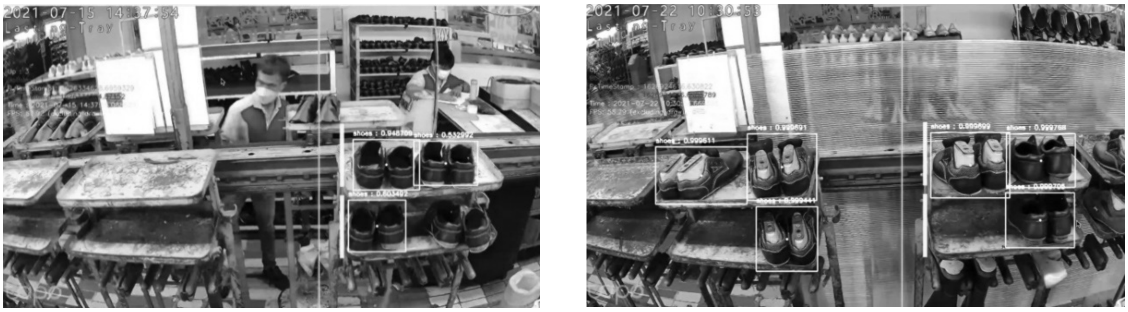

Fig. 12. Before (left) and after (right) adjusting at the lasting workstation

6. The plant manager had a background in accounting and a deep understanding of the production process. She identified root causes in the production line instantly after seeing the data from the pilot project. Moreover, she understood how to apply digital technologies to improve the system.

Conclusions

Implementing digital technologies in the manufacturing industry is challenging. Thai manufacturing gradually adopts modern technologies like CPS, IoT, and automation to improve productivity. However, the study of the implementation is limited. This paper proposed a conceptual design and production tracking prototype in the safety shoe manufacturer in Thailand. QR codes, IoT devices, and video cameras were used to perform image processing and track production status.

The system shows real-time data regarding the temperature of the heat setting machine, chiller machine, and gluing machine. Operators can monitor real-time data on the machine status, the total number of input and output from each workstation. Finally, the system can count the number of passed and defective products before packing. This system helps managers and operators to identify bottlenecks of the process, overall equipment effectiveness, and plan production.

This paper also presents the key success factors of digital technologies implementation in manufacturing. The key drivers are full support from the top management, setting digital strategies aligned with business strategies, the working environment, collaboration with experts, academics, and networks, training and managing project by experts, two-way knowledge and technology transfer, visible usability, and individual mindset. The results can be used as a guideline for developing real-time production tracking in the production line in another factory.

The limitation of this paper is that it mainly focused on qualitative analysis to define the key success factors of digital transformation and the development of the conceptual design for the production tracking system at CPL. Future research should include quantitative analysis and simulation to demonstrate practical effects achieved, such as productivity, number of defects and defective accuracy. Future research should expand the framework by using data retrieved from production tracking to create production planning and scheduling for each shoe model. A real-time data can be used to create daily, weekly, and monthly production planning and scheduling. Furthermore, data can be synchronised and used to create a simulation model to monitor production flow.

Acknowledgements

The authors would like to acknowledge executives and staff from the CPL Group Public Company Limited and Smart Sense Industrial Design Company Limited for valuable information and insights. This research is supported by the Centre of Excellence in Logistics and Supply Chain Systems Engineering and Technology (CoE LogEn), Thammasat University.

The publication of the article for the 11th International Conference on Engineering, Project, and Production Management — EPPM2021 was financed in the framework of contract No. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Volume 13 • Issue 4 • 2021

Engineering Management in Production and Services

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 1 July 2021
accepted: 1 December 2021

pages: 95-114

Competences of innovation brokers - experiences of the GoSmart BSR project

Anna Dyhdalewicz Justyna Grześ-Bukłaho

ABSTRACT

The paper attempts to create a universal model of competences for international innovation brokers combining knowledge, skills and attitudes in the context of tasks aimed at internationalisation and development of innovation in SMEs. The article reviews the relevant literature, uses a bibliometric study identifying the brokers' attributes, innovation and competences using the VOSviewer tool, and presents qualitative research — a case study of the GoSmart BSR project. The paper resulted in a synthetic model of competences for international innovation brokers, taking a holistic approach to defining competences. The presented model is a synthesis of previous experiences with formulating competences for international innovation brokers. The elements of the model of competences and their components are equally significant for accelerating the internationalisation of SMEs and implementing innovations. This model is practical and universal, so it can be used in various organisations working towards the internationalisation and innovation of SMEs. Lessons learned from the GoSmart BSR project can be an inspiration to experiment and introduce new ideas and concepts. The identified competence elements can be considered universal and key in the work of an international innovation broker, but neither their list nor competence components are exhaustive. Therefore, the issues discussed in the article may form the basis for further research in this area.

KEY WORDS
innovation brokers, internationalisation, GoSmart BSR project, competences

10.2478/emj-2021-0034

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Introduction

The article attempts to create a universal model of individual competences for international innovation brokers combining knowledge, skills and attitudes in the context of specific tasks aimed at internationalisation and innovation development of SMEs. The article uses a bibliometric study identifying broker attributes, the VOSviewer tool for innovation and competences, and a case study for qualitative research. It includes a monographic presentation of a positive case regard-

Dyhdalewicz, A., & Grześ-Bukłaho, J. (2021). Competences of innovation brokers – experiences of the GoSmart BSR Project. *Engineering Management in Production and Services, 13*(4), 95-114. doi: 10.2478/emj-2021-0034

ing a network of cooperating quadruple helix entities in the GoSmart BSR project.

The project addressed the low capacity for innovation in less developed parts of the Baltic Sea Region (BSR) by mutual learning, translating Smart Specialisation Strategies (S3) into practical SME joint actions, and employing good practice from more developed regions. The project is fully integrated with S3 and aims to foster effective transnational cooperation between the industry, the R&D sector and authorities. The main expected results were a functioning and sustainable Transnational Innovation Brokerage System (TIBS) and SME Joint Transnational Smart Strategies (JTSS) implemented across partner regions (Kruse et al., 2019).

The project assumes that building and improving competences of international innovation brokers is a prerequisite for achieving its goals. One project result was the specification of their competences, which are conducive to building internationalisation and innovation in SMEs. This solution focuses on the competences of individual brokers, adapting them to the implementation of project objectives. Therefore, the article presents the contexts for identifying the types of competences for innovation brokers that impact the internationalisation and development of potential innovations in the SME sector in the Baltic Sea Region (Mueller-Using et al., 2020).

In conclusion, the main cognitive goal of this article has been to identify the structure and basic dimensions for the competences of international innovation brokers. The main utilitarian goal of the article is to offer a model of the individual competences necessary for innovation brokers to networks of entities supporting the internationalisation and innovation of SMEs. For the purposes of this article, a definition for the term "competences" is considered from the perspective of an individual (broker) and includes three mutually complementary elements: knowledge, abilities, and attitudes, whereby the knowledge and skills of employees can be created in an organisation. These elements, used and developed in the process of providing intermediation services, lead to the achievement of results consistent with the organisation's goals and strategic intentions.

1. Literature review

The literature on the subject includes a number of different definitions of competences and their classification, relating mainly to managerial competences (Prahalad & Hamel, 1990; Moczydłowska, 2008; Brelik & Żuchowski, 2017; Kupczyk & Stor, 2017; Bhardwaj & Punia, 2013; Krajcovicova et al., 2012; Abraham et al., 2001; Patanakul & Milosevic, 2008; Papulová & Mokroš, 2007). Competences are most often rooted in specific management models popular at a specific time and adapted to the current knowledge or market situation (Gonczi & Hager, 2010; Vakola et al., 2007; Staškeviča, 2019). Considering the behavioural concepts, competences from the perspective of an individual are "expectations of the behaviour, skills and other characteristics of employees conducive to achieving success at work" (Jurek, 2012, p. 11). Behaviour that allows for the effective performance of duties is essential. Another approach used today in the Human Performance Technology (HPT) model, created by Gilbert, emphasises the measurement of performed tasks using the performed work results (Chyung, 2005; Stolovitch, 2000). The measure of the results is the relationship between the size of the obtained effects and the incurred expenditure, i.e., the effort related to an activity. With regard to the model of open innovation and the resource theory, to gain competitive advantage, a company should either have unique and valuable resources and appropriate skills or average resources but unique skills. They constitute a competence category in an organisation.

In practice, the functions performed by international innovation brokers are combined with key competences using a practical or situational approach by diagnosing the situation accurately and analysing the organisation's or project's environment and considering the operational conditions of the entities. Contemporary challenges posed by the global environment for the SME sector enterprises are varied (Prasanna et al., 2019; Singh & Deshmukh, 2008; Mundim et al., 2000). Aiming for development and their possibilities to improve competitiveness, SMEs should consider the opportunities offered by internationalisation combined with creating smart specialisations and innovations (Hogeforster, 2014; Andersson et al., 2004; Edwards et al., 2005). The development of these processes depends on the ability and willingness to cooperate with various entities in the environment, the level of their openness to cooperation, and taking up and participating in joint initiatives. It has become a necessity for small and medium-sized enterprises to develop formal, systematic, multidisciplinary and creative knowledge related to the external environment (Chaochotechuang et al., 2019). These enterprises increasingly seek new knowledge sources. They use the services and knowledge potential of external brokers. The roles and functions performed by knowledge brokers require them to have appropriate competences. The important ones allow SMEs to join global cooperation networks for internationalisation and innovation. The system of knowledge brokerage services can be implemented in all areas of socio-economic life. The literature highlights the following areas related to the role of brokers:

(1) Brokers as participants of innovation processes (knowledge brokers); brokers as intermediaries of knowledge, whose function is primarily to acquire external knowledge and to disseminate it within the unit, primarily for the needs of R&D team employees and others using this information (Sergeeva & Liu, 2020). "They are sometimes defined as actors who use their 'in-between' vantage position to support innovation through connecting, recombining and transferring to new contexts otherwise disconnected pools of ideas" (Haas, 2015, p. 1037);

(2) The importance of the network broker subject in relation to corporate innovations, including the social capital issue and the institutional base in the context of building learning regions (Harland & Knight, 2001; Halvarsson Lundkvist & Gustavsson, 2018; Pyka & Janiszewski, 2016).

(3) The role of a broker as a network manager (Macchi et al., 2014; Idiagbon-Oke & Oke, 2019; Leick & Gretzinger, 2020; Srivastava, 2020). In networks composed of various actors, the task of brokers is to facilitate the flow of knowledge and information (Pyka & Janiszewski, 2016).

A broker, as an intermediary of knowledge, connects an organisation with external elements. In networks composed of different actors (these can include, e.g., manufacturing or service companies, universities, private research organisations, affiliated research institutes, public research organisations), a broker's job is to facilitate the flow of knowledge and information. Brokers can facilitate access to new information or resources, knowledge transfer, and coordinate a network effort. Hence, knowledge brokers need to be embedded in research teams or institutions to positively influence the exchange of knowledge. The important term of brokerage is the essence of activities involving the integration of knowledge undertaken by brokers in the network. Entities operating in the network should be able to use the knowledge circulating internally. However, it is argued that there are differences in the results of companies due to asymmetry in access, assimilation and application of new knowledge (Dagnino et al., 2015; Janiszewski, 2019).

Often, many SMEs can only access external knowledge sources with the help of actors who are well connected to global knowledge sources so that they are able to translate information into a form that is useful for local organisations. The first reason why SMEs collaborate with knowledge brokers is that some companies may find it difficult to collaborate with others internationally. The second reason is that knowledge brokers can focus on enabling other organisations to establish and maintain relationships. They can also actively help in building lasting relationships.

Consequently, the emphasis is often placed on the role of knowledge brokers in the knowledge transfer process helping others to translate knowledge coming from the outside. Srivastava listed five different types of brokers, namely, a gatekeeper, a coordinator, a liaison, a representative, and a cosmopolitan broker (2020, p. 438).

The third reason is that companies should try and make their needs desirable for business partners. The services provided by knowledge transfer intermediaries should involve various mechanisms of cooperation with businesses, social institutions, governments and citizens. The critical remarks regarding the use of an external intermediary should also be underlined. "When a company outsources tasks related to innovation, it has big problems with implementing the proposals suggested by external consultants" (Trias de Bes & Kotler, 2013, p. 5).

This article focuses on innovation brokers who operate internationally. Network brokers can be useful when SMEs lack direct contacts with business partners, resulting in fewer interactions, less knowledge sharing, and less trusted relationships (Leick & Gretzinger, 2020).

Business networking, which is defined as "the participation of companies in many overlapping intercompany relationships and collaborative arrangements, actually supports companies in overcoming resource scarcity as it gives them access to new constellations of resources and improves the circulation of knowledge.

These network advantages can increase the innovativeness of enterprises and stimulate innovation processes" (Leick & Gretzinger, 2020, p. 840). As part of the network, companies combine complementary resources, share information and collaborate to achieve common goals (Idiagbon-Oke & Oke, 2019). The sum of knowledge acquired by companies is a key resource for achieving a competitive advantage (Crupi et al., 2020).

2. Research methods

The article used the bibliometric method and a case study.

The bibliometric method is a general interdisciplinary tool employed by researchers from various scientific fields (Glänzel, 2003; Youngblood & Lahti, 2018; Barkun, 2019). The scientific methods applicable in exact sciences were first proposed by de Solla Prince in 1965 (Boyack et al., 2005). Bibliometric methods involve two procedures: performance analysis and scientific mapping (Gaviria-Marin et al., 2019). The former aims to assess the outcomes of research and publications by scholars and institutions. The latter aims to reveal the dynamics and structure of selected scientific disciplines. Such information is of particular significance when a researcher reviews a specific line of research (Zupic & Čater, 2015).

Different approaches exist to research based on bibliometric analysis. This article used the one presented by Gaviria-Marin et al. and others. It involves the following steps: (1) the choice of a research subject, (2) the bibliometric analysis of papers selected as the research object, (3) the analysis of the frequency of keywords indicated by the authors of the selected papers, and (4) the content analysis — a study of the links between keywords (Gaviria-Marin et al., 2019).

A number of techniques and software tools have been developed for scientific mapping (Cobo et al., 2011). The results are usually presented in the form of a map showing relationships among particular elements (Halicka, 2017; Szpilko, 2017; Siderska & Jadaa, 2018; Winkowska et al., 2019). This study used the VOSviewer software, which creates representative and legible visualisations of the more complex networks (van Eck & Waltman, 2007). The tool was specifically designed to construct and visualise bibliometric maps, with particular attention to the graphic representation of network clusters and widespread use of continuous bibliometric investigations (van Eck & Waltman, 2010; Sweileh et al., 2016; Taşkin & Aydinoglu, 2015). Grouping is based on modules, and clusters are created depending on the strength of association between nodes (Waltman et al., 2010).

The article applies the keyword co-occurrence analysis, which is a type of co-word analysis (Lis, 2020; He, 1999). This technique is classified as a scientific mapping method (Zupic & Čater, 2015; Klincewicz et al., 2012). Analysis of keywords is an efficient method that allows examining the relationships between key terms and their evolution in time (Castriotta et al., 2021). For this analysis, the bibliometric data were downloaded from the Scopus database, which is one of the leading databases indexing high-quality scholarly publications.

The experiences of the GoSmart BSR project served as the case study for the article. In this situation, the case study analysis was participatory. The project encountered problems with recruitment for the posts of international innovation brokers (IIBs) and with the development of essential competences for the realisation of the project. The solution addressed the following research questions:

(1) What general framework for measures within the network of cooperating project partners determines the development of international innovation brokers' competences?

(2) What substantive knowledge is indispensable for the effective realisation of measures in an international context?

(3) What skills must be in focus in terms of knowledge applied to solve problems and choose optimal solutions allowing to realise project objectives and enable teamwork in an international environment?

(4) What attitudes, understood as specific aptitudes, are relevant for the efficient work of brokers of innovation and SMEs internationalisation?

The purpose of the research conducted under the GoSmart BSR project was to identify the competences of international innovation brokers (IIBs). The research procedure was mainly targeted at constructing an original model of competences of IIBs responsible for supporting the SMEs sector in terms of internationalisation, smart specialisation and innovation. The study was qualitative.

Generally, qualitative study methods (normative methods) are employed when the investigated phenomena are difficult to represent quantitatively and when creative thinking is necessary (Kononiuk & Magruk, 2008). Brainstorming is among the heuristic methods of creative problem-solving. The term was first used by Alex Osborn in 1942 (Casanovas et al., 2011; Putman & Paulus, 2009). It is a creative and interactive method (Byron, 2012; Hilliges et al., 2007) involving teamwork, thus enabling interaction among participants and facilitating the rapid accumulation of numerous ideas for solving a posed problem (Baruah & Paulus, 2019; Thompson, 2003; Paulus et al., 2011; Wang et al., 2010). Another advantage of the approach is that its participants are more committed to solving problems. In GoSmart BSR, brainstorming was aimed at finding out the opinions and expectations concerning the professional competences required of innovation brokers working in an international environment and proposing the ultimate model of innovation broker competences in an international context. Brainstorming was conducted among brokers, i.e., persons employed in this position in seven partner countries, and among coordinators of measures associated with the Transnational Innovation Brokerage System (TIBS). The research was conducted in 2019–2020. The work on creating the broker competence model was managed by one of the project partners, i.e., from Finland (the moderator of the brainstorming session). As the project partners were located in different countries, the talks were conducted online (via Internet and e-mail) and in-person during training workshops. A step-by-step team method of creative problem-solving was used along with a creative inductive thinking approach.

Before the brainstorming stage, three tasks were set, starting with (1) collecting multiple ideas — listing as many competences as possible. First, views were exchanged, then arguments and counterarguments were presented to generate a high number of suggestions and to initiate a debate among brokers and representatives of the project partners. (2) The second task consisted of identifying groups of ideas; the synergy of ideas allowed to combine them into groups. Next, another debate was held concerning the groups of competences and the range of their specific requirements (in the fields of knowledge, skills and attitudes). The overall proposal was debated again, which resulted in a draft version of the model of international innovation broker competences. In the preliminary version of the model, requirements for six groups of competences were formulated and described. (3) The third task was to develop the ultimate solution entitled Competence Mapping Checklist. The competences were described in an internal document, "TIBS Handbook", available for use by the brokers and project partners.

3. Research results

3.1. General framework of action in the partner network of the GoSmart BSR project

Presented below is the general framework of the GoSmart BSR project, which determines the professional development of the competences expected of international innovation brokers:

(1) The project's primary objective is to support SMEs in internationalisation and innovation efforts. Internationalisation is considered an opportunity for SMEs to encourage action in foreign markets and to raise the level of their innovation performance. According to the updated Uppsala model, it was assumed that knowledge creation and exchange and the project stakeholder interactions were the basis of this process.

(2) Focusing on promising areas for the prospective development of the regional economy and smart specialisations. SMEs operating in the specialisation area united into a cooperation network for the key project stakeholders due to a greater likelihood of success and better business prospects.

(3) Using a broad definition of innovation, based on the terminology from the Oslo Manual, published by the OECD. Innovations were divided according to subject criteria, considering significant technological and other changes. Product, process, organisational and marketing innovations were distinguished.

(4) Using the "open innovation" concept proposed by Chesbrough as a way to implement innovation processes in SMEs. The basic assumption of open innovation is cooperation with various subjects, gaining and adapting knowledge from external sources with a view to raising the efficiency of creating and implementing innovative solutions (Bogers et al., 2018). It was assumed that to streamline their activities and technologies, enterprises could and should rely on knowledge flows, external and internal ideas in their innovative processes, and internal and external paths of launching innovations in the market.

It is important to focus on constructing an environment that is conducive to the development of internationalisation and potential innovations in SMEs, based on the quadruple helix model. Such a network means participation and cooperation of key actors from the field of science and research, enterprises, and central and regional governments for the sake of creating Joint Transnational Smart Strategies (JTSS).

International innovation brokers play a key part in the network of participants. The brokerage system consists of brokers from the Baltic Sea Region.

Internationalisation processes occurring in SMEs have a positive effect of creating and transferring knowledge within a network of cooperating subjects. Previous research confirmed that innovations open opportunities to operate beyond country borders and not the other way around, chiefly in the case of product innovations. The GoSmart BSR project fills a gap by assuming that internationalisation might result in implementing innovations in various areas thanks to the experience gained in foreign markets. This requires, among other things, having a team of brokers with strong individual competences, which add up to team competences in a project. Without the professional expertise of brokers, it is not possible to create knowledge resources, integrate large amounts of information, diagnose these resources or use them to unite groups of enterprises into regional value chains, form groups of businesses that develop joint transnational strategies of smart specialisations and, consequently, obtain an added value of the entire project.

The task of international innovation brokers representing project partners is to implement the TIBS. It is defined as a network-based support system to assist groups of SMEs in defining and implementing their Joint Transnational Smart Strategy (JTSS) across partner regions and beyond. The TIBS service encompasses three groups of activities. First, recruitment, pre-treatment and assessment of the client; second, matching partners; and third, elaboration of transnational business models for a group of SMEs. The range of activities undertaken by international innovation brokers includes:

- Identifying SMEs sector companies in target regions that are willing to cooperate in the project and have high internationalisation potential;
- Building cooperation networks and relationships among brokers representing specific project partners, between brokers and SMEs and other subjects from the business milieu (other business support organisations at a national and regional level), i.e., the stakeholders of internationalisation and innovation development;
- Establishing contacts with SMEs to initiate internationalisation processes through joint broker efforts to develop internationalisation models and, under this framework, potential innovations and cooperation aimed at concluding agreements between SMEs from partner regions.

The TIBS, apart from methods and tools (technology or "content"), required skilled and capable staff directly engaged in service delivery and dealing directly with final beneficiaries. These functions were performed by innovation and internationalisation brokers (IIBs) who were supported methodologically by the project and institutionally by the GoSmart partner organisations. TIBS methods and tools, which defined the process of service delivery to beneficiaries (SMEs and their innovation and internationalisation partners), covered all the steps of the development and care of Joint Transnational Smart Strategies by trans-regional groups of SMEs. IIBs were competent in the field and willing to work with business and R&D actors.

3.2. Attributes of innovation brokers: a bibliometric analysis

One of the purposes of this article is to identify and classify the attributes and competences of innovation brokers as described in the scholarly literature from the field of "Business, Management and Accounting". The study intends to present a review of the subject's research evolution and describe structures typical of the considered topic. The results allow identifying the main areas that have been investigated heretofore and indicating literature gaps, offering an opportunity to explore the topic more broadly in the future. The study is explorative. It was performed using bibliometric analysis and the VOSviewer software (www.vosviewer.com, 14.10.2021). The references were drawn from the Scopus database (www.scopus.com, 12.10.2021).

For the purposes of the study, keywords "innovation" and "broker" were used (also when they occurred in titles and abstracts). In total, 537 publications matched the filters. Retrospection of the subject scope begins in 1980. However, researchers' interest started to increase at the beginning of the year 2000. As Fig. 1 below shows, between 1980 and 1999, the number of publications ranged from 0 to 6. In the years 2000–2004, it was 5–9; between 2005 and 2014, it rose from 12 to 42 annually; in 2015–2020, from 35 to 44 documents were published every year.

As for the subject areas (Fig. 2), the documents concerned: "Business, Management and Accounting" (20 %), "Social Sciences" (17.1 %), "Computer Science" (11.7 %), "Engineering" (10.4 %), "Medicine" (6.4 %), "Economics, Econometrics and Finance" (5.7 %), "Decision Sciences" (5.6 %), "Environmental Science" (5.4 %), "Agricultural and Biological Sciences" (4.0 %), "Arts and Humanities" (3.7 %), and "Other" (10.1 %).

The largest number of publications on the topic of innovation brokers is issued by the United States (111 publications), followed by the United Kingdom (77 publications) and Italy (45 publications). In general, the top ten countries represent Europe plus Canada, Australia and China.

To streamline the study results, the subject area was restricted to "Business, Management and Accounting", and, as a result, 196 publications that

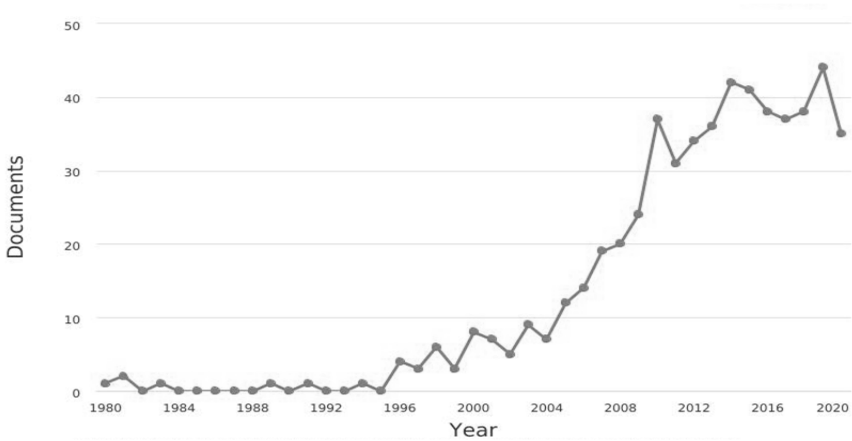


Fig. 1. Distribution of the documents by publication year

Source: Elaborated by the authors based on www.scopus.com (12.10.2021).

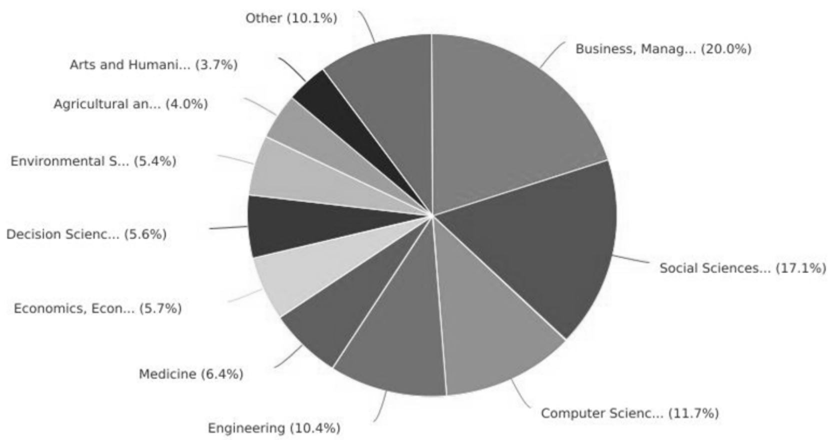


Fig. 2. Distribution of the documents by subject area

Source: Elaborated by the authors based on www.scopus.com (12.10.2021).

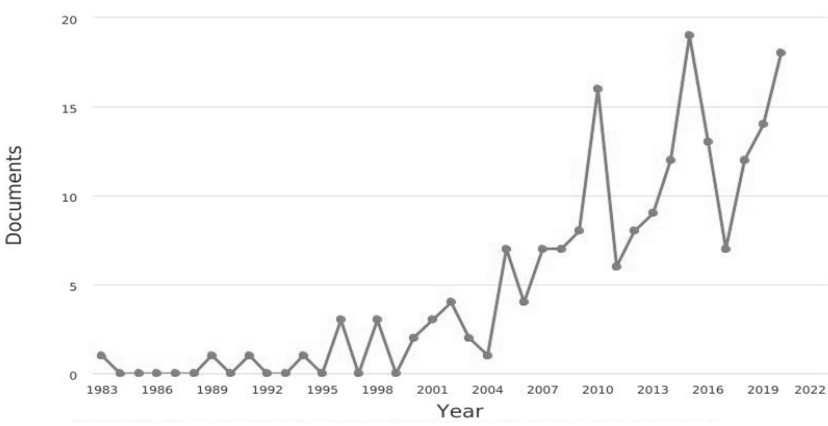


Fig. 3. Distribution of documents in the subject area "Business, Management and Accounting" by publication year

Source: Elaborated by the authors based on www.scopus.com (12.10.2021).

matched the filter were obtained. According to Fig. 3, the first references to the topic of innovation brokers in the subject area "Business, Management and Accounting" appeared in 1983. In the years 1983–2001, the number of publications ranged from 0 to 3, and between 2002 and 2020, from 1 to 19 annually.

In the analysed area, the Scopus database contains publications about 37 countries/territories of origin, plus undefined, concerning the topic of innovation brokers. According to the figure below (Fig. 4), the largest number of publications is connected with the United States (42 publications), followed by Italy (26 publications), the United Kingdom (23 publications), and Germany (14 publications). In general, the top ten countries represent Europe, Canada and China.

For further analysis with the use VOSviewer, the option of co-occurrence of keywords was selected. Overall, 1 044 keywords were generated. A minimum occurrence of three was chosen, as a result of which the number of keywords was narrowed down to 85. Next, filtration of keywords was performed to sort the information obtained from Scopus.

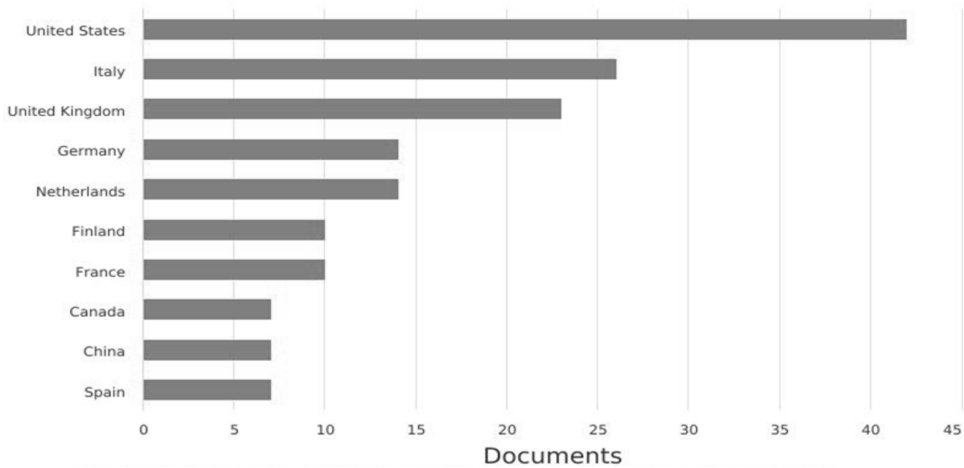
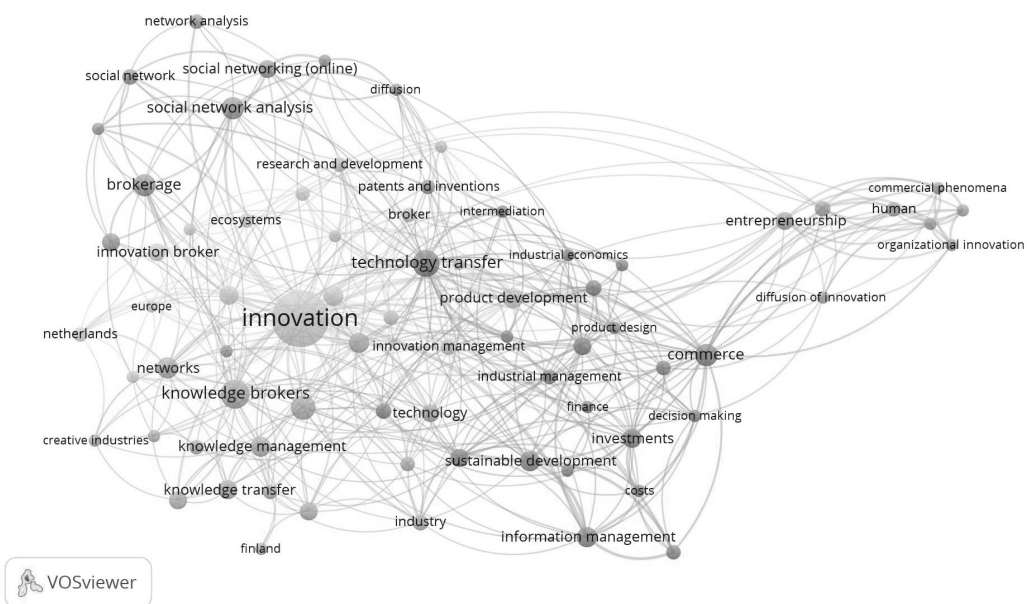


Fig. 4. Distribution of documents in the subject area "Business, Management and Accounting" by country of origin
Source: Elaborated by the authors based on www.scopus.com (12.10.2021).



* The larger the circles, the higher the occurrence frequency.

Fig. 5. Keyword co-occurrence mapping for "innovation" and "broker" topic
Source: Elaborated by the authors based on Scopus, using VOS-viewer software www.vosviewer.com (14.10.2021).

As the figure (Fig. 5) above demonstrates, the most frequently occurring keywords included: innovation, knowledge brokers, technology transfer, commerce, brokerage and social network analysis. Six clusters were identified, four of them interrelated, one slightly peripheral.

Mapping of keywords shows that an innovation broker can have certain attributes. According to VOSviewer analysis (Table 1), six clusters can be formed with a total of 85 items. The first cluster contains 21 items, the second — 16 items, the third — 11 items, the fourth — 10 items, the fifth — 8 items, the sixth – 8 items.

There are differences and similarities across the clusters. It can be assumed that a key difference regarding Cluster 1 is that it comprises issues from several categories: competition, investment, finances, technology and trade. It is also related to social and economic effects and sustainable development. Cluster 2 is thematically oriented towards co-operation, knowledge transfer (knowledge brokers knowledge management, knowledge sharing) and innovation (innovation networks, open innovations, innovation process). Cluster 3 focuses on social networking and also involves attributes of dissemination and brokerage of patents and inventions. Cluster 4 is largely oriented towards brokers/intermediaries of innovation. Cluster 5 is connected with issues regarding R&D and the development of products. Cluster 6 is centred around diverse issues, e.g., people, organisations or dissemination of innovations.

Analysis of scientific mapping reveals that research concentrates on innovation brokers, innovation systems, social networks and knowledge transfer, which is consistent with the assumptions of the GoSmart BSR project.

In view of the topic of this study and the outcomes of the bibliometric analysis obtained for "innovation" and "broker", in the next stage, the scope of the analysis was widened and encompassed "innovation", "broker", and "competences". As a result, 21 publications from all the research areas matched the filters. For further study using VOSviewer, the option of keyword co-occurrence was selected. A total of 247 words was generated. A minimum occurrence of three was chosen, narrowing down the number of keywords to 12 (Fig. 6).

Two related clusters were identified (Table 2). The first contains seven items, the second — five items.

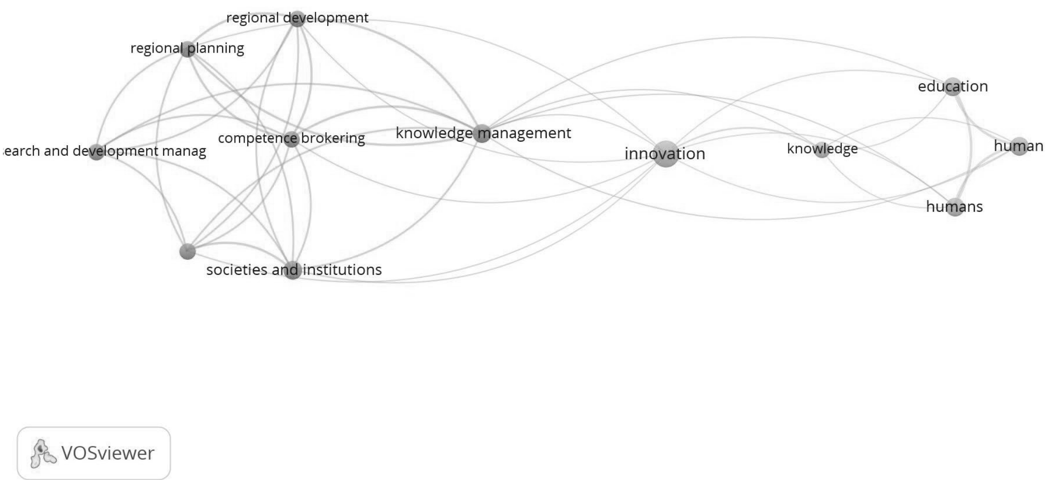
The attributes contained in both clusters fall within GoSmart BSR assumptions regarding innovation, knowledge management, competence brokering and regional development.

Summing up the conducted bibliometric analysis, it should be pointed out that the main identified areas published in Scopus have so far been consistent with the assumptions of the project, which is the subject case examined by this study. On the other hand, gaps can be noticed in previously published articles concerning the competences of international innovation brokers. First and foremost, the project broadens the concept of broker competences, going beyond their

Tab. 1. Keywords clusters

Cluster number	Number of items	Key words
1 (red)	21	commerce, competition, costs, decision making, economic and social effects, economics, electronic commerce, finance, financial innovation, industrial economics, industrial management, information management, innovations, intermediation, investments, marketing, product design, SMEs, sustainable development, technology brokers, technology transfer
2 (green)	16	collaboration, creative industries, Finland, industry, innovation network, innovation process, intermediaries, knowledge broker, knowledge brokering, knowledge brokers, knowledge management, knowledge sharing, knowledge transfer, networks, open innovation, technology
3 (blue)	11	brokerage, diffusion, industrial performance, innovation networks, network analysis, patents and inventions, social network, social network analysis, social networking (online), social networks, social sciences computing
4 (yellow)	10	ecosystems, Europe, innovation, innovation broker, innovation brokers, innovation intermediaries, innovation system, Netherlands, technological change, technological forecasting
5 (light blue)	8	broker, information dissemination, innovation management, new product development, product development, project management, research and development, research and development management
6 (violet)	8	commercial phenomena, diffusion of innovation, entrepreneurship, human, organization, organization and management, organizational innovation, United States

Source: Elaborated by the authors based on www.scopus.com (14.10.2021).



* The larger the circles, the higher the occurrence frequency.

Fig. 6. Keyword co-occurrence mapping for "innovation", "broker", and "competences"
Source: Elaborated by the authors based on Scopus, using VOS-viewer software www.vosviewer.com (14.10.2021).

Tab. 2. Keywords clusters

Cluster number	Number of items	Key words
1 (red)	7	competence brokering, industrial research, knowledge management, regional development, regional planning, research and development management, societies and institutions
2 (green)	5	education, human, humans, innovation, knowledge

Source: Elaborated by the authors based on www.scopus.com (14.10.2021).

knowledge and accounting also for their skills and attitudes. Moreover, the activities undertaken by the brokers of the project are of international character, which in the future may make it possible to apply the identified competences also in other regions beyond the Baltic Sea Region.

3.3. Competences of international innovation brokers – model approach and discussion

Competence is having knowledge and experience in a certain field, enabling the proper performance of duties and making the right decisions (Lenart-Gansiniec, 2018). The partners of the GoSmart BSR project clarified the general conditions that were considered when recruiting for a broker position in each partner country. The starting assumptions are general and specific knowledge gained through work experience at enterprises from the SMEs sector. The central part of the concept is the support for the internationalisation of SMEs in participating regions. In the GoSmart project, the business support system, TIBS, has been developed and tested, supporting SMEs' internationalisation process and initiating collaboration between companies primarily within the GoSmart regions.

The framework for broker activities is the area of project implementation that defines geographic markets and focuses efforts on specific areas of smart specialisation. The process of recruitment and competence development is presented in Fig. 7.

The project partners committed themselves to ensuring the appropriate competences of the employed brokers. It was considered necessary to conduct an intensive international training programme financed by the project. The adjustment and extension of the competences of the employed innovation brokers considered such factors as:

- the scope of duties related to the provision of TIBS services. The basic purpose of the services is to undertake activities in foreign markets and to focus on innovation in the SME community;

Fig. 7. Illustration of the international innovation broker process

- the implementation of an intensive capacity building programme (CBP) in practice;
- the possibility of changes in the competence-building programme depending on the needs reported by brokers in terms of knowledge and skills as well as the implementation of the assumed project objectives.

The intensive formal international training programme was composed of internal and external training with innovation promotion institutions, coaching from external project experts to the host organisation and representatives of other project partners and short-term external placements. The recruitment of brokers was completed in the 3rd Period of the project, and the formal international training in the 4th and 5th Periods. All international innovation brokers (IIBs) completed an intensive training programme composed of internal training within representatives of project partners and external training with innovation promotion institutions; they received coaching on the job and short placement abroad within the project partnership. IIBs participated in three dedicated training events in Vilnius, Riga, and Aabenraa. CBP Part 1–3 focused on the brokers' role, tasks, tools, competences and insights while interacting with SMEs on innovation and internationalisation processes and strategies. Further, the CBP focused on how to make brokers cooperate efficiently. IIBs met to build their capacity in supporting SMEs towards their internationalisation and innovation and to train in processes, tools and cooperation between brokers, making the TIBS's services to SMEs effective. CBP developed areas of broker competence in the network, practical training working with a number of business cases presented by project partners and by external consultants and company visits.

The brokers are specialised in supporting SMEs seeking transnational cooperation within common specialised sectors and identifying potential innovations. The competences are divided into six areas:

- TIBS specific knowledge;
- Innovation-related competences;
- Internationalisation-related competences;
- SME-consulting competences;
- Communication skills;
- Attitudes, professional experiences, and formal competences.

A list of IIBs key competences is presented in Table 3. The competences have been described in the internal document of the TIBS handbook to be used by brokers and project partners. When developing the competence model, the aim was to ensure utilitarian value, which, on the one hand, required the specification of the indicated competence groups and, on the other hand, was limited by the need to embed competences in the assumptions and objectives of the project. The proposed model of competences of international innovation brokers presented in the project may be supplemented with further groups of competences and thus should become a contribution to further discussion and modification.

A graphical overview of the competence areas of international innovation brokers is presented in Fig. 8.

The presented model is a synthesis of previous experiences in the area of formulating competences of international innovation brokers. The model considers five groups of factors that are desirable and can be developed within an organisation.

In addition to the above-mentioned competences in the areas of knowledge, skills and attitudes, in practice, goal orientation, loyalty to the project, social responsibility and the ability to work in an international team were also important. TIBS assumes building a business model of SMEs interested in creating innovations in the international dimension through innovation brokers. The synthesis and integration of dispersed knowledge and skills in the field of its application and broker attitudes lead to discovering opportunities for establishing beneficial cooperation of SMEs in the Baltic Sea Region and initiating joint transnational smart specialisation strategies (JTSS). Interactions and building relationships between brokers and SMEs, and other stakeholders are also of utmost importance. The cooperation of brokers from

Tab. 3. Professional experiences and formal competences — the Competence Checklist according to the experience of the GoSmart BSR project

Group of competences	Description
Knowledge and skills required in connection with the implementation of the project (regarding the assumptions and expected effects of the GoSmart BSR project)	
TIBS specific knowledge	• Understanding the TIBS value propositions
	• Knowledge of the TIBS delivery process
	• Excellence in applying TIBS tools
Knowledge and skills related to internationalisation and innovation	
Innovation related competences	• Knowledge of S3 concept and its application in own region/country
	• Innovation evaluation skills and techniques
	• Innovation process skills and techniques
	• Innovation project management skills and techniques
	• Knowledge of regional/national and international supporting tools and funding instruments for innovations
Internationalisation related competences	• Basic knowledge about S3 of TIBS partner regions, regional strengths, main clusters, etc.
	• Knowledge of internationalisation models, strategies and benefits
	• Knowledge of relevant frameworks for evaluating SME readiness to internationalisation, selecting right markets, operational mode, partner etc.
	• Knowledge of regional/national and international supporting tools and funding instruments for internationalisation of SMEs
Knowledge and skills in the areas of operation of an enterprise and its sectoral environment, planning and forecasting the effects of undertaken actions	
SME consulting competences	• Knowledge of the regional business environment, especially SMEs
	• Wide personal contact network in the local business community
	• Wide knowledge across different industries and Trans-S3 specific knowledge domains, sectors/sub-sectors, technologies and themes
	• Knowledge of regional/national and international supporting tools and funding instruments for SMEs
	• Knowledge of relevant frameworks to evaluate company's current processes and identify company's needs quickly
	• Value chain analysis skills and techniques
	• Financial analysis skills and techniques
	• Problem-solving skills and techniques
	• Strategic planning tools and techniques
	• Action planning skills and techniques
	• Fluency in customer service
Skills and attitudes of building interpersonal bonds	
Communication skills in an international network	• Fluency in written and spoken English in addition to one's local languages
	• Active contacting skills and drive makers
	• Opening doors to business decision
	• Assertiveness in demanding business situations
	• Strong networking skills
	• Negotiation skills
	• Fluency in producing documents, presentations and reports by using modern office information systems and tools
	• Social media skills to promote TIBS and networks
Attitudes and skills of professional operation	

Professional qualities and formal competences	• Proactivity and self-steered working skills
	• Flexibility to changing situations
	• Readiness to travel and co-operate in different working cultures
	• Openness to new approaches, tools and techniques
	• Drive for self-education and professional growth
	• Years of higher education in Management, Business or Technology
	• Working experience in general
	• Working experience in SME sector or business consulting
	• Practical customer service experience
	• Working experience in multicultural teams
	• Experience in applying for EU support programmes

Source: Elaborated by the authors based on TIBS Handbook.

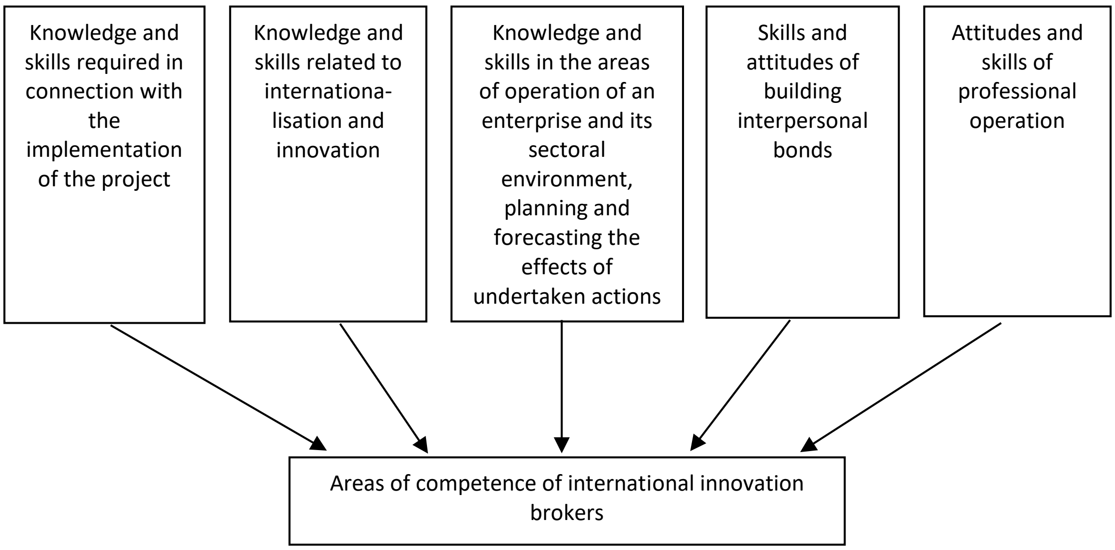


Fig. 8. Areas of competence of international innovation brokers

different backgrounds and traditions, bringing different experiences and their focus on the objectives of the project, favours the initiation of internationalisation and innovation processes of SMEs. It should also be emphasised that the broker activities allow shortening the time needed for identification and communication of partners, as well as reducing the workload of SMEs on acquiring new markets.

The implementation of TIBS services in practice and the identification of the necessary competences and their development during the project, as well as building cooperation between brokers from the area of selected Baltic Sea Region countries, contributed to the following effects:

- A database of 998 potential beneficiaries interested in internationalisation, including SMEs, clusters, R&D units, organisations supporting business from partner regions;
- 171 offers to develop international cooperation in the SME sector;
- An association of 104 foreign partners, and in the case of 44 entities, defining the business model of internationalisation and innovation;
- 22 SME groups developing JTSS.

4. Discussion of the results

In the relevant literature on management and quality, competences are considered from the perspective of an individual (or teams) or entire organisations (Bergenhenegouwen et al., 2020). The first category consists of individual competences of particular employees. Although the knowledge and skills of employees can be created in an organisation, it is much more difficult to instil certain values and standards (Sudolska, 2006). These competencies include knowledge, skills, values, standards, motives, work ethic, enthusiasm and self-image. The second category includes competences of an organisation, understood as the ability to use its material and non-material resources, the ability to use them in processes in a way that helps to achieve the goals of an organisation. According to Penrose, competences constitute a central category of the Resource-Based View of the firm (Sudolska, 2006). In this approach, competences are an element of intangible resources. They are understood as the company's ability to use its resources. Built on the basis of the organisation's resources, they are the main source of its competitive advantage. The diagnosis of competencies of both individual employees and organisational competences is a permanent element of competency management (Moczydłowska & Serafin, 2016).

As part of the GoSmart BSR project, brokers form an international team, i.e., a group of people cooperating with each other to achieve a common goal. This goal is to raise the level of internationalisation and innovation of SMEs in the Baltic Sea Region. The brokers, as knowledge intermediaries in this process, provide SMEs with professional services and the necessary substantive support (information, consultation, advisory). International innovation brokers should have specific competencies when performing the tasks carried out in the project. The ventures supporting the development of their competences were provided by the project partners through the implementation of the Capacity Building Programme.

Despite the fact that competences are an important element of professional human development, there is no clear-cut understanding of this concept. Most often, competences are a combination of knowledge, skills and values of a given person, necessary for particular job positions. There are two trends in defining this concept in the literature (Szczepańska-Woszczyna, 2016). The first is the definitions linking competences directly with the person they concern, defining the scope of knowledge and skills, identifying them with a set of behaviours, abilities, personality traits as parameters that differentiate individuals from one another. The second trend consists of definitions referring to the performed work or the position held and treating competences as the performance of a function in an organisation, which results in specific work outcomes. Contemporary perception of competences requires a holistic approach. The holistic approach adopted in the GoSmart BSR project is consistent with both the behavioural trend and the functional understanding of competences.

By convention, competence is a combination of knowledge, plus skill, plus awareness or attitude (Dingle, 1995; Loufrani-Fedida & Aldebert, 2021). According to Filipowicz (2016, p. 46), "competences are dispositions in the field of knowledge, skills and attitudes that enable the performance of professional tasks at an appropriate level". "For a team to be competent, its members must be competent" (Tidd & Bessant, 2013, p. 190). The individual competences of innovation brokers consist of knowledge, skills and attitudes (Fig. 9). The combination of these elements determines the effective implementation of professional tasks. They also serve to achieve the goals of the organisation. Specific skills and knowledge are the so-called hard competences. Knowledge (general, acquired and accumulated from experiences related to professional work inside and outside the project) creates the basis for the implementation of various activities. Skills are repeatable models of activities; they refer to practical proficiency in carrying out specific tasks to introduce SMEs to foreign markets and to develop innovation in various areas. Skills depend on the creation, exchange and use of knowledge to solve problems creatively.

These competence elements undergo a transformation. Each of the brokers, in the course of training, acquires new substantive knowledge that directly relates to the task being performed and conditions, and at the same time enables further development of skills (teaches task behaviour, performing tasks). Interpersonal skills are also important, being vital in shaping relations between project stakeholders. Another element of competencies are attitudes that are equated with personality traits, specific values required from the broker, which may be conducive to achieving project goals. Attitudes that create the so-called soft competences are often mentioned and presented in the form of character traits and personality traits, such as, e.g., creativity, responsibility, independence, recognising one's strengths and weaknesses, high motivation, resistance to stress. The term "soft skills" denotes the mental skills of an individual and their ability to cope with social situations, necessary for effective and efficient interaction (Robotham & Jubb, 1996). These features can influence the professional performance of brokers. Developing soft skills is not easy. However, their activation in the form

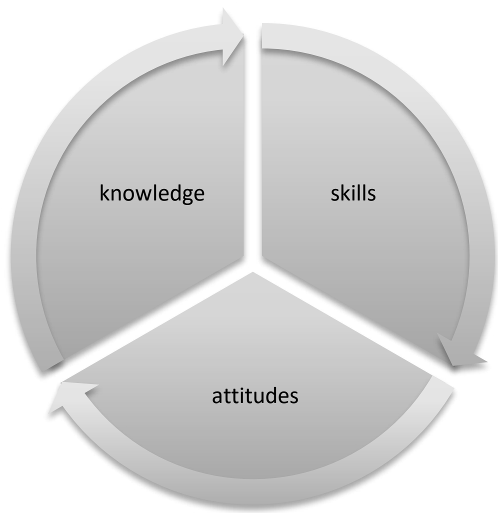


Fig. 9. Components of competences of innovation brokers

of specific, observable and desired actions of brokers depends on the rights granted under the project and working conditions, with particular emphasis on the role of an incentive system and the related organisational culture (Moczydłowska, 2008; Szydło, 2018; Szydło & Grześ-Bukłaho, 2020).

The synthetic model of competences for international innovation brokers proposed by the authors adopts a holistic approach to defining competences. This model has the attribute of practicality and universality, i.e., the possibility of being used in various organisations working for the internationalisation and innovation of SMEs. This model is based on the following assumptions:

- The level of individual competences depends not only on the knowledge and skills but also on the broker attitudes (personality traits of brokers, predispositions, or their cognitive abilities); hence, the model considers such components as knowledge (mainly procedural "know-how"), skills (the ability to implement assumed behaviour patterns, ensuring the achievement of goals or results) and attitudes (willingness to take specific actions and use knowledge).
- The model assumes that due to the support of the organisation, individual competences contribute to the creation of competencies at the level of the entire organisation and the implementation of tasks in a manner consistent with the standards required for the provision of intermediation services and in accordance with the organisation's goal. Hence, the basis is the assumption that support from the organisation in their development has a positive effect on the level of broker tasks. Broker competences are deeply embedded in the method of management and are supported by the organisation (open culture, promoting the participation of all brokers in the creative process, promoting cooperation, exchange of knowledge, experiences); the relationship between competences and the level of task performance seems natural.
- The model considers the knowledge and skills grouped into four categories in the competence structure, which can be developed with the help of the organisation and by cooperation with other brokers. In addition, it includes elements of personality traits and broker attitudes that affect the overall quality of the work performed, which makes them desirable in the context of supporting the internationalisation and implementation of innovation in the SME sector.
- The input competences are primarily general knowledge and knowledge of the specificity of the business and experience in working with enterprises from the SMEs sector (knowledge and practical skills), as well as specific employee attributes. They represent a specific potential that the organisation then develops.
- The output includes benefits, effects, i.e., something valuable for stakeholders from the perspective of a broker (professional development), the organisation (achieving the assumed indicators, building relationships), and beneficiaries (SMEs — the impact on internationalisation and innovation).

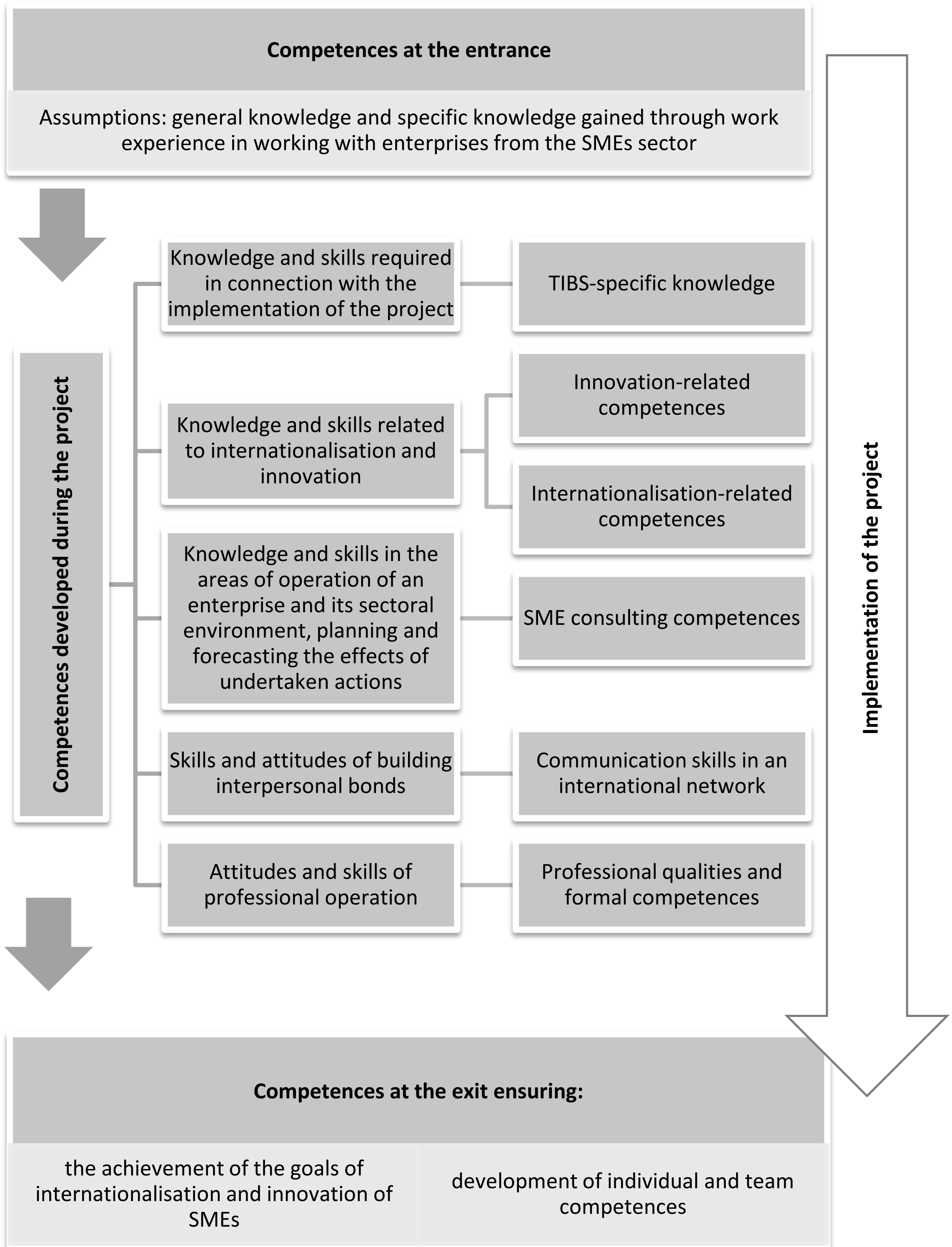


Fig. 10. Model of competences of international innovation brokers

A graphic presentation of the competency model of international innovation brokers is given in Fig. 10. Overall, it can be said that many SMEs can only access external knowledge sources with the help of actors who are well connected to the global sources of knowledge so that they can translate information into a form that is understandable to local organisations. This is one of the reasons to expand the activities of international innovation brokers. In the project, their competences were developed and used to build a network of international cooperation, to integrate individual knowledge, and used for the internationalisation and implementation of innovation in SMEs, which is the overall goal of the project. The authors did not specify the degree of importance of the detailed competence elements and their components, thus giving them equal importance in the process of accelerating the internationalisation of SMEs and the implementation of innovations. Based on the proposed model, the competences of brokers are largely based on knowledge and skills. The authors assumed that this model, built on the basis of the experience gained during the GoSmart BSR project, is an inspiration to experiment and introduce new ideas and concepts. The identified competence elements can be considered universal and key in the work of an international innovation broker, yet their list and components of competences are inexhaustive. The issues discussed in the article require further research.

Conclusions

The article presents a pragmatic model approach to the competences of international innovation brokers. This approach is an attempt to describe them and can be considered a research field that requires further study. GoSmart BSR project partners did not use ready-made solutions when creating it. Instead, they undertook a search to match the model solution to the assumptions and goals of the project. As a result of the conducted research and analyses, a six-element competency model was developed. The authors are aware of many limitations of the presented research approach. The research, although carried out on the scale of one project, may constitute a reference point for other networks of collaborating entities on an international scale for the internationalisation and innovation of SMEs. The proposed model of competences of international innovation brokers can be used in practice to set target conditions for their recruitment. Of course, all models are limited in various respects. Nevertheless, both an organisation and individual employees gain the opportunity to independently check what is expected of them and what knowledge and skills should be acquired. When used in a recruitment strategy, the model makes it easier to find suitable candidates for a broker position and, at the same time, indicates investing in creating an environment that will enable them to perform their duties. Further empirical research based on the model presented in the article is certainly necessary.

Another important issue is the flow of knowledge in regional network systems. This is because of problems of global knowledge sources, especially emerging in less developed regions, the creation of network structures optimal for the flow of knowledge, and knowledge transformation so that it can be adapted by local companies from the region covered by the project, i.e., the Baltic Sea Region. The premise is, therefore, that knowledge brokers are not only able to initiate collaboration that involves the flow, exchange and creation of knowledge but also participate actively in it. The processes of flow, exchange and creation of knowledge are influenced by the obtained knowledge resources and the skills in applying them to solving new problems and choosing the optimal solution.

Acknowledgements

This research was supported by the project 'Strengthening smart specialisation by fostering transnational cooperation (GoSmart BSR)' which has received funding from the European Union Interreg Baltic Sea Region Programme 2014-2020.

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
GoSmart BSR

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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received: 10 August 2021
accepted: 1 December 2021

pages: 115-130

Challenges and barriers to connecting World Class Manufacturing and continuous improvement processes to Industry 4.0 paradigms

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ABSTRACT
This paper exposes the difficulties in integrating "Industry 4.0 Practices" and "World-Class Manufacturing" due to the rapid expansion of production systems and the increasingly complex data monitoring. The applied methodology was to study multiple cases with the aid of a semi-structured questionnaire. The analysis comprised responses of 15 large companies with different expertise from five countries and three continents. The results show that when a company's strategy is linked to Industry 4.0 practices and the World-Class Manufacturing method, they boost productivity by monitoring the shop floor, applying analytical tools, and spreading the organisational culture aimed at improving processes. The results also indicate that human resources are essential in this integration. The conclusion indicates robust barriers to the increasing progress of these procedures, such as the costs associated with the use of technologies, the lack of knowledge of the applied methods and tools, the lack of trained and qualified human resources, and the resistance of people to the use and application of the newly adopted practices. The continuous improvement practices do not keep up with the speed of development that the Industry 4.0 practices propose, requiring studies directed to "World-Class Manufacturing" and "Industry 4.0 practices". Although there is a coexistence of improvement and innovation in world-class manufacturers, the literature has not yet provided a complete understanding of how this coexistence can be achieved at the manufacturing level. Therefore, the paper presents the main actions to overcome these barriers.

KEY WORDS
Industry 4.0, World-Class Manufacturing (WCM), continuous improvement

10.2478/emj-2021-0035

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Introduction

In the last ten years, companies have been led to reorganising their productive arrangements, considering the technological development associated with their processes, directing them towards the implementation of technologies that bring greater efficiency as a result. The paper studies this technological advance in productive means and the barriers encountered to implementing the World Class Manufacturing (WCM) method in an environment that uses

Terra, J. D. R., Berssaneti, F. T., & Quintanilha, J. A. (2021). Challenges and barriers to connecting World Class Manufacturing and continuous improvement processes to Industry 4.0 paradigms. *Engineering Management in Production and Services, 13*(4), 115-130. doi: 10.2478/emj-2021-0035

Industry 4.0 practices. The WCM method consists of a set of tools and procedures to improve the operational performance of companies, making them more efficient and integrating the entire corporation, from operational to strategic management.

The core of Industry 4.0 practices lies in increasing production efficiency and making companies competitive at a global level through the massive use of digital technologies.

Carefully identified operational barriers allow adding value to products and services, establishing the necessary conditions for the encouragement, advancement, and definition of new technologies, as well as adopting decentralised policies that help the preparation and composition of organisational systems in this new reality.

This new organisational composition leads to questions regarding different continuous development forms, maximising organisational possibilities and results, with the commitment to expanding knowledge and the need for staff corresponding to the needs of increasingly structural companies.

Considering this new organisational arrangement — continuous process improvement through the application of the WCM method and Industry 4.0 practices — this paper seeks to answer the following question: "What are the challenges in the management of operations and performance of companies, when considering the necessary adaptations in the WCM method for transformations that Industry 4.0 practices propose?"

Apart from the Introduction, the paper contains four parts: Literature Review, Research Methods, Discussion of the Results, and Conclusions.

1. Literature review

According to Paranitharan et al. (2017), integrated manufacturing systems are one of the main operational strategies adopted by companies to overcome the uncertainties of Industry 4.0 practices. Ebrahimi, Baboli and Rother (2019) affirmed that strategy forces companies to transform their production systems to be much more flexible and agile. Traditional mass production systems must evolve towards on-demand mass production to achieve this objective.

The association between World-Class Manufacturing (WCM) and Industry 4.0 Industry practices fits this profile. While WCM values production efficiency, Industry 4.0 practices allow for a rapid expansion of production systems.

There are some important differences between the principles of WCM and Industry 4.0. While WCM is mainly based on continuous improvement and cost reduction, Industry 4.0 is based on using all accessible information and data of systems and making decentralised decisions, both involving a global vision and a systemic approach to global profit optimisation (Ebrahimi, Baboli, & Rother, 2019).

In this context, the connection between WCM and Industry 4.0 practices paradigm should transform the factory into a fully interconnected environment, where decisions can be quickly made based on reliable, accurate, precise, and real-time data (D'Orazio, Messina, & Schiraldi, 2020).

Besides, other challenges must be overcome: the barriers to continuous assessment of organisational performance (Sangwa & Sangwan, 2018), the resilience of companies to unforeseen changes in business environments (Lotfi & Saghiri, 2018), the use of technologies, and the ability to assimilate new knowledge quickly (Sartal et al., 2017), and the variety and speed of data that drives companies to adopt and improve data analysis functions to improve current processes and their performance (Dubey et al., 2016).

WCM assists with these challenges. It consists of a set of tools and procedures aimed at improving the operational performance of companies. The method is applied from top to down, i.e., from strategic to operational management, integrating the entire corporation. Being an organisation classified as WCM means not accepting to be the second-best (Nagaprasad & Yogesha, 2008). It means being more competitive in price, quality and offering a set of associated products and services.

The objective of the method is to establish strategies capable of facing the competitiveness between companies, mainly in the global scenario (Khan et al., 2007). As a result, there is a greater direction for the use of best management practices. The cost analysis, the integration of people, the flexibility in processes, and technological innovation stand out, corroborating Ebrahimi, Baboli and Rother (2019).

Furlan and Vinelli (2018) stated that even if world-class manufacturers attested to the coexistence of improvement and innovation, the literature had not yet provided an understanding of how this coexistence could be achieved at the manufacturing level. No definitions exist for the minimum efficiency parameters, and the results have not yet been demonstrated satisfactorily, showing a gap in this area. To date, the scientific literature does not include studies specifically focused on the relationship between Industry 4.0 practices and WCM. On the other hand, numerous papers and isolated case reports are available on applying Industry 4.0 practices in different industrial contexts (D'Orazio, Messina, & Schiraldi, 2020). However, this does not help analyse differences and similarities between Industry 4.0 practices and WCM.

Current continuous improvement practices do not have the speed of this new technological standard (Rossini et al., 2019), and there is not much research regarding the holistic application of Industry 4.0 concepts towards continuous improvement, which clarifies the potential for improving its effectiveness (Peças et al., 2021). Therefore, this can lead to divergences during the transition from the current model to the proposed technological model.

The Industry 4.0 practices comprise a variety of technologies that allow the development and integration of different areas (Kamble et al., 2018) and also constitutes an important opportunity for the improvement of industrial management (Nota, Peluso, & Lazo, 2021). However, the transition from the traditional industry, with little or no technologies introduced in its processes, to the Industry 4.0 practices requires a complete review of operations (Ghobakhloo, 2018). This new industrial paradigm changes the roles of human resources and machines in production processes, restructuring the very essence of the workforce concept (Terziyan et al., 2018).

Workforce routines need to be designed to guarantee the quality of processes. The information must be incorporated into products and services in an organised manner and reflect how automation helps human work (Sartal & Vázquez, 2017). Besides, the change in the mindset of the workforce is identified as a contribution to the adoption of Industry 4.0 practices (Maisiri & Van Dyk, 2021). Industry 4.0 practices are more than technology-oriented policies, making human resources stand out (Schallock et al., 2018). The demands and challenges point out the importance of qualifying and developing human resources.

Papetti et al. (2021) affirm that integration of human factors in the (re)design of production systems is essential. Kazancoglu and Ozkan-Ozen (2018) assert that some criteria are important in the workforce, considering the implementation of Industry 4.0 practices. The ability to deal with complexity and problem solving, thinking about overlapping processes and flexibility to adapt new roles to work environments, organisational and procedural understanding, and the ability to interact with modern interfaces stand out, with collaborative technology and human approach (Turner et al., 2021; Gajdzik et al., 2021; Kohnová et al., 2019).

In this new model, it becomes important to invest in organisational knowledge and learning from a strategic perspective (Synnes & Welo, 2016). Dalenogare et al. (2018) argued that companies wanting to start their journey towards Industry 4.0 practices must first think about their strategic objectives before implementing any technology.

The identification of relevant strategies leads to a structure that accommodates skills and technology, governance, and collaborative practices in different environments (Hamersly & Land, 2015). Competitive manufacturing, which delights customers, requires not only the development of WCM but also the continuous evolution and improvement of processes (Peças et al., 2021; Arms et al., 1994).

The real incentive to implement Industry 4.0 practices is to maintain a competitive advantage (Davies et al., 2017). Although this model is considered a new industrial stage, where the integration of processes and connectivity with services can help companies achieve higher performance, little is known about how to do this (Dalenogare et al., 2018).

Buer, Strandhagen and Chan (2018) affirmed that ideas related to Industry 4.0 and lean practices reveal different gaps that guided this paper. The authors highlighted the paradox between continuous improvement, which considers the employee possibilities to get involved in projects for continuous improvement and optimised processes, leading to a decrease in low-skilled work and an increase in high-skilled activities, and making the human aspect the biggest challenge to achieving excellence in this new industrial age (Ebrahimi, Baboli, & Rother, 2019; Tiep et al., 2020).

However, continuous improvement processes are in an incipient state concerning the implementation of Industry 4.0 practices, requiring advanced studies that relate them to WCM (Fettermann et al., 2018). Besides, the inexistence of an effective information system and its documentation management leads to not using knowledge acquired in previous continuous improvement initiatives, which might result in reworks in finding root causes (Peças et al., 2021).

It is necessary to consider behavioural and technological aspects and skills that include greater flexibility, human and material resources to increase productivity (Luthra & Mangla, 2018), all playing a vital role in this phase in the manufacturing and services.

Thus, this paper aims to contribute with answers to the presented gaps by identifying barriers that impact the processes, operations management, and organisational performance when considering the integration between WCM and Industry 4.0 practices.

2. Research methods

Yin (2017) stated that a case study is an empirical investigation examining a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and the context are defined indistinctly.

In this perspective, this study evaluated multiple cases transversally. All corporations were large, with more than 1000 employees. The sample included 15 companies with different expertise from five countries and three different continents: South Africa, Argentina, Brazil, and the United States in the Americas, and France in Europe.

The study proposal was based on the literature review, which indicated gaps that gave rise to the research question. In addition, the literature review also provided the necessary subterfuges to design the survey. The research flowchart is shown in Fig. 1.

The collection of information from the companies took place through a semi-structured questionnaire, shown in the appendix. The questionnaires were sent, by email, to employees directly linked to the production process. This guaranteed the confidentiality of the source and the protection of the answers from the

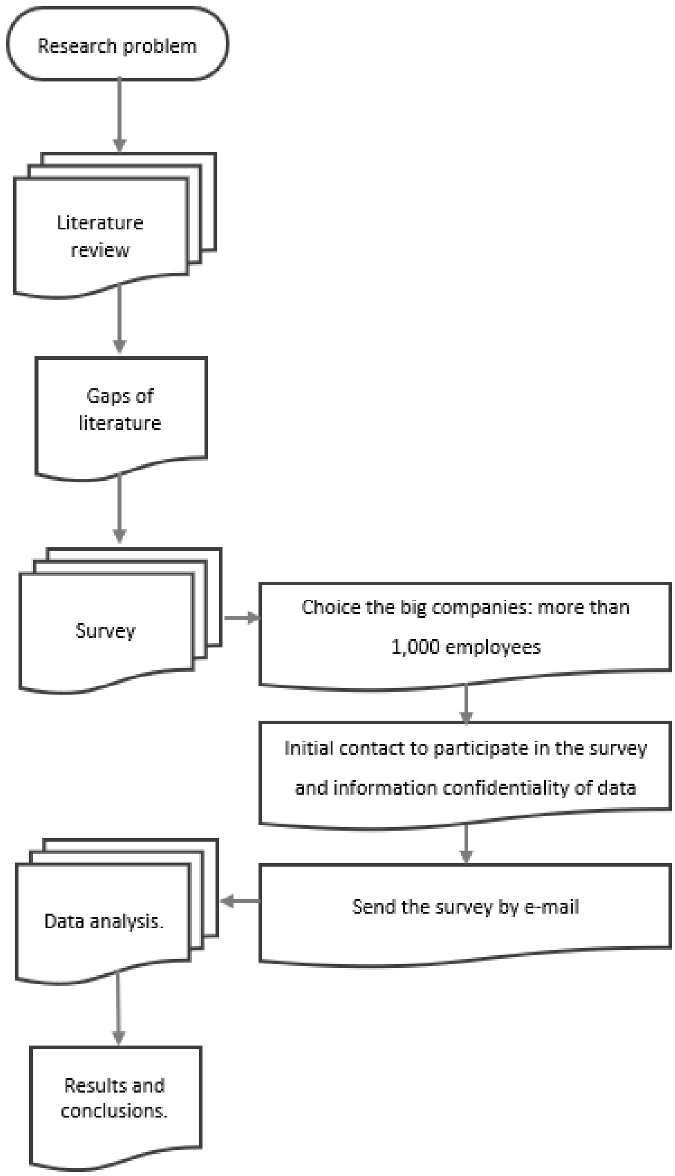

Fig. 1. Flowchart developed for the research

Tab. 1. Relationship between the expertise of the researched company and the country

	Argentina	Brazil	France	South Africa	United States
Automotive		1			
Chemistry		1			2
Consumer goods		1			
Electric materials	1		1		
Food		1		1	
Industrial components					1
Industrial equipment		2			
Metal mechanics			1		
Pharmaceutical		1			
Services		1			

influence of the researchers. The questionnaire assessed the relationship between process improvement, used tools, adopted strategies, and human resources for each organisation. Table 1 presents a summary of the answers.

The relationship between the country and the expertise of the companies shows the transversal nature of the study. This made it possible to analyse, more robustly, the connections between WCM, Industry 4.0 practices and the adopted strategic guidelines. It also allows carrying out analyses that consider not the expertise of the companies but the application of the WCM method and Industry 4.0 practices by these companies, as per the objective of the study.

3. Discussion of the results

The results show the relationship between continuous improvement processes from the viewpoint of applying the WCM method with integrated Industry 4.0 practices. Fig. 2 presents the summary of this sampling.

All respondent companies stated that they knew the concepts and tools applied in Industry 4.0 practices. This fact is evident from the current popularity of the topic and the position of companies aiming to modernise.

These practices are not yet rooted in companies; three of them (20 %) did not adopt the practices of Industry 4.0, and four (27 %) did not employ these practices in the development of the strategic plan.

Many Industry 4.0 practices are innovative and drive different knowledge. The massive use of data, the integration between different production systems, and real-time analysis stand out. This knowledge causes significant changes in production systems and business models, adding disruptive technologies and methods. They usually cross the barrier of established standards and models.

Companies face several difficulties in striving for these goals. Examples are the reconfiguration of manufacturing systems and business processes. Malavasi and Schenetti (2017) highlighted the drastic and radical changes that Industry 4.0 could generate in production systems.

The WCM method used for continuous process improvement also finds it difficult to disseminate its practices. Of 15 companies, two responded not knowing the method (13 %), and three did not apply the method in their processes (20 %).

Of the companies that apply the WCM method (12), only 10 involve employees in training, i.e., 17 % do not have qualification measures for human resources. Training emphasises the importance of professional development and investment in human resources. These measures increase the ability to apply tools aimed at Industry 4.0 practices and continuous improvement.

Regarding the strategic plan and From among the companies that knew the WCM method, only nine (69 %) adopted the WCM method in their strategic plan. These companies seek to foster and disseminate the continuous improvement culture through different operations.

3.1. Continuous improvement

The association of methods for continuous improvement and technologies faces various difficulties. For 93 % of the evaluated companies, the use of technologies depends on organised and effective

Fig. 2. Knowledge and application of the WCM method and Industry 4.0 practices

operational management and requires the availability of qualified human and technological resources, which are not always present in companies or available in the market.

The development of methods and the use of appropriate tools for the manufacturing systems assist in the use of long-term continuous improvement practices, facilitating application and collaborating in the understanding of internal processes. Fig. 3 shows this perspective.

Six Sigma is the most used tool by companies in the continuous improvement process, followed by Plan, Do, Check and Action (PDCA), Value Stream Mapping (VSM) and Kanban and 5S.

All companies highlighted associating one or more tools to problem-solving, depending on the application. They also asserted that the unfolding of improvement practices, associated with the continued use of these tools, favoured the breaking of operational barriers, making it more flexible and facilitating the insertion of continuous improvement in the organisational culture.

The improvement process includes product modification and refinement activities associated with existing services, equipment, process technologies and operating practices. Such actions involve the use of tools to eliminate variation in processes and increase the stability of operations (Furlan & Vinelli, 2018), the fundamentals of WCM.

For 47 % of the companies, a barrier to these applications was the employee resistance to the imposed changes. Companies that achieved the most success with continuous improvement programmes extensively use practices related to human resources, such as training employees to perform multiple tasks, partnering with suppliers and engaging the customer, together with technical and analytical tools.

The companies' expertise and the type of market in which they operate influence how improvement processes are implemented. For the production chain to be included in a constant evolution cycle, combinations between different types of resources, technical or human, are essential.

Most companies (60 %) considered that the implementation of the WCM method in factories with high variability and production on demand did not jeopardise the integrated management of operations. For the other 40 %, this statement was not true since companies supplying products manufactured on demand found it difficult to maintain the balance between a non-repetitive process and increased operational efficiency. The non-repeatability of processes

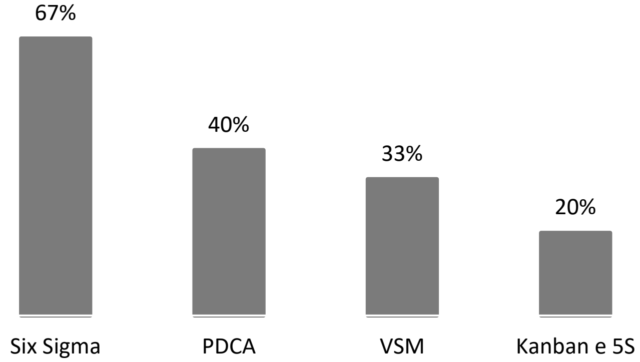

Fig. 3. Tools mostly used by the companies in the continuous improvement process

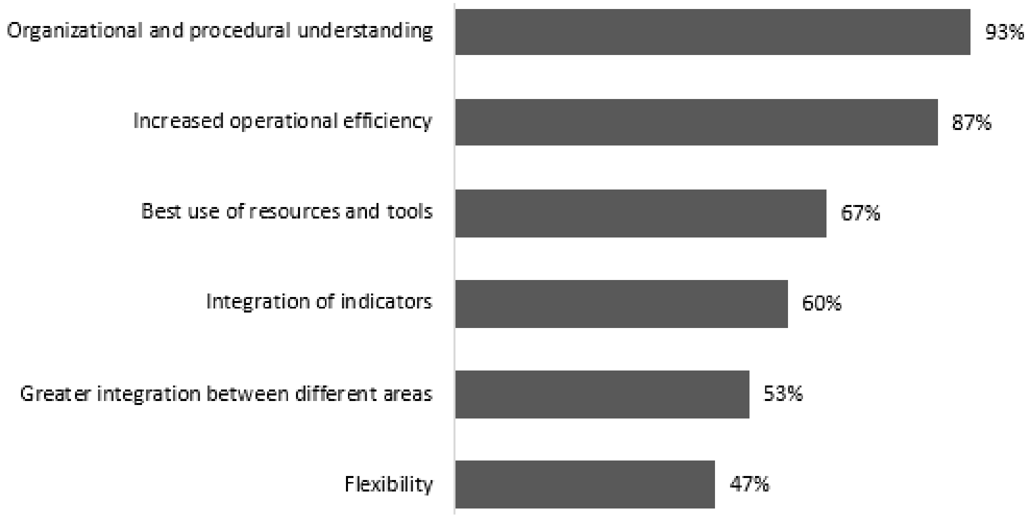

Fig. 4. Practices used by companies to reduce digital barriers

becomes a barrier to the standardisation of procedures.

Digital production systems tend to start breaking down these barriers and facilitate the adaptability of used Industry 4.0 practices in processes, as shown in Fig. 4.

For these companies, improvements occur through organisational and procedural understanding and increased operational efficiencies, such as the redistribution of skills and the involvement of people, facilitating innovation processes (Mróz, 2018), continuous assessment of activities (Sangwa & Sangwan, 2018), the use of associated technologies and the ability to assimilate new knowledge quickly (Sartal & Vázquez, 2017), and the adoption of new tools for data analysis (Dubey et al., 2016).

Also, better use of resources and tools, i.e., six sigma, standardised work and 5S, stand out by their use and implementation (Satolo et al., 2018). The connection between products, people, processes, tools and technologies as a single system (Synnes & Welo, 2016) highlights the importance to invest in knowledge and learning. Integration is another important aspect, touching upon the integration of indicators, i.e., the integration of process indicators with human resources, finance, administration, supplier and customer management (Sangwa & Sangwan, 2018), and the integration between different areas for development, with more efficient processes, resulting in reduced manufacturing lead times and better product quality (Dalenogare et al., 2018; Kamble, Gunasekaran, & Gawankar, 2018). This also results in facilitated communication of lean production in a digital network, the facilitated emergence of a unified and common communication interface (Kolberg, Knobloch, & Zühlke, 2017), and flexibility with the possibility to adapt new features in the work environment and the ability to interact with modern interfaces (Kazancoglu & Ozkan-ozen, 2018). The ability to adapt behavioural and technological skills (Buer, Strandhagen, & Chan, 2018; Luthra & Mangla, 2018; Kolberg, Knobloch, & Zühlke, 2017) allows an integrated evolution of companies (Villalba-diez et al., 2018; Mrugalska & Wyrwicka, 2017). As a consequence, the maturity degree of companies to use Industry 4.0 practices increases, generating a cycle of self-development and greater capacity to respond to unforeseen events, according to different circumstances.

3.2. Strategy

Paranitharan et al. (2017) claim that to compete in the current market, companies need to redesign their strategies, which allows not only the best allocation of resources but also dynamic gains over time. Besides, to compete globally, it is necessary to invest in changing strategic paradigms for manufacturing and in the manufacturers' mentality.

Companies need to adopt a mix of concepts and principles as a strategy with a focus on best manufacturing practices, reducing delivery times, developing suppliers and improving productivity. Table 2 presents a summary of the main technologies used by the companies to increase competitiveness.

According to Table 2, the use of technologies in their processes helps to increase productivity for 73 %

Tab. 2. Main technologies used by the companies to increase competitivity

	Additive manufacturing	Big data	Shop floor management	Internet of Things — IoT
Technologies that increase productivity and are oriented to the strategy	27 %	53 %	67 %	73 %
Technologies that allow the association between WCM and a strategic model for creating and adding value	20 %	67 %	73 %	60 %

of companies. This is due to the constant transformation of companies, adding value to their products, leveraging the application and use of a set of tools, methods and procedures. Shop floor management was cited by 67 % of companies and the use of big data by 53 %, but only 27 % had perspectives about different technologies used in their flow production. This suggests that the use of technologies is more frequent. However, the full automation of processes and the use of more advanced technologies still face barriers as they require the most capable and trained human resources, e. g., in the application of additive manufacturing.

Table 2 shows that the use of complementary technologies assists in the development of continuous improvement procedures. From the perspective of the association between WCM and a strategic model for creating and adding value, the shop floor management percentage changed from 67 % to 73 %, and big data — from 53% to 67%, allowing companies to make the transition to a strategic model for creating and adding value associated with continuous improvement processes.

Integration facilitates strategic adaptations. On the one hand, companies seek to achieve excellent levels of efficiency and productivity using existing methods, while on the other hand, they also try to associate new technologies in their processes. WCM allows the use of a wider range of tools and procedures capable of increasing and improving productivity. This relates the method to the strategic guidelines, causing a greater impact on companies.

Creating value for the customer is one of the results brought by WCM. It is in adding value to products that bottlenecks are identified, mitigating errors. When associated with Industry 4.0 practices, these activities allow for continuous monitoring and careful study of information, ensuring process control.

Data collection was cited by 80 % of companies as the main vector that helps the WCM method. This vector leads to constant improvement actions that prioritise competitiveness, training in Industry 4.0 practices and integration between areas. For 47 % of the companies, these actions occur due to the management directed towards different technologies. All companies stated that the technology strategy and skills drove sustainable processes, assisting in operations management. Oliveira et al. (2016) claimed that companies wanting to build long-term competitive advantages seek to develop WCM practices and, at the same time, remain flexible to stay up to date. Thus, technological integration with the sustainability of processes stands out.

For 87 % of companies, the differentiation strategy enabled competitiveness through the digital integration of manufacturing, and 93 % affirmed that the WCM method was capable of determining competitive strategies in different markets worldwide, establishing long-term competitive advantages. This way, companies aim for competitive advantages in their processes, allowing for higher quality products and services and recognition by competitors.

To carry out these actions successfully, companies must maintain their strategies in line with the improvement of processes, technologies and the organisational structure, directing efforts towards critical resources. This work makes it possible to monitor the actions adjacent to the procedures, with the ability to prepare the organisation for sudden changes.

Thinking long-term, the WCM method stands out by valued pursuit of goals in contradiction to short-term financial goals. These results have positive consequences on the processes since they are consolidated in the organisational culture. Consequently, they are used as a basis for the strategic plan to be adopted by companies.

3.3. Human resources

Practices based on human resources, such as training, employee involvement and empowerment, teamwork, qualified and multifunctional workforce (Sangwa & Sangwan, 2018), are considered a strategic differentiator for companies. All companies consider that the development of human and organisational skills allows them to explore new and different opportunities for innovation and technological enhancement with an impact on strategic management.

For this production chain to work efficiently, it is necessary to continuously develop human resources and compensate for the improvements suggested and implemented. These actions are often overlooked by senior management.

For 93 % of companies, the availability of intellectual capital was increasingly necessary for the development of processes, often created quickly and adapted, producing transformative results. The development of human resource skills with technology was cited by 80 % of companies. Managers need to consider behavioural and technological aspects and skills that include greater flexibility and productivity (Luthra & Mangla, 2018). The short- and long-term strategic impact of Industry 4.0 practices in manufacturing, services, and global markets is immense, difficult to understand and to meet all customer needs efficiently (Sony, 2018).

However, only 67 % of companies consider it important that intellectual capital is associated with process development. Therefore, the transition from traditional industry, with little or no introduction of technologies in its processes, to the Industry 4.0 model requires a complete overhaul of operations, from top management to manufacturing.

WCM is concerned with the integration of strategy and best practices, and human resources. The increase in productivity seeks to maintain and improve human resources before thinking about new equipment and automation. Ghobakhloo (2018) affirms that this model is an integrative value creation system, bringing customers and suppliers closer together. The strategic roadmap points to an increasingly integrated management between human resources, the use of technology and intelligent manufacturing.

The coexistence between technologies and workers becomes a constant learning process since this new industrial paradigm leads to significant benefits in the production processes. Thus, a new model emerges between human resources and Industry 4.0 practices, reorganising the way of working.

Conclusions

With the constant transformation of companies, the application and use of a considerable set of tools, methods, and procedures that lead to increased productivity, continuous improvement in processes, and reduced operating costs have been leveraged. These factors are preponderant for adding value to products, placing companies on a different level compared to the global market.

The WCM method does not excessively demand labour; instead, it changes the way processes are executed, making them simpler and more efficient.

As a result, it seeks to foster and disseminate the culture of continuous improvement through different developed operations focusing on strategic visions of companies. Industry 4.0 practices allow achieving operational excellence, resulting in a structured development capable of leveraging the production systems. Processes tend to be more efficient, resulting in reduced manufacturing times, a better quality of products and services and gradual growth in organisational performance.

This paradigm shift has forced the search for more efficient production means, with greater agility in reaching different customers in a global market. Along with these transformations, the constant evolution of the productive means and how the quality tools work directs companies towards methods that are increasingly engaged in the search for greater efficiency and productivity.

Meanwhile, there are barriers that Industry 4.0 practices do not show. The lack of knowledge in internal processes, the use of correct technologies and trained human resources are the biggest bottlenecks. The consequences are even worse when the processes are designed to analyse the levels of maturity in operations management and to monitor and report information in real time.

For these actions to materialise in a sustainable way, it is necessary to make the processes more flexible. Thus, it is possible to reduce production times and add exclusive services.

Actions aimed at continuous improvement and more frequent use of Industry 4.0 practices become strategic drivers. These actions allow offering products and services with more quality and that reach different and exclusive markets, aiming at project-oriented companies. However, companies face a set of difficulties to implement these changes. Table 3 presents the main barriers to implementing WCM with Industry 4.0 practices.

The barriers that hinder the increasing progress of these procedures are robust, given the desired progress. Among them are the costs associated with the use of technologies, the lack of knowledge of the

Tab. 3. Main technologies used by the companies to increase competitivity

	Continuous improvement	Strategy	Human resources
Barriers	Cost to implement new technologies.	The adaptability of WCM to Industry 4.0 practices for on-demand projects.	Intellectual capital and training.
	Add methods and tools for continuous improvement with Industry 4.0 technologies.	Introduction of long-term quality policies and digital manufacturing integration.	Resistance to use and apply new technologies.
	Development of interactive processes with associated technological potential, the integration of different processes and the use of quality tools.	Change in organisational culture through the adoption and implementation of a consistent project of investment in human and material resources.	Adhering to a dynamic management model, where changes occur quickly, from top management to the shop floor.
	Application of methods and tools that allow massive data analysis.	The use of Industry 4.0 practices to identify new strategic trends in product development.	Top management knowledge about the difficulties encountered by the use and application of new technologies by workers.
	Continuous technological innovation and development.		

methods and tools applied, the lack of trained and qualified human resources, and the resistance of people to the use and application of these new tools.

WCM practices can influence the way products are manufactured and services offered. However, there is not enough data to prove that customer perception of the value of products and services is associated with the use of technologies used in the production system.

These barriers apply to WCM and Industry 4.0 practices. In many cases, these factors are neglected by top management, which concurs with Jabbour et al. (2018). They claim that for this to happen coherently, top management has the responsibility to provide organisational opportunities to integrate technology into a manufacturing system.

Another difficulty is the way they are applied. While WCM values slow processes, the Industry 4.0 practices value more dynamic results. Hence the great difficulty: pairing the two vectors, seeking greater productivity and efficiency.

Satolo et al. (2018) stated that lean tools, such as kaizen and 5S, stand out for their simple use and easy implementation. Fettermann et al. (2018) emphasised that companies had to provide the basic tools to assist in the implementation of technologies and overcome technological barriers. The beginning of the paradigm shift requires the use of simple tools that are easy to use by workers. As processes evolve, more complex tools must be inserted into the process. The objective of this gradual process is to implement the culture of continuous improvement and the reduction of costs and waste, converging on simple and practical solutions.

The difficulties encountered with the management of the operation and the standardisation of the production means, especially with products made on-demand, is also a significant obstacle. The ability of manufacturing to run flexibly can become a strategic agent in meeting the diverse needs of an increasingly complex customer base. Although most companies find that Industry 4.0 practices facilitate process adaptability, few link these improvements to cost and waste reduction projects with a broader strategic vision.

There are many difficulties in adapting technologies to existing processes. Although companies consider the process of adding value to the use of technologies, a significant portion of companies does not adopt Industry 4.0 practices and the WCM method in their strategic policies.

The constant monitoring of data, the use of big data and the comparison with other players in the market allow drawing a parallel between different companies and the outline of strategic guidelines.

The sustainable use of resources, including humans, allows the application of technologies in improvement projects through the reorganisation of working methods and the use of correct techniques and tools.

In practical terms, direct efforts towards the continuous monitoring of processes and use of data to generate improvement projects, cross-training of human resources and technological applications, focused on the practices of Industry 4.0, according to the established strategic plan.

For this process to occur, the first step is that the top management must start to focus on very clear objectives and also have a correct understanding of necessary investments. The second step consists of creating an organisational culture focused on innovation and continuous development for all areas of the organisation, from lean office to lean manufacturing, along with the application of methods and tools that allow massive data and information analysis capable of generating continuous improvement projects associated with operations management. In the third step, the organisation must also be able to understand the deviations that may occur during this transition phase. For this to happen in a less impactful way in the management of operations, the changes should not be abrupt. For each evolution and result achieved, a phase of adaptation to the new concept is necessary, like a PDCA cycle.

Considering the obstacles pointed out to the application of the WCM method associated with the practices of Industry 4.0, future research may direct its efforts in a conceptual framework capable of showing how these associations will occur efficiently, overcoming the existing barriers.

The limitations of this paper include the set of studied companies. Future researchers may include companies of different sizes, analysed by their expertise, generating a more specific set of information and greater diversity of countries involving different cultures.

Acknowledgements

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES, Brazil.

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Appendix – Survey

Block 1 – Interviewee characterisation

Name:____
Phone (country code + phone number):______________________________
E-mail:____
Current position on the company:_________________________________
Time on the company:

[ ] Until 2 years
[ ] More than 2 up to 5 years
[ ] More than 5 up to 10 years
[ ] More than 10 years

Your company:

Know the WCM method?	[ ] Yes [ ] No
Apply the WCM method?	[ ] Yes [ ] No
Know the concept and tools of Industry 4.0?	[ ] Yes [ ] No
Apply the Industry 4.0 concept and tools?	[ ] Yes [ ] No

Block 2 – Company characterisation

Name of the company:_____________________________________
Country of the company:___________________________________

Regarding the number of employees, the company or group to which the company belongs has:

[ ] Up to 100 employees
[ ] More than 100 up to 500 employees
[ ] More than 500 up to 1000 employees
[ ] More than 1000 employees

Area of expertise:_______________________________________

About the implementation of WCM and Industry 4.0 methods in your company:

Do employees receive training on the WCM method?

[ ] Yes
[ ] No
[ ] I am not sure about that

Is the company's strategic plan related to the WCM method?

[ ] Yes
[ ] No
[ ] I am not sure about that

Is the company's strategic plan related to the Industry 4.0 concept?

[ ] Yes
[ ] No
[ ] I am not sure about that

Block 3 – Characterisation of applied methods

1. The relationship between the WCM method and Industry 4.0.

The development of human and organisational skills allows us to explore new opportunities for innovation and technology enhancement, impacting strategic management.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Through the use of technologies in manufacturing processes, the WCM method is able to establish strategies for competitiveness in different markets, establishing long-term competitive advantages.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Important for the deployment of Industry 4.0 (up to 3):

[ ] Organisational and procedural understanding.
[ ] Flexibility.
[ ] Integration of indicators.
[ ] Complex problem-solving management models.
[ ] Parallel processes.
[ ] Employee resilience to change.
[ ] None.

The availability of intellectual capital is needed to develop processes, often quickly and iteratively created and to produce adaptive results.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Which knowledge, among different manufacturing methods, allows to identify strategic trends in the development of quality products (up to 3)?

[ ] Value Stream Mapping – VSM.
[ ] Kanban e 5S.
[ ] Plan, Do, Check, Action – PDCA.
[ ] Six Sigma.
[ ] Total Productive Maintenance – TPM.
[ ] World Class Manufacturing – WCM.
[ ] None.

Which technologies increase productivity and are oriented to the strategy adopted in your company (up to 3)?

[ ] Big data.
[ ] Internet of Things – IoT.
[ ] Additive manufacturing.
[ ] Factory floor monitoring.
[ ] None.

The use of technologies depends on organised and effective operations management and requires the availability of qualified human and technological resources.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Access by all employees to quality programmes helps to add more value, facilitating problem-solving.

[ ] Yes [ ] No

WCM enables companies to transition to a strategic model of value creation and aggregation with the help of the following technologies (up to 3):

[ ] Big data.
[ ] Internet of Things – IoT.
[ ] Additive manufacturing.
[ ] Factory floor monitoring.
[ ] None.

The company uses as a differentiation strategy in value-adding: technology development, Industry 4.0 deployment and digital integration in manufacturing:

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

In your company, which vectors help the WCM method with strategic policies, which focus on competitiveness and training with Industry 4.0, through management models directed to different technologies (up to 3)?

[ ] Total quality management and continuous data collection.
[ ] Integration of resources and areas.
[ ] Reengineering.
[ ] Process automation (Robotic Process Automation - RPA).
[ ] Process virtualisation.
[ ] None.

2. Strategic definitions of corporate operations management using the WCM method and Industry 4.0.

Developing long-term quality practices and the flexibility to serve customers helps break down operational barriers.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

The difficulty in deploying the WCM method in factories with high variability and on-demand production puts at risk the integrated operations management with Industry 4.0.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

In your company, how mature is operations management in relation to the implementation of Industry 4.0?

[ ] Very good: all processes are virtually interconnected and monitored.
[ ] Good: Processes are interconnected and monitored virtually, with occasional problems.
[ ] Fair: Processes are interconnected but not monitored virtually.
[ ] Bad: Few processes are interconnected and not monitored virtually.
[ ] Too bad: processes are not interconnected.

Technology strategy and competencies drive sustainable processes and assist in operations management.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Volume 13 • Issue 4 • 2021

Companies that use the WCM method are focused on value addition.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

3. The WCM method and Industry 4.0 influence changes in organisational and productive concepts.

Digital production systems facilitate process adaptability based on the value stream model for Industry 4.0.

[ ] Strongly Agree [ ] Agree [ ] Indifferent [ ] Disagree [ ] Strongly disagree

Which methods of Industry 4.0 driven by employee involvement encourage process efficiency, resulting in increased and improved productivity (up to 3)?

[ ] Best use of resources and tools.
[ ] Increased operational efficiency.
[ ] Greater integration between different areas.
[ ] More employee safety.
[ ] Waste reduction.
[ ] None.

The strategic objectives for manufacturing are directed to (up to 3):

[ ] Technology development.
[ ] Technology integration.
[ ] WCM.
[ ] None.

Block 4 – Final considerations

Does the company wish to receive the survey results at the end of the study?

[ ] Yes [ ] No

Does the company allow its name to be included in future publications, the result of this study?

Volume 13 • Issue 4 • 2021

Engineering Management in Production and Services

received: 30 June 2021
accepted: 30 November 2021

pages: 131-147

Barriers related to the implementation of intelligent transport systems in cities - the Polish local government's perspective

Ewelina Julita Tomaszewska

ABSTRACT
Intelligent transport systems (ITS) are undoubtedly an opportunity for the sustainable development of smart cities today. ITS is based on advanced transport technologies that help minimise the emission of harmful substances to the environment. Smart mobility and ITS are related to the use of ICT. The implementation of technologically advanced ITS is associated with several benefits, barriers and difficulties. However, transport, ITS and smart mobility (as a component of a smart city) are indicated as the most desirable option for sustainable urban transport systems. The article aims to identify barriers related to the implementation of ITS in cities from the point of view of people responsible for the organisation of urban transport representing the local government of selected voivodship cities in Poland. The goal formulated in this way allowed to identify the following research question: what are the problems and barriers of implementing ITS in the city from the local government's perspective? To achieve the paper's aim, the author based their analysis on a qualitative technique of collecting empirical data. Ten individual in-depth interviews were conducted with representatives of local governments (vice-mayors and members of urban transport organisers) in voivodship cities, which represented six Polish macro-regions. Research results and findings indicate the main categories and subcategories of barriers related to the ITS implementation. The identified barriers are grouped into the following categories: economic, social, organisational, technological and legal. The contribution is twofold: first, in the presentation of the theoretical and practical barriers to ITS in juxtaposition; and second, in identifying the intelligent transportation impact, which affects the provision of being a smarter city. The findings can positively influence as important factors for local governments to focus on intelligent transport.

KEY WORDS
intelligent transport systems (ITS), smart city, smart mobility

10.2478/emj-2021-0036

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Introduction

Currently, urbanisation is one of the most important social processes from the perspective of urban development. According to UN statistics, by 2050, about 70 % of the global population (i.e., 7 billion people) will live in cities, which means that by 2050, urban areas will accommodate another 2.5 billion people (United Nations, 2018). This implies an inevitable expansion and densification of urban space. However, it can already be seen that the way cities and

Tomaszewska, E. (2021). Barriers related to the implementation of Intelligent Transport Systems in cities – polish local governments perspective. *Engineering Management in Production and Services, 13*(4), 131-147. doi: 10.2478/emj-2021-0036

their spaces are designed should be thoroughly considered (SWECO, 2021). Otherwise, in the near future, few of us will want to live in a city where the problems associated with its excessive growth will make everyday life much more difficult, e.g., by reducing the capacity of urban roads, transport congestion, etc. Cities face environmental, economic, social and spatial problems. With increasing globalisation, urbanisation processes and growing economic development, there is a growing demand for high-quality urban transport services (Rodrigue et al., 2016). The popular concept of a smart city as a progressive city of the future assumes sustainable urban development based on innovative technologies, the application of which is to support the residents and provide them with comfortable, economical and safe lives (Kos, 2019; Komninos et al., 2011). Therefore, in recent years there have been records of increased interest on the part of local authorities in the search for sustainable, innovative and intelligent technological solutions to optimise the urban transport system.

Improving mobility and transportation, ensuring accessibility and decreasing traffic congestion are significant elements of smart cities and some of the greatest challenges facing them today (Iqbal et al., 2018; Pawłowska, 2018; Kachniewska, 2020). The organisation of transport as a basis for the daily functioning of society and the economy in cities is an issue widely reported in the literature. However, reliance on motorised transport as an everyday function contributes significantly to global climate change (Chapman, 2007). Some of the most common local government proposals for reducing carbon emissions include encouraging innovation and deployment of low-carbon technologies; encouraging modal shift from the private car to less polluting options, i.e., walking, cycling, and public transportation; promoting more efficient forms of traffic management and driving styles; and executing strategies that aim to reduce the need to travel totally (e.g., land use planning) (Grant-Muller & Usher, 2014). Therefore, a special role is assigned today to modern, intelligent technological solutions to facilitate urban transport management, including intelligent transport systems (ITS). ITS demonstrate a new approach and application of advanced management and technical-technological solutions, and ICT has renovated the urban transportation perceptions (Mandžuka, 2020; Mathew, 2020). The availability of services offered by intelligent transport systems is the key to developing the smart city concept (Lewicki et al., 2019). Technological advances and the global connectivity provided by the Internet today are causing transportation systems to undergo a profound transformation that is significantly changing the way people and products move through cities. Existing and emerging transportation challenges are prompting a search for ways to adapt modern technologies to the needs of users. This is facilitated by a range of computational tools for compiling and analysing real-time data that help to predict and optimise the performance of urban transport services in the next step. As a result, it is possible to improve mobility for all users of urban services, increase the economic efficiency of the city and reduce pollution levels. It is therefore expected that in the future, smarter, more autonomous and safer vehicles that communicate with other vehicles and urban buildings, road signs and other infrastructure will become the standard (Jimenez, 2018).

In recent years, increased interest in ITS and the benefits associated with their implementation have been apparent in local governments and academic circles. An increasing number of researchers are addressing the existing and anticipated implications of the ICT revolution for transport (Banister & Stead, 2004; Giannopoulos, 2004; Cohen et al., 2002). Increasing globalisation and technological development also increase the number of scientific studies on intelligent transport systems, their applications, benefits, as well as the factors determining their development. The number of scientific publications published between 2001 and 2020, containing the phrase "intelligent transport systems" or "intelligent transport" in their topic (title, abstract and keywords) amounted to 6 065 papers available in the Web of Science database and 1 3671 in the Scopus database. Over the last 20 years, the interest in this topic has multiplied and almost annually shows an upward trend (Fig. 1). This is undoubtedly related to the observed dynamic development of technology and telematics in transport and the desire of local governments to "be a smart city". On the other hand, it is influenced by the enormous increase in the number of people living in cities and the progressive urbanisation.

The paper aims to identify barriers related to the implementation of intelligent transport systems in cities from the point of view of people responsible for the organisation of urban transport representing the local government of selected voivodship cities in Poland. To reach the goal, the article uses qualitative research, namely, individual in-depth interviews (IDI) with representatives of local authorities.

The theoretical part of the paper presents the smart city concept with a particular focus on intelli-

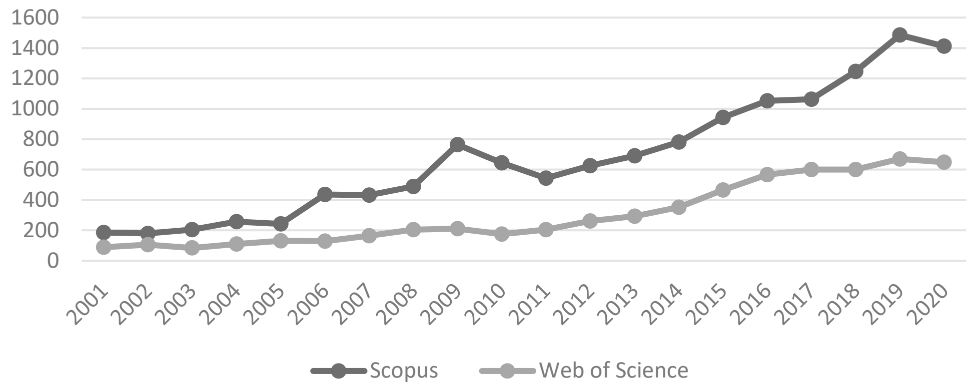

Fig. 1. Number of publications in the field of "Intelligent transport systems" published in 2001–2020, available in the Web of Science and Scopus databases.

gent mobility and intelligent transport systems (ITS). Based on the literature review, the author enumerates the barriers associated with ITS deployment in the city, as earlier identified in the works of previous researchers. The next part of the paper presents the results of the qualitative research and proposes main categories of barriers related to ITS, and then indicates new contributions to the existing literature on the subject.

1. Literature review

1.1. Smart city concept

In search of the ideal city, the answer could be a metropolis that retains the benefits of urbanisation at the same time eliminating its negative effects, which is the complex and multidimensional concept of a smart city (Kos, 2018). It is one of the most promising ideas for the future development of cities, and at the same time, a response to the increasing urbanisation processes. The intelligence of such a city manifests itself in the sum of various improvements in urban infrastructure, resources and public services (Allwinkle & Cruickshank, 2011).

Smart city issues are widely described in the literature (Bashynska & Dyskina, 2018; Bibri & Krogstie, 2017; Albino et al., 2015; Wang & Wu, 2015; Allwinkle & Cruickshank, 2011; Komninos, 2009; Szpilko, 2020; Hajduk, 2021). Researchers have shown that many cities are being developed under the smart city banner (Cugurullo, 2020). The academic definitions of a smart city are varied because the label "smart city" is a fuzzy concept and is used in ways that are not always consistent (Nam & Pardo, 2011). Gil-Garcia et al. (2015) indicate the need to develop an integrated and holistic approach to a smart city. The majority of publications related to the concept of a "smart city" is focused on the technological aspect, but in fact, cities can hardly become smart because of technology alone (Nam & Pardo, 2014). As Neirotti et al. (2014) emphasised, a smart city represents a kind of "ecosystem that is largely developed through the effective use of technology to improve the quality of life of citizens through efficient integrated systems and services". In turn, Guo et al. (2017) defined a smart city as an urban development based on the integration of many information and communication technology (ICT) solutions to manage the city's resources. Similarly, Peng et al. (2017) stressed that a smart city uses a set of advanced technologies, such as wireless sensors, smart meters, intelligent vehicles, smartphones, mobile networks or data storage technologies. According to the literature review, smart city phenomenal is related to the use of ICT, sustainable urban environment, advanced infrastructure, encouraged community participation, well-being and satisfaction of citizens, optimum utilisation of resources, well-performing governance, innovations, information management, and sustainable economic growth (Samarakkody et al., 2019). In this context, a smart city should be seen as a city that is better, more sustainable, improves the quality of life for its citizens to better meet their housing, transport, energy and other infrastructure needs, creates a more welcoming environment, and has stronger economic development prospects as a key strategy to combat poverty and inequality, unemployment and energy management (Barrionuevo et al., 2012; Lazaroiu

& Roscia, 2012; Lee et al., 2014; Yigitcanlar, 2018; Winkowska et al., 2019; Mundada & Mukkamala, 2020; Szpilko et al., 2020a; 2020b). The smart city is most often defined by models with specific dimensions of smart cities (so-called "smart factors"). The most widespread is the one established by Griffinger et al. (2007), characterising a smart city with six dimensions: smart economy, smart governance, smart environment, smart mobility, smart living, and smart people with their activity of self-decisive, independent and aware residents. Still, Lim et al. (2018) provided twelve application areas related to smart cities, i.e., smart home, smart health, smart transportation, smart energy, smart building, smart logistics, smart farming, smart security, smart hospitality, smart education, smart device, and smart environment. According to various research approaches, among the basic dimensions of the smart cities' model, there is always "transportation" (or "mobility" and "transport infrastructure"). It is recognised that economic growth is increasingly linked to transport development. Mobility can be viewed as a reliable indicator of urban development since limited mobility hinders development, while increased mobility is its catalyst (Rodrigue, 2016).

The growing population in cities and the increasing complexity of their mobility (Kiryluk et al., 2021) needs have necessitated the evolution of transportation systems. The efficiency of the urban transport sector can be improved by the development of information and communication technologies (ICT) observed in recent years (Machin et al., 2018). One dimension of a smart city is smart mobility, which usually refers to ICT-based sustainable mobility (Mangiaracina et al., 2017; Papa et al., 2017; Caragliu et al., 2011; Kitchin, 2014; Szymańska et al., 2021). According to literature, a basic principle for achieving sustainable mobility is reducing the inconvenience inherent in urban transportation and transferring using various means of transport (Hernandez & Monzon, 2016). Urban mobility is one of the global smart city projects. Wang & Wu (2015) highlighted that it offers real-time traffic management, passenger transportation asset management, tracking applications and logistics, car-sharing services, parking management, and smarter mobility services (Yue et al., 2017). The task of smart (intelligent) mobility is, therefore, to use advanced technologies to make rational use of the transport infrastructure while optimising traffic flow. ICT can support greater automation in the transport system, and using intelligent speed adaptation, they can also represent a further step towards environmental protection by reducing carbon dioxide emissions (Grant-Muller & Usher, 2014). According to Albino et al. (2015), efficient public transport is considered key for city growth. Thus, many of the new approaches related to urban services (for instance, urban transport) have been based on harnessing technologies, helping to create intelligence of a city. In this context, smart mobility is perceived by the accessibility of information and communication infrastructure through the development of sustainable, innovative and safe transport (Winkowska et al., 2019).

1.2. Intelligent transport system in a smart city

In the above context, intelligent transportation greatly impacts the possibility of a city being smarter. According to Reyes-Rubiano et al. (2021), interrelationships between a smart city and transportation are noticeable because some authors consider that the smart city favours smart transport, while others consider that without intelligent transportation, there would not be any smart city. Currently, stable urban mobility and efficient passenger transport cannot be guaranteed without integrating modern technological and organisational solutions in transportation with the management of the urban transport network (Tzvetkova, 2018). ITS is a solution that may address these challenges, offering advanced applications that aim to provide innovative services related to different modes of transport and traffic management. These systems aim to provide better information and a safer, more coordinated and "smarter" use of network transport to different users (Directive 2010/40/EU). These are currently the most effective instruments for improving the efficiency and quality of the city's transportation system, increasing travel safety (Zhang et al., 2011). They allow, among other things, to control traffic, create special zones of limited traffic, which, in connection with the reduction of the number of private cars in city centres, contributes to environmental protection and low carbon dioxide emissions (Strategy…, 2013). In accordance with Directive 2010/40/EU, ITS "integrate telecommunications, electronics and information technologies with transport engineering in order to plan, design, operate, maintain and manage transport systems" (p. 14).

The main components of ITS include transport infrastructure, service and software infrastructure, vehicles, telematics equipment for transport infrastructure elements and vehicles, intelligent sign systems, variable message signs and traffic signals with remote control capability, and centres for collecting and processing information, decision-making and traffic management (Rudskoy et al., 2021).

ITS applications for road safety can be divided into three basic operational areas: data collection, information sharing, and emergency response and enforcement (Shinde & Waghmare, 2019). According to Rudskoy et al. (2021), ITS of the modern city include:

- continuous and fast collection of information about the traffic situation on the roads (via detectors, cameras, etc.);
- a powerful but easy to use tool for storage, processing, validation and analysis of measurement data;
- a state-of-the-art tool for predicting the traffic situation for the nearest 15 minutes and the next day (using real-time, continuously updated detector data);
- use of modern equipment for traffic signal control and creation of a single real-time traffic control centre, as well as providing a quick response to vehicle accidents and other unpredictable traffic situations.

Hence, Chandra et al. (2017) stated that the main objectives of ITS are to evaluate, develop, analyse and integrate new technologies and concepts to achieve traffic efficiency, improve environmental quality, save energy and time and, at the same time, improve the safety and comfort of drivers, pedestrians and other traffic users. According to Rudskoy et al. (2021), the three basic functions of ITS include transport modelling, regulation and monitoring of traffic lights, planning and management of the transport network. They claim that using these means significantly helps ITS in solving the following tasks (Rudskoy et al., 2021):

- optimising the distribution of traffic flows on the network in time and space;
- increasing the capacity of the existing transport network;
- ensuring travel priorities for a particular transport mode;
- managing transport in case of accidents, disasters, or measures affecting transport traffic;
- improving road traffic safety (in effect, increasing traffic capacity);
- reducing the negative impact of urban transport on the environment;
- providing information on the state of the road to all interested users.

In light of the literature, many publications consider benefits related to ITS implementation. Thus, they ensure reduced congestion and a more efficient transport network (Rodrigue, 2016; Molnar & Alexopoulos 2008; Alrawi, 2017; Małecki et al., 2014; Smith et al., 2005), encourage and mobilise passengers to choose an environmentally friendly mode of travel, and use public transport or another green mode of transport, and ensure information exchange and cooperation between people, vehicles and technical infrastructure (Huang et al., 2017). ITS collect, process, and deliver data in a high-quality and efficient way, reduce congestion, thereby reducing wasted time, fuel and energy consumption, and traffic pollution emissions, and ultimately, reducing traffic accidents and increasing safety (Grant-Muller & Usher, 2014; Tomaszewska & Florea, 2018; Neverauskiene et al., 2021; Huang et al., 2017; Barth & Boriboonsomsin, 2009). With technologies such as electric cars and autonomous vehicles, ITS minimise toxic emissions into the environment while improving the car's interaction with the surrounding infrastructure to avoid accidents (Zhao & Jia, 2021). Researchers emphasise the numbers in favour of ITS, which make transport more sustainable (for instance, reduced energy consumption by 45–70 % or of pollutant emissions by 30–50 %) (Barth & Boriboonsomsin, 2009; Njord et al., 2006; Oskarbski et al., 2006; Alrawi, 2017; Crişan et al., 2021). As Barth & Boriboonsomsin (2009) highlight, that most of these improvements are additive (greater benefits can be achieved when multiple environmentally friendly ITS subsystems are implemented).

Definitely, fewer publications focus on barriers and problems with the implementation of ITS. The transformation of cities into smart cities includes, but is not limited to, the development of ITS as the core urban service on which all other services are based (Schlingensiepen et al., 2016). The reliability of the entire system is therefore crucial. The ideal situation is when the entire ITS system works autonomously without human intervention, while employees should only be involved in implementing and monitoring such a system (Levina et al., 2017; Singh et al., 2019). However, there are many factors and barriers that hinder the construction and management of ITS. The most important inconvenience related to ITS deployment is its cost intensity (Shinde & Waghmare, 2019). Typically, local governments struggle with the lack of sufficient funds for this purpose and the problem of ensuring efficient and cost-effective selection and prioritisation of urban projects. A number of co-financing initiatives with regard to such projects fostered by the European Union come in handy (Intelligent Transport Systems, 2019). Problems may also relate to the legal aspects of ITS construction and the lack of a common urban policy as well as inadequate legislation (Kozerska & Konopka, 2018). According to the European Commission, deployed ITS systems in the Member States are not interoperable for a variety of reasons, including inconsistencies in the interpretation of legislation, technological standards (specifications) and their inability to work together (Nowacki et al., 2012). Another problem identified in the literature related to ITS deployment is that they are vulnerable to security threats. The main security problems in operational transportation are related to the fact that ITS operate large data sets with heterogeneous concepts, request platforms and resources (Crişan et al., 2021). In ITS, the most significant issues are security and privacy, and the open nature of ITS as a wireless communication technology leads to many related challenges. These mainly concern confidentiality, authentication, integrity, non-repudiation, location privacy, identity privacy, anonymity, certificate revocation and certificate recognition (Ali et al., 2018). On the other hand, the lack of appropriate road infrastructure or the lack of telecommunications infrastructure necessary for the implementation of ITS (as is the case in developed countries) is a particularly important problem in developing countries (Mfenjou et al., 2018).

While looking at ITS deployment problems, it should be noted that they may occur at different stages of implementation, i.e., the process of system design, implementation, monitoring and supervision. The aspect of the system design itself is extremely important, giving rise to the need to find specialists competent in integrating knowledge from many different fields, e.g., transport modelling and information systems development, GIS, etc. This is a major issue as the integration of knowledge and systems will be a key factor in ITS development (Taie & Elazb, 2016). Due to its direct impact on the safety of road users, ITS can only be considered effective if it has been designed following certain standards and requirements (Nowacki & Kamiński, 2011).

Neverauskiene et al. (2021) identified problems appearing in the ITS area in the current conditions of globalisation. According to the authors, difficulties are faced mainly by ITS providers and countries planning to install ITS. As the researchers emphasised, it is connected with high competitiveness, migrations, insufficient funds for ITS implementation and insufficient cooperation with other countries. On the other hand, Kozerska & Konopka (2018) emphasised that in the case of Polish ITS, the implemented projects are mainly insular, i.e., independent and unconnected. In their analysis, the authors also noted that Polish ITS were not interoperable in the technical (connections between computer systems and services), semantic (guaranteeing the intelligibility of the exchanged information for another application – not originally developed for this purpose), and organisational context (defining business processes and initiating cooperation between administrative units, which may be characterised by different internal structures and procedures).

2. Research methods

The paper aims to identify the main barriers associated with the implementation of ITS in cities from the point of view of people responsible for the organisation of urban transport, representing local governments of selected voivodship cities in Poland. The aim formulated in this way allowed to investigate the following research question: what are the barriers to implementing ITS in the city from the local government's perspective?

The authors selected an individual in-depth interview (IDI) as a research method since the analysed problem requires more profound knowledge of research participants who are difficult to access. IDI assesses a given phenomenon and understands the process of its generation using freely and openly expressed opinions. The IDI scenario as a tool for qualitative research has an unstructured form, which means questions can be adjusted for each respondent according to the course of the interview and the given answers (Bryman & Bell, 2007; McDaniel & Gates, 2010).

IDIs were conducted in the first quarter of 2019 in selected Polish voivodship cities representing individual macro-regions of Poland, i.e., the city of Gdańsk (northern macro-region), the city of Poznań (north-western macro-region), the city of Wrocław (south-western macro-region), the city of Kraków (southern macro-region), the city of Łódź (central macro-region), and the city of Białystok (eastern macro-region) (Fig. 2). The capital city of the country representing the Mazowieckie voivodship macro-region was deliberately excluded from the study, as its size is incomparable to other voivodship cities (due to the incomparably larger urban area and the population). The authors assume that voivodship cities, due to their size and function, are a good analysis example and that each macro-region reflects and represents a situation characteristic for a given area. While intentionally selecting these cities for the study, the authors assumed that the sampling quality would comply with the "suitability" criterion (Flick, 2007). When selecting interviewees, the following criteria were considered: broad knowledge of the analysed subject and several years of experience related to active ITS deployment in a given city. The analysed voivodship cities are examples of good ITS implementations on a national scale (ITS Poland). It is worth emphasising that the Polish ITS projects usually constitute large and complex transportation solutions consisting of many subsystems (Qumak, 2015).

In the research process, two IDIs were planned in each of the six analysed cities. Finally, a total of ten interviews were conducted. The group of interviewees consisted of executives in charge of transport management and organisation and/or ITS management in the city (including two city vice-mayors responsible for sustainable development and urban transport) (Table 1). Each interview lasted between 60 and 90

Fig. 2. The division of Poland into NUTS 1 units

Source: Central Statistical Office.

Tab. 1. Structure of IDI participants

City (macro-region)	IDI number	Number and structure of IDI participants
Wrocław (south-western)	1	3 (1 — Head of the Department for Traffic and Public Transport Management, Roads and City Maintenance Authority; 1 — Intelligent Transport System Construction Specialist, Roads and City Maintenance Authority; 1 — an employee of the Department for Traffic and Public Transport Management, Roads and City Maintenance Authority)
Łódź (central)	2	2 (1 — Vice-Mayor of the City; 1 — Head of Traffic Control Team at the Traffic Engineering and Control Department, Road and Transport Authority in Łódź)
Kraków (southern)	2	2 (1 — Head of Transport Organization Department, Public Transport Authority in Kraków; 1 — senior specialist, Public Transport Authority in Kraków)
Białystok (eastern)	2	2 (1 — Head of Traffic Management Department, Municipal Roads Management; 1 — Director of Białystok Municipal Transport Authority)
Gdańsk (northern)	1	2 (1 — Vice-Mayor for Sustainability; 1 — Head of Traffic Engineering Department)
Poznań (north-western)	2	2 (1 — Deputy Director of Public Transport, Public Transport Authority; 1 — Head of Traffic Control Department, Municipal Roads Authority in Poznań)

minutes and was recorded. The author used a research tool in the form of a prepared interview scenario and analysed the research area related to ITS evaluation. The respondents were asked to answer to open-ended questions freely and express their opinions. Interview transcripts were analysed using content analysis and a set of categories developed by the author.

3. Research results

To answer the research question, the respondents were asked about the perceived problems and barriers related to ITS deployment. As indicated by the interviewees, several barriers related to ITS development can be distinguished. Besides the most important financial barrier, participants face a technological barrier and a social barrier, i.e., the reluctance of the inhabitants to innovate. The survey results and suggestions provided by the interviewees clearly indicate that the problems associated with ITS deployment and expansion can be grouped into the following five main categories: economic, organisational, legal, technological and social, as presented in Table 2.

Considering the category of economic problems, it should be noted at the outset that the costs of ITS implementation are very high. Thus, the basic barrier is, of course, financial. The process of financing ITS always encounters numerous obstacles, which is especially important in the context of limited budget funds for investments. All respondents are fully aware that insufficient funding — low budgets and enormous cost-intensiveness of such solutions — hinders the realisation of transport investments, including ITS. All interviewees indicated that this includes both ITS construction costs, including initial project expenses, construction and installation costs, operation and maintenance costs, and system upgrade costs, system and equipment maintenance, and other unexpected expenses. According to the participants, the investment costs are likely to be even higher than the expected monetary benefits in the future. However, based on their experience, the most expensive solutions are usually also the most effective. ITS acquisition costs are related to their complexity and the extent of the coverage in the city. The respondents emphasised looking for optimal solutions in terms of cost-effectiveness and, depending on the available financial resources, planning, improving, or increasing the scope of ITS. According to the analysed local government's perspective, public transport is well organised nowadays, although there are places where certain issues should be improved further. Considering the available financial resources, public transport and the network of transport connections mostly correspond to the real needs of residents. According to the interviewees, the availability of external co-financing is important, as it makes a wide range of investments possible. The respondents emphasised that without the support of EU funds, local governments would be forced to significantly reduce costs and thus reduce the scope of ITS (a small number of subsystems), or they would not be able to build them at all. One of the interviewees emphasised that there

Tab. 2. Problems and barriers of ITS in the opinion of IDI interview participants

No.	Problem category	Identified barriers according to responses by interviewees
1	Economic	• high costs of ITS implementation • low budget of local government units for ITS investments due to other, growing expenditures (the need to subsidise the project)
2	Organisational	• dependence on ITS provider • availability of a wide range of ITS makes it difficult to choose the most effective solution • difficulties in recruiting experts with broad multidisciplinary knowledge • difficulties in managing ITS
3	Legal	• security of collected data • limited activity of local authorities due to legal procedures
4	Technological	• ageing of technology • limited availability of highly modern and intelligent transport solutions
5	Social	• growing needs and too high expectations of all traffic users (difficult to reconcile) • aversion to change among citizens • lack of trust in local governments with regard to the undertaken investments • mistrust barrier especially visible in cooperation between public and private sector entities

is quite a high level of the cumbersomeness of the procedures related to obtaining the financing, both in terms of the number of required documents and formalities to be fulfilled. The respondents also perceived currently emerging categories of problems, such as the increase in prices of construction services, which has been particularly visible recently. Unfortunately, as a result, they will not be able to implement many good and "cool" investments or have to postpone them.

Organisational barriers constitute a broad category of problems. The interviewees emphasised that ITS require domain expertise. In the event of an ITS shutdown (or system failure), people will suffer significant losses in terms of time, health, mobility, etc. The interviewees also noted great difficulties in employing specialists with wide, multidisciplinary knowledge of this type of advanced system operation, which is necessary, especially at the ITS design stage. A highlighted and important problem is the issue of selecting a system contractor because to change anything in the system, it has to be done through the supplier as well as interdependence on system providers. Another problem involves the selection of the ITS manufacturer/supplier and the decision of whether it will be a leading foreign company. Local authorities are aware of the risk related to the dependence on one ITS provider, so they are afraid of such close cooperation, but on the other hand, they are forced to accept a certain level of risk.

As these are large systems and cannot always be split up or done independently, the key issue is this dependence on a system provider that could prove problematic in the future. Most analysed cities are "doomed" to one provider, which is undoubtedly a certain barrier. In the opinion of participants, knowing that they are somehow dependent on the contractor may in the future lead to contractor-imposed cooperation conditions. Some local government officials opposed this approach and brought it to their attention during the design and procurement of the system.

So, their system was based on complete openness and access to the "inner layer" of technology so that they were independent of any system provider. Thus, having access to all possible algorithm layers, ITS engineers have already reprogrammed all intersections with traffic lights. However, most cities in Poland have semi-centralised systems, while fully centralised ones exist as well. Several cities in the world manage the whole system on such a level, becoming practically self-sufficient.

National and international interest in ITS is growing, reflecting the willingness of authorities to implement them and gain tangible benefits. In terms of legal aspects and regulations on ITS, as identified by the interviewees, the difficulties relate to the processing of large data sets and the security of such a large amount of collected and processed data on the network. As the interviewees point out, they are using Big Data solutions but still struggling to take full advantage of the opportunities offered by analysing huge data sets. The respondents also commented on the future of Big Data. As they emphasised in the near term, the problem will be both the abundance of data and costs associated with their processing. Thus, the limitation in the future of ITS will be the abundance of collected data and its selection. Although, some procedural barriers may arise when planning ITS investments. The respondents also noted that the traffic structure would undoubtedly change, as will all ITS, or Big Data, which would be key to the communication system.

Technological problems are related, among other things, to the choice of appropriate information and communication technology as a facilitating factor in creating a new kind of smart city environment. It should be emphasised that many countries, including Poland, are lagging behind existing transport management systems in European cities in installing new transport infrastructure in cities to optimise networks for multimodality and cohesion (Strategy for Sustainable.., 2019). Considering novel technologies, it is worth noting that the availability of a wide range of ITS subsystems also makes it difficult to choose the most effective solution. Often, the above-mentioned choices are conditioned by the financial resources at one's disposal; however, for example, the purchase of low-quality equipment (and associated financial savings) ultimately results in the loss of these resources, and at the same time is connected with an inability to obtain the assumed or expected benefits. Innovative scientific and technological achievements are the basis for the functioning of ITS, e.g., the perception and interaction of traffic conditions, simulation and control of urban road networks and vehicle networks, coordination of vehicles with infrastructure and the management of road safety intelligence. In addition, ITS use a variety of technologies, the selection and adaptation of which to user needs is also a very important and time-consuming process. The organisation of transportation in the city, according to the interviewees, is problematic due to the uncertain future and preferred amenities or technological transportation solutions: "Even if we don't have some functionalities today, it doesn't mean that we won't use them soon. What is more, we do not use all the functionalities available to us today". Another category of ITS-related problems is inadequate infrastructure and technology ageing. Due to a relatively long implementation time, modern solutions at the moment of their "purchase" by the local government administration become "old" before they are implemented (there is a risk that new, better adjusted technological solutions may enter the market in the meantime). As the respondents stressed, technology ageing is a factor that undoubtedly has a negative impact on the decisions made. They emphasised that this is exactly the kind of field that requires the use of modern technology, and the current technology offers enormous possibilities. For instance, in analysed cities, the traffic light control system is optimised and very well adapted to traffic conditions while ensuring user safety. IDIs participants were aware of the ageing technology and the need to upgrade the system in the future and develop the architecture of the intelligent transportation system by implementing new solutions. The main problem they need to overcome is exact predicting what will happen in several decades, given the rapid development of technology. The aim is to improve ITS, to create an integrated, highly technologically advanced and user-friendly system.

Some issues facing intelligent transportation are social, such as active collaboration and highly reliable communication. It is crucial to recognise transportation needs so that planned investments (including both their scope and location) meet the expectations of different groups as much as possible. The interviewees pointed out that today, ITS meet the transport needs of inhabitants and are constantly improved to fit their needs even better. It should be stressed that according to the participants of interviews, the local urban community was increasingly aware of the benefits resulting from the application of ITS solutions and expected new investments from the local government in this field. Many ITS systems focus on enabling the users to change their behaviour (e.g., shifts in driver behaviour), which is also problematic, as it is connected with their resistance and unwillingness to change. The problematic issue is then the attempt to reconcile different users of traffic, including, e.g., drivers, pedestrians, public transport passengers, and cyclists. Each of these groups expects the system to, for example, improve its performance, safety, and environmental protection. According to the respondents, the specific goals and interests of individual traffic users and their preferred way of moving around the city also translate into different expectations as to the direction and scope of transport investments, which may cause various conflicting situations. For example, the conflict of interests may concern the prioritisation of public transport and the preference for launching the so-called "green wave" for individual drivers. The interviewees were highly aware of the existing resistance to change among traffic users, or the choice of the right mode of transport, which makes them reflect on the whole transport system only from the point of view of their individual needs, sometimes even conflicting with the needs of other travellers. The participants stressed that the system was never built just for the sake of having it, but it was designed and then improved for the sake of residents as the ultimate end-users. However, the main problem is that not everyone perceives it this way. Residents see their own difficulties, their individual needs, their so-called self-interest without looking at the bigger picture of the entire system. Undoubtedly, the social problem involves educating residents about what the transportation system is and for what it is used. The interviewees noticed that they missed one thing in the construction of the system to avoid social problems — a good explanation of why and how the system works. Thus, giving a priority for transit to certain groups of vehicles and traffic users means that others have to wait longer for their turn. However, changing the perception of public transport and matching the urban transport system to the needs of the population is currently a particularly important and developing issue in the context of developing lanes for urban cycling, cars or buses.

The problem identified during the research also relates to the mistrust barrier evident in the cooperation between public and private sector entities. To implement ITS efficiently, the public sector should expand opportunities for close cooperation with private sector entities providing transport services. This will contribute to mutual benefits, e.g., through the openness of the local government to novelties, new forms of cooperation, or agreements with suppliers.

Fig. 3 illustrates the main established categories of barriers and proposes its key subcategories identified by the author. In light of the conducted research, the most important are economic and social barriers related to improving transport towards intelligent solutions (forming the base of the pyramid). The economic category is based on high costs of ITS and the source of its funding, the social category is related

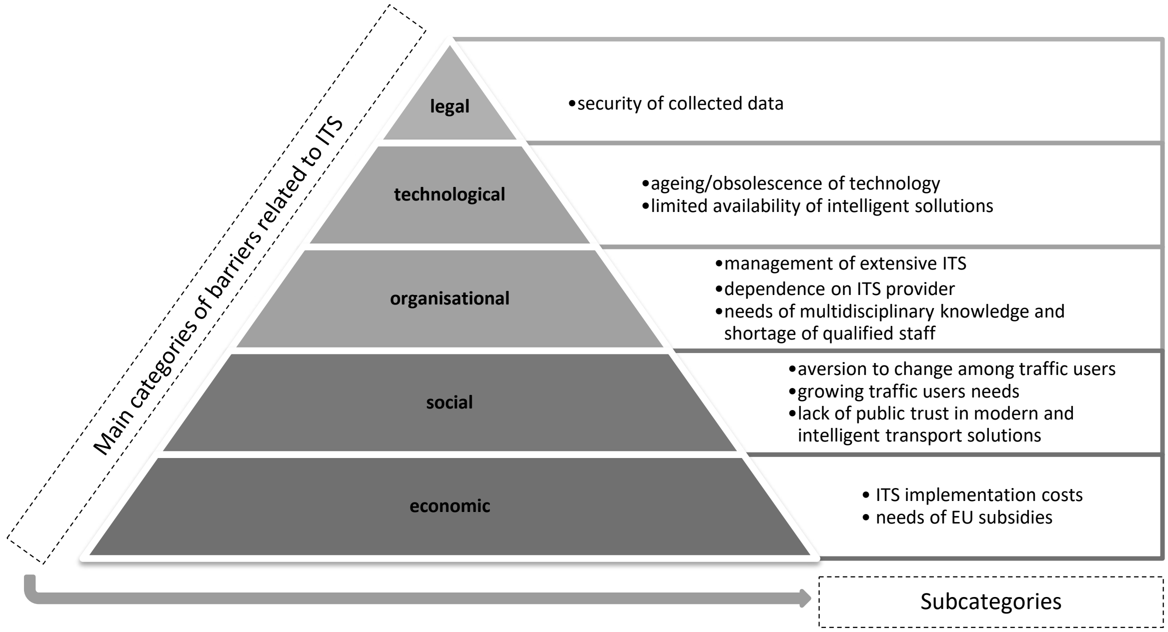

Fig. 3. Main categories and subcategories of barriers related to ITS

to attitudes, evaluation, perception of the local community, the organisational category — to the organisation and management of the ITS, the technology category is related to intelligent technology solutions and the problem of its ageing, and the legal category — with the care for the security of big data.

4. Discussion of the results

The literature indicates that ITS cannot fully solve various urban transportation problems. However, they constitute a valuable set of instruments allowing to significantly reduce them (Jarašūniene, 2006). By perceiving, processing and publishing traffic information, ITS ensure information exchange and cooperation between people, vehicles and technical infrastructure (Huang et al., 2017). Moreover, they enable the collection and sharing of essential real-time traffic information to help traffic users make more informed and sustainable choices about their travel. Thus, they encourage and mobilise passengers to choose an environmentally friendly mode of travel and use public transport or another green mode of transport. They are intended to make these journeys more efficient and thus help reduce the negative impact of transport on the environment, which may be one of the primary objectives of ITS deployment worldwide (Neverauskiene et al., 2021; Pel & Boons, 2010).

For ITS, the benefit-to-cost ratio is typically 10:1, making the political case for investing in or supporting this type of technology (Shinde & Waghmare, 2019). The key in analysed problems is to communicate with system users and to provide access to information about possibilities, benefits connected with the choice of a particular transport mode to all traffic users in a given city to raise their awareness. The creation of some kind of vision of ITS development accepted by the society could be helpful in overcoming the resistance to changes and facilitating communication with users (Jarašūniene, 2006). When considering the social aspect, it should be noted that by introducing a number of improvements or by upgrading the urban infrastructure, sometimes the opposite effect can be achieved, as car transport becoming more efficient may eventually encourage people to travel more often. The literature provides that while considering the potential impact of ITS systems, it is important to recognise the possibility of negative secondary effects (Tuominen & Ahlqvist, 2010; Jänicke & Lindemann, 2010). As Pel & Boons (2010) argued, some ITS may reinforce dependence on cars instead of "greener" modes of transportation. As Grant-Muller & Usher (2014) aptly described, the primary goal should therefore be to consider the full range of possible impacts of ITS on the development of a transportation strategy. When talking about costs, ITS can also be considered in terms of social costs related to, e.g., saving travellers' time. Also, Zhang et al. (2018) analysed the cost-effective evaluation of Intelligent Public Transport Systems, examining it from three perspectives: public transport companies, passengers, government and society.

Focusing on the problems and barriers of mobility and intelligent transport systems, it should be noted that these are insufficiently analysed scientific areas. According to Kachniewska (2020), as a component of a smart city, transport or mobility relates to the hard and technic domain of a smart city. Therefore, the most important barriers and threats to smart mobility are related to the highest importance to technological factors. Jarašūniene (2006) made conclusions similar to the findings identified during the present research by claiming that the introduction of ITS in the transportation sector encounters various problems and barriers, such as:

- considerably low level of technical and organisational knowledge in this field;
- low-level political and public awareness and support;
- uncertain financing from public and private sources;
- difficulties of interinstitutional cooperation.

As the author pointed out, ITS architecture needs to be developed to coordinate all system components into a single framework so that interoperability can be achieved in providing necessary services to customers. In addition, the low commitment to intercity cooperation results in a continued lack of consistent improvements on a national scale. As Jarašūniene (2006) claimed, the ITS environment is complex and multifaceted, and the problem of their creation should be considered at all levels of the country, i.e., by the central government, municipalities, stakeholders and all traffic participants. This will ensure close cooperation of the above institutions.

The research author confirmed some problems identified in the literature and related to ITS. The main categories and subcategories of barriers were indicated. Based on the opinions of people responsible for the organisation of transport and ITS cities, the conducted survey allows identifying key problems and barriers in the analysed area, which are grouped into broader five categories. Individual interviewees had in-depth knowledge of the problems and barriers related to various stages of ITS deployment and city transport organisation in general. The main barrier limiting the wide range of ITS implementation and innovative technological solutions in transport is costs (economic barrier). First of all, the low budget of local government units is a key factor, limiting the possibilities of activities in this area considerably. Since local governments have to implement various investments in parallel, they need EU subsidies for projects and other forms of planned activities in the city. The interviewees emphasised that the implemented ITS usually do not have a holistic approach, and initially, they most often amount to traffic regulation. The interview participants also had high awareness of organisational and cooperation barriers with suppliers, especially with respect to interdependence on ITS provider and difficulties in employing specialists (both at the stage of system design and management). Among legal barriers, the key issue is to ensure the security of large sets of collected data. The main technological problem results from the observed technological progress and rapid ageing of available technologies. Finally, the category of social barriers refers primarily to the growing needs and high expectations of all traffic users (the difficulty of reconciling individual interests). Another crucial factor, according to the respondents, is the observed reluctance to change among citizens, such as changing the mode of transport, existing habits of traffic users, etc.

Conclusions

The smart city concept, implemented in many cities worldwide, has captured the attention of theoreticians and practitioners from local governments. As Papa & Lauwers (2015) stressed, the transport and mobility domain has the highest number of initiatives worldwide within the approach to a smart city. Transport systems play a key role in supporting socio-economic activities around the world. In particular, they provide users with better transport services characterised by high reliability and frequency while implementing low-carbon solutions (Molnar & Alexopoulos, 2008). Transport, understood as an element of the economy, has a significant impact on the environment and requires special attention to its protection. Thus, the emission of pollutants associated with urban transport has a wide range of environmental consequences that ultimately have to be borne by society (Rodrigue, 2016).

According to the literature, most scientific research confirms the idea that ITS support smart mobility in a city (Mangiaracina et al., 2017; Papa et al., 2017; Papa & Lauwers, 2015). Undoubtedly, ITS bring a city closer to being intelligent. Particularly in large cities, ITS applications play a significant role in combating climate change and reducing environmental pollution by providing greater flexibility in urban traffic (Molnar & Alexopoulos, 2008). Consequently, ITS lead to, among other things, reductions in the number of accidents, congestion and greenhouse gas emissions while at the same time improving the quality of urban transport services (Neverauskiene et al., 2021). Beyond any doubt, ITS bring several benefits to all users of the transport system, e.g., drivers, road users, passengers, public transport, people with reduced mobility, and institutions involved in transport activities (Grant-Muller & Usher, 2014; Shaheen & Finson, 2013).

The presented research results confirm some of the problems and barriers identified in the literature review. For instance, interviewees emphasised the lack of financial support from external funds, which makes it impossible to take specific action to improve urban transport and ITS. However, in light of the research, there is a certain discrepancy between the theoretical assumptions presented at the beginning of the article and the perspectives of local authorities of a voivodship city. The structure of urban traffic has changed significantly in recent years, and mobility management has become one of the most challenging areas of urban management. Nowadays, cities especially struggle with a shortage of finance and technological competence related to ITS. Additional problems and barriers can be identified considering the experience of local governments.

The author of the study indicates that local government representatives are highly aware of the barriers of ITS related to their implementation. The identified barriers are grouped into the following categories: economic, social, organisational, technological, and legal. However, without EU funds, cities would not necessarily be able to afford the highly expensive construction of a system. The universal value of the research is deepening the knowledge of ITS and their potential while highlighting the barriers related to their implementation. The interviewees emphasised that currently, cities do not fully use the available technological solutions to facilitate urban transport management. Therefore, the dissemination of knowledge on the subject and experiences of various cities will influence the improvement of implemented transport systems. Following the experience of local governments, this will make it possible to verify the validity of selected subsystems in terms of achievable benefits, their multiplication and planning the most sustainable solutions in this area. The findings can have a positive influence as important factors for local governments to focus on intelligent transport. Additionally, the dissemination of knowledge will allow other local governments to eliminate many problems related to ITS.

Undoubtedly, the research challenge involves the identification of barriers concerning ITS deployment. The theoretical contribution is twofold: first, the juxtaposition of theoretical and practical benefits of ITS; and second, the identification of the impact made by intelligent transportation, affecting the becoming of a smarter city.

The author is aware of certain limitations of this study based only on the implementation of exploratory qualitative research. Another limitation is the scope of the research and the fact that the analysis covered only a small number of voivodship cities, representing particular macro-regions of Poland. This poses a significant limitation to the interpretation of the obtained results and the conclusions drawn on their basis. The conducted in-depth interviews are a turning point and inspiration for further research in a wider scope and descriptive analysis. The multifaceted nature of issues concerning the identified benefits of urban transport and ITS, in connection with their observed dynamic development, provides a substantive direction for further scientific analysis. In the next stage of the research work, the author plan to widen the research focusing on the analysis of barriers and benefits of ITS and conduct quantitative studies concentrating on smart mobility and ITS that include cities from other European countries.

Acknowledgements

The publication of the article for 11th International Conference on Engineering, Project, and Production Management - EPPM2021 was financed in the framework of the contract no. DNK/SN/465770/2020 by the Ministry of Science and Higher Education within the "Excellent Science" programme.

Ministry of Science and Higher Education
Republic of Poland

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Engineering Management in Production and Services

Volume 13 • Issue 4 • 2021

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 15 June 2021
accepted: 30 October 2021

pages: 148-159

Use of Target Costing methodology in the construction of wood-aluminium windows — case study

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ABSTRACT
The paper concerns the practical application of Target Costing to a specific product of the woodworking industry with a particular emphasis on customer needs and value analysis principles concerning individual components and functions of the product — a wood-aluminium window Gemini Quadrat FB. Based on principles of value analyses, the study used the functional cost analysis, the quantified target cost index of relevant components and the target cost chart for the allowable cost of components. Two levels of the q parameter — 5 % and 10 % — were used to construct the target cost chart. The target price (EUR 513.19) was assessed. The target production cost was at the level of allowable production costs (EUR 379.31). The results were used to confirm that the ideal value of the target cost index was not achieved for any component, and a higher value of the parameter q can be marked as soft. The paper provides assumptions for the assessment of possible alternatives and potential corrections. The case study presents the description of the Target Costing methodology along with the nuanced characteristics of the approaches used by various authors and the strengths and benefits of using the method.

KEY WORDS
allowable cost, price, profit, Target Costing, target cost index, wood-aluminium window

10.2478/emj-2021-0037

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Introduction

An effective cost management system is a part of strategic business management. So, it is imperative for the system to show positive results. Solutions must be found to increase the enterprise's competitiveness. The Target Costing (TC) method based on the value analysis seems to be one such possible solution. This method allows applying a cost management system that could meet the requirements of the enterprise and the customers. By applying the

Potkány, M., Krajčírová, L., & Stasiak-Betlejewska, R. (2021). Use of Target Costing methodology in the construction of wood-aluminium windows — case study. *Engineering Management in Production and Services, 13*(4), 148-159. doi: 10.2478/emj-2021-0037

Target Costing methodology, a particular enterprise could increase its competitiveness by understanding customer preferences. According to Gonçalves et al. (2018), Target Costing is known as a competitive tool of Japanese enterprises. Lang (2005) saw reasons for the application of Target Costing to rapid and dramatic market changes. These are caused by the increasing global liberalisation and strong competitiveness. According to him, traditional calculations have not been effective.

If enterprises want to hold their position and survive in the market, they have to implement other managerial, planning and control tools. This cost management value system brings both positives and negatives. If the information provided by Target Costing is reliable, they can increase the quality and rationalisation of production and the inventory reduction. Target Costing information has to be compatible with the enterprise's opportunities and ideas to meet these goals. Based on the analysis of relevant studies of national and foreign authors, no case was found of applying the Target Costing methodology under the conditions of woodworking enterprises or enterprises producing wood-aluminium and other types of windows, indicating a research gap.

The research object of the applied functional cost analysis was a wood-aluminium window Gemini Quadrat FB. The research aimed at the practical application of Target Costing to a specific product (a wood-aluminium window) under the conditions of the woodworking industry with the particular emphasis on customer needs (market research among customers) and the value analysis related to individual components and functions of the specified product.

This paper contains the following chapters. Literature Review presents and compares viewpoints of many relevant authors on the TC topic and the methodology from the theoretical point of view. The chapter on Research Methods presents and describes the TC methodology application on s particular product — a wood aluminium window.

Results and Discussion deals with the reached results by the calculated/assessed levels of costs, target costs, index of target costs, the "q" parameter and, finally, the target costs chart. The part on Conclusions contains reached results from applying the TC methodology in the process of wood-aluminium windows production, limits of the paper and further research orientation.

1. Literature review

In product design, many activities have to be coordinated to create a product that meets the customer's and manufacturer's needs. The demands and preferences of the customers usually change over time. Therefore, an enterprise has to synchronise a customer demand with its own demand. A product has to be manufactured at the optimum cost and using the most effective operations. At the same time, actual customer demands and requirements must be considered, although customers are not interested in production costs. The customer's principal interest is the target price. The difference between the acceptable target price and the target profit creates the level of allowable cost. According to Kee (2010), Target Costing is the cost management system for designing products with reasonable profitability related to their production. The strategy of Target Costing has come from the standpoint that 80 – 85 % of product lifecycle costs are assessed during the product research and development phase. For this reason, Target Costing focuses on the research and development phase having the greatest potential for cost management.

Vedder (2008) stated that the origin of this calculation technique dated back to the 1970s when the private sector income in Japan rapidly increased and people started to explore a greater diversity of their needs. Many latest research studies have been dealing with Target Costing. Sakurai (1989) defined Target Costing as a cost management tool to reduce the overall product cost over its entire life cycle with the help of production, engineering, R&D, marketing and accounting departments. The Target Costing topic was also studied by Tanaka (1993). Hradecký et al. (2008) stated that the Target Costing methodology was based on customer requirements. The focus on the market and customer has been highlighted by Coenenberg et al. (2016). Based on particular studies, Gonçalves et al. (2018) believed it was very difficult to implement Target Costing outside of Japan. Saatweber (2011) saw the success of the Japanese industry applying Target Costing to a flexible, fast and customer-oriented production system. Comprehensive time and quality management enable high productivity, meeting high-quality standards and flexibly adapting to customer demands and market changes. Target Costing can be described as a valuable approach to the balance between R&D costs and an acceptable market price. All arrangements and methods that will be used can contribute to a transparent cost structure. Kee (2010) referred to Target Costing as a cost management system designed to develop a new product with the level of profitability that considers the production. According to Kato (1993), Target Costing is not only a method of cost reduction but a comprehensive system of strategic profit management. He also noted that Target Costing is an activity focused on reducing life cycle costs for new products together with quality assurance, reliability and other consumer requirements. According to Okano and Suzuki (2006), several leading researchers, such as Kato (1993), Monden and Hamada (1991), Sakurai (1989), Tanaka (1993), and Tani et al. (1994), described Target Costing as neither accounting nor costing. According to them, it enables comprehensive planning and management of profit through frequent and mutual communication and strategy. According to Schlink (2004), Target Costing is an integrated target cost management approach. This system includes a comprehensive package of planning, control and cost assurance tools. Product development and construction comprises specific steps before it is placed on the market. In product planning, research and development, and prototype development, all possible cost-reduction ideas must be explored. According to Saatweber (2011), Target Costing goals dealing with success cover the entire product life cycle. Cost targets are based on the anticipated market requirements when the products enter the market. Balance with the goals is monitored by Target Costing throughout the whole phase of product development.

Based on many international studies, e.g., Novák and Popesko (2014), Potkány and Škultétyová (2019), Dejnega (2010) and Ahn et al. (2018), the Target Costing methodology represents a particular managerial approach aiming to integrate cost management oriented towards the marketplace and customers. These studies also focused on the greater significance of cost management, cost behaviour analyses, and appropriate cost projection to adequate cost systems.

According to Kato (1993), the entire Target Costing methodology is based on a straightforward principle: the target costs represent the difference between the expected market price and the target profit. Based on Kee (2010), Target Costing begins with researching attributes and quality products demanded by customers. At the same time, a price is specified that could be accepted by the customers. Teplická (2011) said that the core idea of Target Costing is market marketing research. The market offers specified product properties and target prices according to customer demands. Kato (1993) considered the target price the starting point for all activities focused on target costs. The sales price determination was influenced by the product concept, consumer expectations, product life cycle, and planned volume of sales, but especially by the competition. Kato (1993) also stated that many Japanese enterprises use the function-based pricing method. This method is based on decomposing the product price into several elements, each reflecting the value that customers want to pay for this element. It is necessary to consider that the products have a function mix, and each can be decomposed into several sub-functions. So, the estimated price is the sum of these values. Based on Ebert (2011), the target price can be determined by market research, and it considers the expected impact of competition. According to Schlink (2004), traditional price calculation approaches are based on the supply market. Ellram (2002) stated that setting the target price begins with understanding the unfulfilled market demands.

Based on Kee (2010) and Kato (1993), the next step in the TC methodology is to determine the allowable costs by the deduction of profitability required by a company from the market price of the product. All of the following activities are focused on achieving allowable costs of the product. The production of a given product has considerable potential if this cost level is ensured. Otherwise, the product is rejected as unrealised from the financial point of view. Ax et al. (2008) said that setting a target profit for a future product is usually based on a long-term profit plan. The target profit can be determined based on both profit levels for similar products and the relative strength of competing offers. Considering the market impact, it is also possible to regard both the actual profit of the previous product and the target profit of the product group. Generally, the target profit is not determined in the absolute level but rather in percentage, usually applying the Return on Sales value (ROS). Tumpach (2008) presented a formula for the target profit calculation (1): According to Šoljaková (2009), the Return on Equity (ROA) could be applied to the calculation of the target profit, and according to Foltínová et al. (2007), it could be applied to the profit margin for the calculation of the target profit. Šagátová (2006) also dealt with possibilities to determine the target profit by calculating the profitability of costs.

$$\text{Target Profit} = \text{Target Price} \times \frac{\text{ROS}}{100} \qquad (1)$$

Based on Kato (1993), target costs should be set for each product. Therefore, it is necessary to know the expected sales price and the target profit for each product. According to Ebert (2011), target costs must be selected and specified, and their control must be ensured to achieve effective control of target costs. According to Schlink (2004), Target Costing focuses on the demand market. The expected required profit is deducted from the product's real market price, and then target costs are assessed. They should not be exceeded and, therefore, it is necessary to respect the assessed target cost. Schlink (2004) also identified that all enterprise's fields could be considered variables significantly affecting the level of costs already in the development phase. Any market pressure is important to be monitored and integrated into cost management.

The TC methodology also includes the application of value analysis principles, which according to Pollak (2005), systematically and creatively examine all cost items. The goal is to reduce or eliminate costs that do not bring acceptable value from the customer's point of view. At the same time, the required quality and relevant performance must be observed. Based on Kastrup (1999), the value analysis can focus on any function performer. The principal category of value analysis is those functions performed by the components, and they represent a source of benefit to the customer. According to Popesko (2009), target costs are achieved by the value analysis by identifying improvements that could reduce costs but do not limit the product's functional properties. The second option is to eliminate unnecessary functions that can increase costs. According to Coenenberg et al. (2016), the value analysis is not focused only on the cost reduction for individual functions or properties of a product, and it also includes their change to increase the product value.

The TC methodology contains the assessment of the target cost index, and the achieved results can be presented using the target costs chart. According to Saatweber (2011), the target cost index describes the alignment of target costs and the customer's benefit. The proposed solution for managing the differences between a benefit and a function can be too simple, and the relevant function is too complex and complicated. Based on Saatweber (2011), the index is determined by the ratio of market importance to costs. The target cost index allows checking the agreement between the relative importance of the customer and the cost-share of each products component. Jung (2011) considered the target cost index the key indicator comparing the functional weight of individual product functions and their cost-share. If the cost ratio is higher than the relative weight of the function, it reflects the target cost index values. According to Joos-Sachse (2001), this key indicator presents a deviation between the market importance and the causal relationship of costs. Reichmann (1997) also considered the TC index as a control tool of cost adequacy related to the weight of its functions. A result below 1 explains that the cost share is higher than the relative weight of its function. When the result is higher than 1, the product is relatively cost-effective compared to its functional significance. Joos-Sachse (2001) stated that if the index was higher than 1, the component was implemented with insufficient investment money. Vice versa, the index below 1 shows that the component implementation was too expensive, i.e., higher costs were spent. Schneider and Pflaumer (2001) also noted three possible results of the target cost index values: the optimal cost-benefit ratio for the customer, the production being too expensive or too cheap, and the customer emphasis on components rather than costs. The obtained index describes how important are the decision and relevant steps. Horváth (1993) determined the TCI by the weight of the allowable costs from the TC methodology and the weight of the component from a preliminary calculation.

According to Ebert (2011), the importance of each component is calculated from the overall function of the product. First, an index for particular components and then a control chart of target costs should be created. Jung (2011) declared that the results of cost allocation could be visualised in the chart of target cost. The scheme helps to identify those components that need the most corrections. Based on Schneider and Pflaumer (2001), a target cost chart is an important cost-benefit tool for developers and production planners. According to Reichmann (1997), it presents a target cost zone with values below and above the optimal cost level. Ideal values are presented on the line that comes from the beginning. The values on this line represent the balance between the percentages of function weights and the costs. So, there is the ideal value of the target cost index, which equals 1. Based on Schneider and Pflaumer (2001), the key consideration describes the limit of target costs and the also graphical presentation of the target costs level. It is necessary to define the optimal target cost zone because the optimum level with the target cost index equal to 1 is very unusual. Mussnig (2001) stated that the target cost zone is defined by two curves. The upper limit is on the cost zone, and the lower limit is on the benefit zone. According to Schneider and Pflaumer (2001), the target cost zone is defined by two curves. They show that the allowed deviations from the optimum value are higher in the zone of small partial weights than in the zone of high partial weights. The target cost zone represents a space possibly spanning costs of components. For this purpose, the X-axis shows weights of component benefit, and the Y-axis gives real cost shares. These two functions set the target cost zone. According to Saatweber (2011), the target cost chart has a defined target area for each assembly, component or production process as the ratio of the target cost to the benefits. According to Saatweber (2011), the target cost zone in which the components should be located shows deviations. A deviation from the ideal value could be between the upper and lower limit. An enterprise sets its own limit values. According to Joos-Sachse (2001), the parameter q defines the target cost zone. The higher "q" means a more open target cost zone. Accepted limits for deviations are wider. If the costs are too high compared to the benefit, they are above the target cost zone. Then, it is necessary to focus on cost reduction without losing quality. According to Schneider and Pflaumer (2001), "q" indicates the intersection of two functions with the X-axis or the Y-axis. Based on Saatweber (2011), the value of the parameter q at which the zone starts in an axis or in a vector depends on the enterprise. The zone is stricter with the higher target potential of the goal achievement. It also depends on the level of employees' experience. According to Jung (2011), the assessment of the "q" indicator depends on the importance of target costs in the enterprise. It also depends on the importance of production costs and costs of the competition. The assessment of "q" is always strongly influenced by experiences. If the components are outside the target cost zone, action is necessary. According to Schneider and Pflaumer (2001), deviation limits depend on the choice of the „q" indicator. During the determination of the decision-making parameter "q", it is necessary to decide on the basis of the target cost significance, then actual costs, and finally, the costs of competition. The more important the selling prices are (influenced by costs), the smaller "q" should be chosen. The determination of the decision parameter will be influenced by empirical values always.

The study presents the description of the Target Costing methodology together with the characteristics of the nuances in the approaches of various authors and the recognition of strengths and benefits of using the method. Based on the literature review, a research gap was identified, and the following research question (RQ) was formulated.

RQ: Is a comprehensive application of the Target Costing methodology possible in an enterprise manufacturing an innovative product — wood-aluminium window Gemini Quadrat FB?

2. Research methods

The object of our research was an innovative wood-aluminium window Gemini Quadrat FB (Fig. 1). It is a product with excellent resistance properties against weather conditions, and by that, it meets customer demands.

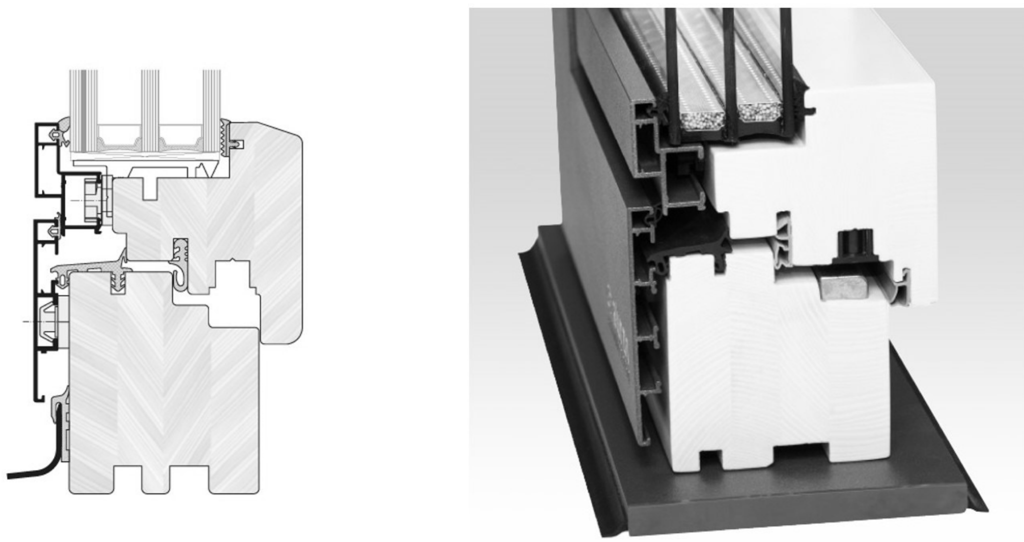

Fig. 1. Wood-aluminium window Gemini Quadrat FB

Source: (http://www.aluron.pl/de/offer/quadrat-fb-2/).

According to Štulrajter (2016), the product consists of the following components:

Frame (K1). The basic construction element is a wooden window block made of spruce, pine and oak. The window profile is covered in the aluminium profile. The window is perfectly protected against the weather long-term, and it also has a longer life.

Fittings (K2). This product contains a system designed for tilt-opened windows. The fitting is hidden in a full-circuit design and complemented by several integrated safety features ensuring a higher safety class.

Insulated glass (K3). The product uses insulated triple glass with excellent thermal insulation properties. A thin layer of noble metal is applied on the inside plate of the glass panel. During winter, it provides excellent insulation properties, and in summer, it protects the interior from excessive overheating. Good-quality glass provides sun protection and is more resistant to accidents; it reduces noise and creates a pleasant interior climate. The heat transfer coefficient is 0.8 W/m2K, the thermal transmission coefficient Ug = 0.7.

Surface finish (K4). The profile is treated by an ecological surface finishing. It provides protection against mould, rot, and water and ensures high vapour permeability and resistance to weather conditions and UV radiation.

Weatherstrips and insulation (K5). A quality system prevents condensation decreasing the chances for mould. At the same time, this will ensure lower heating costs and better insulation. Weatherstrip covers all window sides, the external, internal and central strip between the window frame and the window's wing.

Drip moulding (K6). A rainwater drain is provided to the outer parapet and protects the lower horizontal surfaces of the wooden frame.

The Target Costing methodology was applied to identify weaknesses of the releasing product: wood-aluminium window Gemini Quadrat FB. The frame of this product was made of spruce. Plans exist to extend the product portfolio with pine wood, making the product wood-aluminium window Innovative FB in a higher density and more expressive colour. For insulating glass, the consideration is to use glazing 4-18-4-18-4 instead of 4-12-4-12-4.

The research methodology consists of two phases. The first phase covers the survey, summarising customer preferences and specifications of the research object — the wood-aluminium window. Data collection by the questionnaire was performed from February 2020 to August 2020 using Google Forms. In total, 100 potential customers were interested in buying the research object. The second phase included the application of the TC methodology using the principles of value analysis.

According to Kato (1993), in the initial phase of the TC methodology, the target costs were determined by the formula (2).

The formula (3), according to Šagátová (2006), was used to establish the target profit.

The target price was determined on the basis of a questionnaire survey – step 1. Marketing analysis provided information about customer preferences of the monitored product.

In the second step, the costs of individual components for the Innovative FB product were calculated. They were quantified using the product calculation configured by the departments of construction, research and development. Next, quantitative-functional analysis was used. It identified the relationship among individual functions (customer preferences) and product components. Then, the significance of individual product components was assessed.

The value analysis principles were applied during the implementation of the Target Costing methodology. Analysing customer preferences and using the quantitative-functional analysis, it is possible to determine the percentage of allowable costs of individual components. A complete calculation is based on the multiplication between the significance component and the percentage share of this component on its properties. Consequently, it was possible to determine the target cost index (TCI) for each component using the formula (4) according to Horváth (1993) and then, results were transformed into the target cost diagram.

$$\text{Target Costs} = \text{Expected Sales Price} - \text{Target Profit} \tag{2}$$

$$\text{Target Profit} = \frac{\text{Target Price} \times \text{Cost Profitability Factor}}{1 + \text{Cost Profitability Factor}} \tag{3}$$

$$\text{Target Cost Index} = \frac{\text{Relative Weight Of The Component From Target Costing Methodology}}{\text{Relative Weight Of The Component From Preliminary Calculation}} \tag{4}$$

$$\int_1 = \sqrt{x^2 - q^2} \quad (5)$$

$$\int_2 = \sqrt{x^2 + q^2} \quad (6)$$

Formulas (5) and (6) were used for the determination of lower and upper limits of the target cost zone.

The q value represents the tolerance level, in our case it was determined at 5% and 10%.

3. Results and discussion

The results are based on the questionnaire survey evaluation (returned by 100 respondents) on customer preferences for the wood-aluminium window. The most preferred requirements were the thermal and sound insulation properties of the window (P5) and the product life cycle (P9) (Fig. 2). Both properties exceeded the level of 12 %.

Customers also highly preferred product safety (P4). The percentage results of other properties exceeded 10 %; the least preferred property was design (P2) (10.25 %). Thus, customer expectations of particular product properties have about the same importance level. The survey provided an overview of perceived customer preferences for particular product properties. Information is one of the possible sources for further methods applied in this case study.

Formula (2) was applied for the determination of allowable costs. The survey also examined the acceptable product price for customers. The result was a value close to EUR 616, including the value-added tax (VAT). After the deduction of VAT (20 %), the value is close to EUR 513. The profit margin was set at the level of the expected 15 % cost profitability (EUR 66.94), as is presented in formula (3). Using formula (2), the level of allowable costs was set to EUR 446.25. Departments of construction, research and development assessed the conversion calculation respecting allowable costs for the wood-aluminium window Innova-

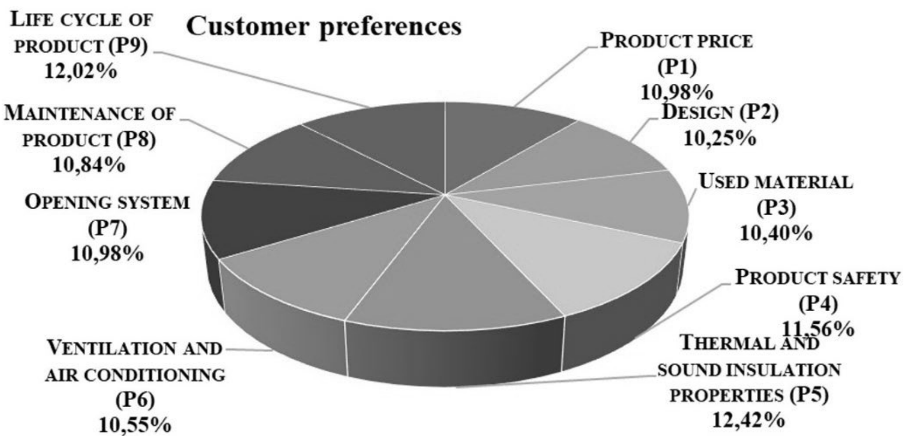

Fig. 2. Customer preferences (P) (%)

Tab. 1. Cost calculation of the Innovative FB in EUR/product

Cost items	Conversion calculation of Innovative FB
Direct material	258.83
Direct wages	80.32
Supply and production overheads	40.16
Production costs	379.31
Sales administration costs and management administration overheads	66.94
∑ Costs	446.25
15 % profit	66.94
Price without VAT	513.19
VAT	102.64
Sales price	615.83

tive FB (Table 1). Particular components should respect the percentage distribution of conversion calculation values for the original window Gemini Quadrat FB. Production costs reached 85 % of the total costs. The level of allowable costs is EUR 379.31.

Quantitative-functional analysis was elaborated by an expert assessment of the construction department. The relationship was identified between customer preferences (9) and particular components (K) (Tab. 2).

We can mention that the component K1 Construction (20.98 %) has the highest importance (Table 2) as a customer preference, the second important component is Fittings K2 (20.46 %). The results of the analysis were used to quantify allowable costs of individual components based on the level of allowable production costs of EUR 379.31 (Table 3).

The comparison of the target costs of individual components with the costs determined by the conversion calculation for the components (Table 3) showed that the company should decrease costs of all components except for the insulating glass K3 and the surface finish K4. These components have higher allowable costs than the costs determined by the preliminary conversion calculation. More detailed analysis and the application of the TC methodology determined the target cost index (formula 4) for each component of the product (Table 4).

Subsequently, a target cost chart (Figs. 3 and 4) was constructed applying formulas (5) and (6).

So, for no component the calculated costs by the enterprise (TCI = 1) did not meet the customer expectations. When a more moderate tolerance limit is assessed by the coefficient q = 10 % (Fig. 3), all analysed components are located in the tolerance zone, because they correspond to the permitted deviation from the target value. The insulation glass K3 and the surface finish K4 can be considered as inexpensive components (their target cost index value is higher than 1). Other components have the target cost index below 1, which means there are considered expensive (cost-intensive), and managers should think about rationalisation steps leading to cost reduction.

Applying a stronger tolerance limit by the coefficient q = 5 % (Fig. 4), the tolerance area is significantly smaller. Only two components are located in the toler-

Tab. 2. Quantitative-functional analysis and the importance assessment of particular components

	K1		K2		K3		K4		K5		K6	
	Share	∑share	Share	∑share	Share	∑share	Share	∑share	Share	∑share	Share	∑share
P1*	30.00%	3.29%	25.00%	2.75%	25.00%	2.75%	10.00%	1.10%	5.00%	0.55%	5.00%	0.55%
P2	30.00%	3.08%	5.00%	0.51%	25.00%	2.56%	30.00%	3.08%	5.00%	0.51%	5.00%	0.51%
P3**	20.00%	2.08%	10.00%	1.04%	10.00%	1.04%	30.00%	3.12%	10.00%	1.04%	20.00%	2.08%
P4	30.00%	3.47%	20.00%	2.31%	20.00%	2.31%	0.00%	0.00%	10.00%	1.16%	20.00%	2.31%
P5	10.00%	1.24%	5.00%	0.62%	25.00%	3.11%	5.00%	0.62%	40.00%	4.97%	15.00%	1.86%
P6	10.00%	1.06%	30.00%	3.17%	0.00%	0.00%	0.00%	0.00%	30.00%	3.17%	30.00%	3.17%
P7	20.00%	2.20%	50.00%	5.49%	0.00%	0.00%	0.00%	0.00%	30.00%	3.29%	0.00%	0.00%
P8	20.00%	2.17%	20.00%	2.17%	20.00%	2.17%	25.00%	2.71%	5.00%	0.54%	10.00%	1.08%
P9	20.00%	2.40%	20.00%	2.40%	15.00%	1.80%	15.00%	1.80%	10.00%	1.20%	20.00%	2.40%
∑	-	20.98%	-	20.46%	-	15.74%	-	12.43%	-	16.43%	-	13.97%

*P1 vs K1 = 10.98% 0.30 ≐ 3.29%; **P3 vs K1 = 10.40% 0.20 ≐ 2.08%

Tab. 3. Preliminary conversion calculation of components for the Innovative FB compared to target component costs

Component	Preliminary cost of Innovative FB product	Allowable cost from Target Costing methodology of Innovative FB product
K1	81.43	79.59*
K2	78.87	77.60
K3	52.90	59.69
K4	43.00	47.14
K5	67.07	62.32
K6	56.04	52.99
∑	379.31	379.31

*K1 = 20.98% from 379.31 € = 79.59 €

Tab. 4. Target cost index for particular components

Component	Target cost index
K1*	0.9773
K2	0.9839
K3	1.1284
K4	1.0962
K5	0.9291
K6	0.9456

$^{*}TCI_{K1}$ = 20.98%/(85.60/398.70) = 0.9773

ance area, i.e., the Frame K1 and the Fitting K2. However, they are considered expensive (cost-intensive) because their TCI is below 1. The difference between allowable costs and the costs determined by the conversion calculation for K1 is at the level of EUR 1.84. K2 is characterised by allowable costs lower than EUR 1.27. Both of these components significantly contribute to meeting the customer preferences (each by more than 20 %). The examination of customer preferences demonstrated that more than 11 % of customers emphasised product safety. Therefore, the search for the best alternative of lower-cost fittings should result in a supplier that could relevantly meet this requirement. Although these two components are located in the tolerance zone, and cost variations are

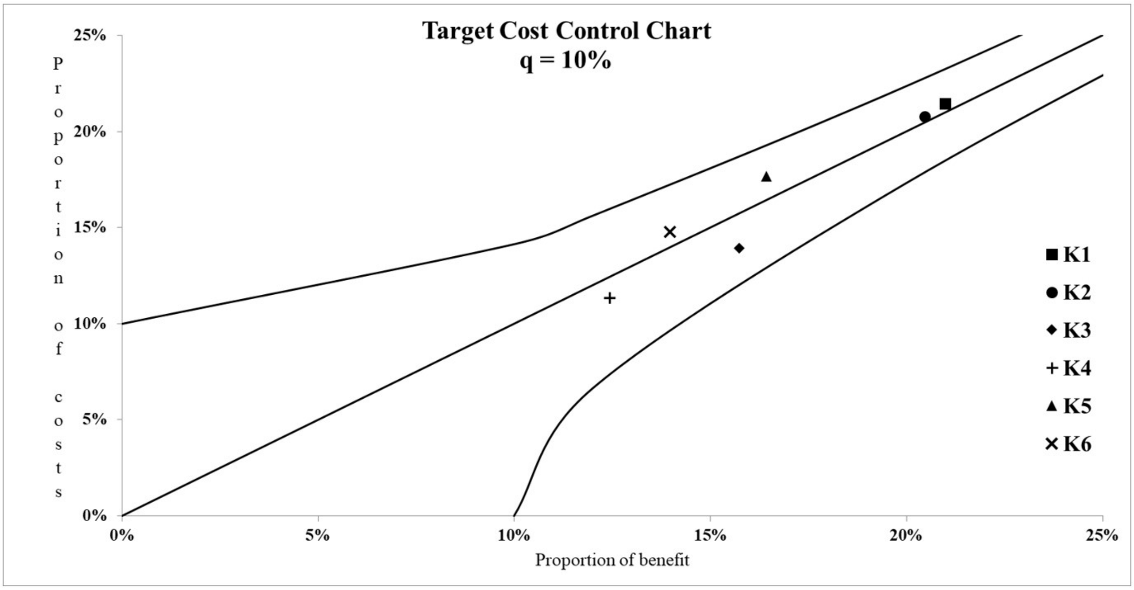

Fig. 3. Target Cost Control Chart comparing different levels of the coefficient q = 10%

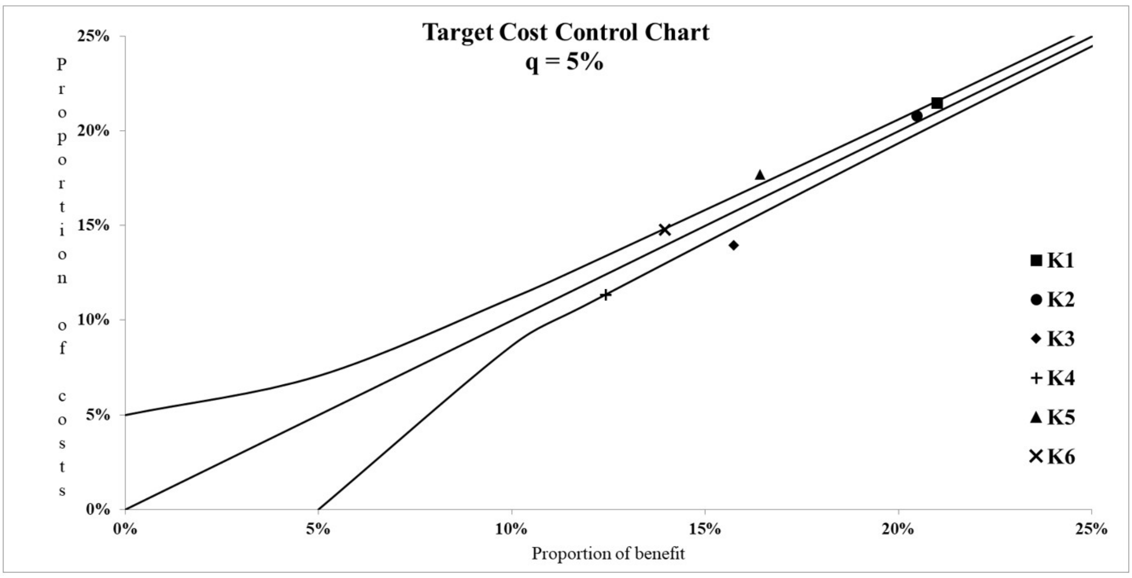

Fig. 4. Target Cost Control Chart comparing different levels of the coefficient q = 5%

still acceptable, the enterprise should deal with them because of their importance for customers. Alternatives for costs reduction should be found while respecting the quality requirements. Allowable costs can be a limit for the purchasing price of these components from an external supplier. In the case of the cost reduction below their allowable limit, the quality of this component should be carefully monitored in the context of meeting customer requirements.

The surface finish K4 and the drip moulding K6 have only limited values. K4 can be considered a cheap component, and K6 can be considered a cost-intensive component. K6 costs are more EUR 3 higher than necessary. On the other hand, a higher focus on quality is required in the case of K4. The allowable costs are about EUR 4.14 higher than the costs assessed by the conversion calculation. Lower costs of a component can result in the value decline of the whole product. The range of colours could be extended, which might increase expenditure and, thus, to be closer to allowable costs.

The insulating glass K3, weatherstrips and the insulation K5 are outside the tolerance zone. If the components are outside the target cost zone, it is necessary to find possible corrective actions. Either the activities will focus on cost reduction or feature improvement. It depends on the position of a particular component in the chart. On the basis of these results, K3 can be considered the cheapest component. Its target costs are about EUR 6.79 higher. These costs cover more than 15 % of functional product properties.

The insulating glass has not yet represented the optimally required benefit for a customer. There is an opportunity to increase its benefit by optimising product functions. In this case, a new type of triple glazing product is launched. So, the enterprise could find a supplier who will declare the higher quality of the particular component at a higher price. Another step could be to use a new type of glass, as stated by Štulrajter (2016), the so-called multifunctional glass. This type of glass covers a wider spectrum of radiation reflection.

The price for this glass is higher than the price for the earlier used triple glazing. It is an advantage for the customer because of significantly lower heat losses resulting in higher heating energy savings. The component weatherstrips and insulation K5 is the most expensive component based on obtained results. This component is very important for thermal insulation functions, and the effort to make savings with this component could lead to its functional damage. A solution could be to re-evaluate the current supplier or agree on a lower purchase price together with agreed long-term supplies or agreed higher purchased volumes of the component.

Conclusions

Target Costing is a cost-effective methodology that can be used by any enterprise, and it can help meet cost management goals. One of its benefits lies in the acceptance of customer preferences and in the market-acceptable level of sales prices. This paper mainly aimed to refer to the practical application of Target Costing to a specific product of the woodworking industry with a particular emphasis on customer needs and value analysis in relation to individual components and functions of the product —the wood-aluminium window Gemini Quadrat FB. The result of the methodology application should be an innovative product — the wood-aluminium window that fully respects customer requirements and satisfies the ideas and demands of the production enterprise. Based on the research results, the Target Costing methodology could be applied to an enterprise producing wood-aluminium windows. The presented case study focused on the application of the Target Costing methodology under specific conditions of wood-aluminium windows production. The established methodology was used to determine the target price (EUR 513.19) and the level of target costs for the product. Production costs were confirmed as the priority and were quantified at the level of allowable production costs (EUR 379.31). Calculating the target cost index for each component and creating the target cost chart while accepting the q parameter at levels of 5 % and 10 %, assumptions were formulated for the assessment of possible alternatives and potential corrections. The results confirmed that with a higher value of the parameter q, the tolerance zone in the diagram enlarges, and the parameter can be marked as soft. The ideal value of the target cost index was not achieved for any component. If an enterprise wants to succeed in the market and compete, it can use the Target Costing methodology as the target costs (set in the initial phases of research and development) are a decisive aspect in the management of all business processes. Ferreira and Machado (2015) stated that Japan and Asia were areas with the highest percentages of Target Costing application, followed by the United States and Europe. Currently, the application of the Target Costing methodology can be seen in various fields. Cunha Callado et al. (2020) and Goncalves et al. (2018) applied this method to information technologies. Alwisy et al. (2020) and Pennanen et al. (2011) dealt with the Target Costing application in the construction industry. The Target Costing Application in the automotive industry is presented by Baharudin and Jusoh (2015) and Ibusuki and Kaminski (2007). Potkány et al. (2012) investigated customer preferences of simple wood-based houses for the purpose of using the target costing. Other examples of the use of the Target Costing methodology can be seen in hotel management (Aladwan et al., 2018), the agriculture sector (Lima et al., 2016), and healthcare facilities (Macuda and Orliński, 2017). Johansen et al. (2021) focused on large and complex infrastructure projects in the context of the Norwegian construction industry.

The practical application of the generally well-known Target Costing methodology under specific industrial conditions is a suggested limitation of the paper. Further research should be focused on furniture-making with a relevant customer preference survey regarding the chosen product.

Acknowledgements

This research was supported by projects APVV-18-0520 "Innovative Methods for Analysing the Performance of Wood and Forestry Complex Using the Principles of Green Growth", and project KEGA 005TU Z-4/2020 "Economics, Management and Enterprising in Wood Industry Companies — University Textbooks with the Support of Visualisation in Virtual Space". This publication is also the result of the project "Progressive Research of Performance Properties of Wood-based Materials and Products (LignoPro)", ITMS 313011T720 supported by the Operational Programme Integrated Infrastructure (OPII) funded by the ERDF.

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Volume 13 • Issue 4 • 2021

sciendo

International Society for Manufacturing, Service and Management Engineering

received: 20 August 2021
accepted: 10 December 2021

pages: 160-173

Applying blended foresight methods for revealing incentives and future strategies of key national innovation system players

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ABSTRACT
The paper aims to develop and apply a methodological approach that could help to reveal incentives and future strategies of key National Innovation System (NIS) players considering the influence of global social, economic, scientific, technological and ecological trends. To fulfil this aim, a blended foresight methodology was applied, grounded on the platform of economic and classic foresight theory and considering four possible directions for using foresight methods: investigating and building a common vision; supporting evidence-based decisions; promoting communication and participation; inducing transformation and integration into the decision-making process. The main results and findings of the research include a list of 19 global trends, defined from literature analysis and the author's expert knowledge, a short description of their influence on key NIS players, including society, business, infrastructure and institutions, science, education and government; and mapping more than 35 different foresight methods that could be used for revealing incentives and future strategies of key NIS players. The article's theoretical contribution to economic theory consists of several parts. First, a NIS conception is examined through the prism of global trends and a dynamic aspect, whereas it is mostly investigated from statistical and static perspectives. Second, applying foresight as an instrument for researching NIS as a system is a developing academic area with some theoretical gaps, considered in this article by designing a conceptional research framework. Third, blending different foresight methods is always a craft, and the approach applied in this article contributes to it. Finally, the article presents several important trends which will appear in NIS and its key players' transformation in the nearest 5–10 years. From practical implications, this article could be useful for proactive policymakers in the field of science, technology and innovation policy at national and regional levels for designing and providing measures for supporting innovation systems effectively. Foresight practitioners and experts are offered useful, practical ideas of different foresight methods and their possible combinations for everyday activities.

KEY WORDS
foresight methods, blended foresight, technological change and its management, national innovation system, global trends, new institutional economics, planning models and policy

10.2478/emj-2021-0038

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Introduction

National Innovation Systems (NIS) will be radically transformed in the nearest future under the influence of global trends, primarily connected with Industry 4.0, widely spread Internet of Things (IoT) and artificial intelligence (AI), total digitalisation and new models of conducting research and innovations which become open, shared, multidiscipline and multicultural (OECD, 2021). Although there are hundreds of theoretical and empirical investigations

Chulok, A. (2021). Applying blended foresight methods for revealing incentives and future strategies of key national innovation system players. *Engineering Management in Production and Services, 13*(4), 160-173. doi: 10.2478/emj-2021-0038

and thousands of academic papers describing the current status of NIS in different countries and various aspects, approaches to global trends revealing and assessing their effects, the overall research landscape is still seriously fragmented. Key NIS players — business, science, government, education and society — are changing dramatically along with technologies brought by a new technological wave, standards and requirements, such as non-carbon, ESG (environmental, social, and governance) or ethical, face new challenges and opportunities. Their incentives for demand and supply of goods and services shift to new strategies that lead to their repositioning in the NIS conception. Accordingly, the role of NIS is challenging and expanding to become an ecosystem for all participants (Sena et al., 2021), providing more social and inclusive functions, supporting the adaptation to uncertainty as a new reality and forthcoming wild cards (events with low probability, but large-scale effects (Chulok, 2021)), such as the pandemic and its effects, and encouraging the transformation of international and domestic economic, social and technological systems.

A fully-fledged scientific approach that could provide a theoretical framework for all these sophisticated transformations is still in progress, as well as its instrumental part needed for revealing incentives and future strategies of key NIS players from the point of view of global trends. In this respect, the foresight approach has successfully proven its efficiency for identifying global trends and creating a future vision at national, industrial, corporate and regional levels for more than 70 years and within three-thousand projects that were conducted using foresight all over the world (Miles et al., 2017; Andersen et al., 2017; Sarpong & Meissner, 2018). Once a landscape of global trends is identified, different foresight methods could be blended to create a toolkit for dealing with key NIS players in several directions: investigating and building a common vision; supporting evidence-based decisions; promoting communication and participation, and inducing transformation and integration into the decision-making process.

A research gap to which this article contributes consists of two parts: the methodological part, explaining how the future development of NIS and its players could be investigated and predicted through the prism of global trends and using different foresight methods; and the empirical part, precisely establishing what global trends should be considered and what changes in NIS and its players could be induced. Consequently, more than 35 different foresight methods were mapped for dealing with different NIS players (i.e., representing business, society, science and education) considering 19 global trends.

1. Literature review

Classical works on NIS traditionally refer to research made by Lundvall (1992), Freeman (1995) and Nelson (1993) at the beginning of the 90s of the last century. They set a basic framework of this concept, which lately was enhanced by the contribution of Edquist (1997) and other authors (OECD, 1997). This period in the economic theory was aimed at searching for different competitiveness factors at national, regional and corporate levels, and innovations were widely empirically tested to be one the most important factors along with a country's financial and institutional conditions. Initial approaches to NIS included business, science, education and several stakeholders as key players within rather a linear approach. As this conception became popular in policy-making agendas and more data were gathered, processed and investigated, the framework was moving to a more sophisticated view (Godin, 2007; Lundvall, 2007; Acs et al., 2017; Godin, 2017; Lee et al., 2021). Nowadays, several different approaches and conceptual frameworks of NIS can be distinguished, which are primarily aimed at getting a snapshot of the current status of key players at national and regional levels (Lo et al., 2013; Leydesdorff & Porto-Gomez, 2019), searching for a new type of players, such as venture funds, start-ups, or industrial associations (Datta et al., 2019), delving deep into the process of knowledge creation and dispatch, including the conception of the so-called triple and quadruple helix (Etzkowitz & Leydesdorff, 2000; Carayannis & Campbell, 2009; Leydesdorff, 2012; Carayannis et al., 2018; Maruccia et al., 2020). Some authors include systemic, ecosystemic and dynamic approaches to embrace all NIS changes and transformations, including the Big Data analysis (Dedehayir et al., 2018; Prokop et al., 2021; Sena et al., 2021).

One of the main research questions to be resolved is forecasting possible future NIS visions. This academic landscape is still rare. Some attempts were made by using agent-based and similar models, but they do not provide a full-fledged overview and have several limits and restrictions concerning data and the integration into the decision-making process (Zhangqi et al., 2021; Paredes-Frigolett et al., 2021). On the other hand, foresight as a theoretical and empirical instrument has been widely used to serve very similar goals. With a vast history since the start as an expert-based technique for forecasting perspective directions for science and technology development (e.g., applied by RAND in the USA (Georghiou et al., 2008) or Delphi survey in Japan (Zartha et al., 2019)) and the transformation into a very serious and sophisticated methodology that drawn on dozens of different research methods from social sciences, mathematics and econometric modelling, marketing and strategic management and even philosophy and psychology (Georghiou et al., 2008; Sokolov & Chulok, 2016; Gokhberg et al., 2017; Miles et al., 2017). Foresight could be used for investigating and creating future visions for business, education and scientific organisations, traditional and new industries, cities and regions, nations and even geopolitical unions (Vecchiato & Roveda, 2014; Rohrbeck et al., 2015; Cagnin et al., 2015; Keller et al., 2015; Piirainen et al., 2017; Do Couto e Silva et al., 2017), i.e., all current NIS players (Georghiou & Harper, 2011; Andersen, 2014; Aguirre-Bastos & Weber, 2018). The increase in foresight methods and instruments gave rise to more classifications. Apart from traditional approaches that distinguish qualitative, quantitative and semi-quantitative methods, the most profound include the Foresight Diamond suggested by Popper, who distinguished four knowledge sources, i.e., creativity, evidence, expertise and interaction (Popper, 2008). Later, he upgraded his approach to the S.M.A.R.T. Futures Jigsaw, using five classification indicators: scoping futures, mobilising futures, anticipating futures, recommending futures, and transforming futures (Popper, 2011). Saritas et al. used a systemic approach and created the 7I classification following the key foresight study steps: intelligence, imagination, integration, interpretation, intervention, impact and interaction (Saritas, 2013). This idea is close to what Popper invented during his analysis of the main foresight loop, which includes pre-foresight, recruitment, generation, action and renewal (Popper, 2008). Some authors suggest a "client-oriented" approach to foresight method classification in parallel with business offers: "basic", "optimal", and "professional" (Chulok, 2021). They differ by expenditures, required resources, requirements for expertise and special software, the time of conducting, the granularity and accuracy of results, and provide potential foresight clients with a deep understanding of the pros and cons of each "package", also managing expectations.

In summary of the relevant field of these studies, NIS and foresight conceptions were developed initially to provide decision-makers at national, industrial, corporate and regional levels with relevant information of a future vision and help them set appropriate priorities for their tactic actions in the field of science, technology and innovation. The initial pre-assumption for the first foresight studies in the early 50s–70s of the last century was that the future could be predicted or forecasted mostly by mathematical models or within large-scale expert surveys, such as Delphi. Later, as the external environment became more sophisticated, more research instruments and techniques had to be used and elaborated. The basic hypothesis for that period, which is still relevant, was that the future could be formed or designed by stakeholders (e.g., key NIS players) more than forecast by a limited number of highly professional experts. Nowadays, both conceptions admire the complexity and nonlinear linkages between stakeholders and search for a new theoretical and methodological platform for future development. This is somewhat coherent to what can be observed in the economic theory in its recent search for a deeper understanding of economic agent's behaviour, incentives, causality and drivers, and attempts to build linkages between micro-, meso-, and macrolevels. Similar changes occur at a practical level in the field of strategic development and futurism, where some experts warn about the fundamental shift from the so-called VUCA (volatility, uncertainty, complexity, and ambiguity) approach to the BANI conception (brittle, anxious, nonlinear, and incomprehensible). Anyway, in such turbulent theoretical and practical movements, foresight could be nominated as a universal platform or ecosystem to unite them all.

Recent trends in foresight studies include more emphasis on stakeholder mapping and engagement (Saritas, 2013; Miles et al., 2017), deeper integration into the decision-making process (Gheorghiu et al., 2016; Pombo-Juárez, 2017; Minkkinen et al., 2019; Wang & Li, 2019; Wright et al., 2020; Robinson et al., 2021), increasing future literacy as a capability (Miller et al., 2018), and using a systemic approach to its organisation and conducting (Munigala et al., 2018; Van Dorsser & Taneja, 2020). These make a realistic idea of applying foresight methods for revealing incentives and future strategies of key NIS players.

Thus, this article answers the following research question: how foresight could be applied for better understanding incentives and future strategies of key NIS players? In search of an answer, conceptional frameworks were elaborated to understand NIS players in light of global trends, create a list of global trends that could influence key NIS players in the nearest future till 2030, and develop four bases of applying foresight methods. As a result, 19 global trends were identified, and 35 foresight methods were included in the final matrix (Table 2).

The article contributes to the conceptual bridging of economic theory and practice in the field of technological change, innovations and economic systems. It presents a research methodology that reveals foresight possibilities for investigating NIS future and its key players, provides practical recommendations for decision-makers, including policy-makers for blending and choosing instruments for that, and opens the floor for further discussion.

2. Research methodology

Considering the approaches and results of the abovementioned works, the following research design (Fig. 1) and research methodology (Fig. 2) were applied.

Step 1 — identification of key NIS players. Six different stakeholders were distinguished for this article: society, business, infrastructure and institutions, science, education and government. It can be argued that at least twice as many players exist, such as research funds, start-ups, different associations, expert societies and communication platforms that also play an important role in NIS. It is certainly true; however, for this conceptual model, it is enough to examine the created approach and leave some room for further improvements and discussions.

Step 2 — setting global trends — was a challenge due to numerous profound reports, academic papers and research efforts devoted to their analysis. Among the most influential and scientifically proven originated in China, Japan, the UK (Saritas, 2013; Miles et al., 2017) and Russia with S&T Foresight 2030, containing a detailed description of more than 150 global challenges for seven priority areas, such as ICT, nanotechnologies and new materials, medicine, biotechnology, energy, transport systems, and rational use of natural resources (Sokolov & Chulok, 2016; Gokhberg et al., 2017). Finally, a list of 19 global social, technological, economic, environmental and political trends were elaborated according to the following system of criteria: a trend should be global, e.g., the influence should go beyond geographical or sectoral borders; sustainable, for at least the nearest 10–15 years; and influential, e.g., has a significant current or potential impact on incentives and strategies of investigated key NIS players (Table 1).

Step 3 — choosing appropriate foresight implementation — was made considering four groups:

Group 1 “Exploring and building common vision” is connected with different foresight instruments that provide insights about the future based on scanning global trends, extracting expert knowledge using various sociological methods and platforms (as technological platforms or wiki portals).

Group 2 “Supporting evidence-based decisions”, including innovation and investment strategies and plans, stands upon hard data methods such as statisti-

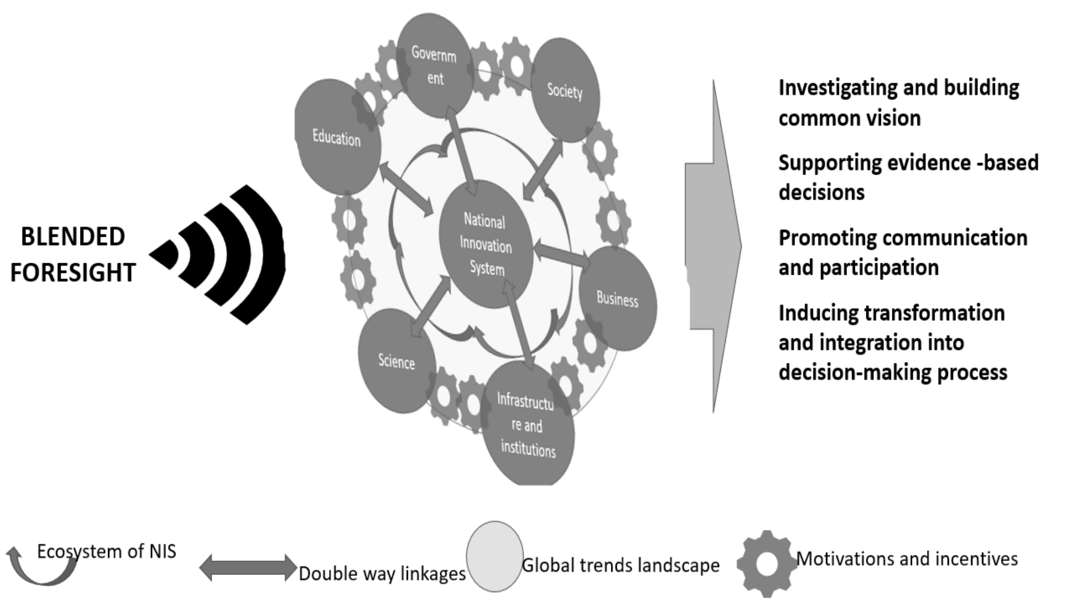

Fig. 1. Conceptual research design framework

cal, bibliometric or patent analysis, mathematics and econometric modelling on statistical or empirically gathered data, Big Data analytics.

Group 3 "Promoting communication and participation" deals with a huge range of sociological and physiological methods aimed at inducing stakeholder interaction and making it sustainable, using modern IT technologies and opportunities.

Group 4 "Inducing transformation and integration into the decision-making process" is one of the most demanded parts of foresight as it helps to translate results into actions and provides the NIS stakeholder navigation from "point A to point B", applying such instruments as technological and business roadmaps, policy recommendations, scenarios and priorities.

Step 4 — applying a blended foresight for creating a recommendation list for the most efficient methods that could be used for revealing incentives and future strategies of key NIS players by the above-mentioned four groups. More than 35 different foresight methods were finally included (Tables 2–7).

3. Research results

The results of applying the developed methodology to six key NIS players are presented below in the following format: first, a short description of affecting global trends to incentives and strategies is done, and then, the foresight methods divided into four groups are depicted. Some methods are universal, such as STEEPV or scanning for mega- or global trends; however, they differ in their emphasis and estimations concerning a particular NIS player, while others are more bound with a player, such as investigating research fronts for science or citizen panels for society.

Tab. 1. Global trends affecting key NIS players

Social
Growing social tension and the emergence of new social classes
Digital citizenship
Developing practices of responsible consumption
Ageing of the population and an increase in active longevity
Economic
Widespread of remote forms of employment
Increasing competition for talents
Development of a green economy and ESG principles vs new energy crisis and possible raise of demand for fossil fuels
Growing corporate social responsibility
Development of the concept of a "smart" city and a "smart" region
Hyper-connectivity and growth of the amount of generated data
Strengthening competition for natural resources
Science & Technological & Education
The new industrial revolution and the increasing pace of the innovation implementation
Accelerating the development of digital educational systems
Environmental
Growth in the rate of climate change and the scale of its possible effects
Aggravation of the problem of biodiversity and degradation of ecosystems
Increase in the number of extreme natural phenomena
Development of climate management and terraforming technologies
Political & Global
Global security issues, including cyber, economic, bio and food security
Increasing the likelihood of the pandemic spread

Source: Elaborated by the author based on Chulok et al. (2021).

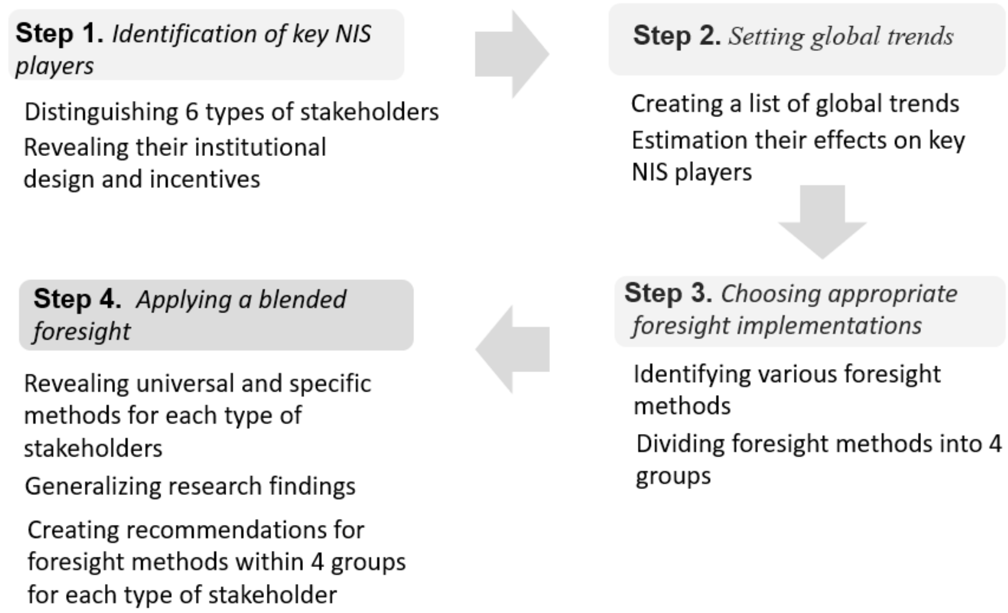

Fig. 2. Research methodology: key steps

3.1. Society

Global trends encourage society to go digital, age-active, behaviour-responsible and tolerant, increase the requirements for security in a broader sense, and create a resilient and smart envi-ronment, personalised products and services. Human capital plays an increasingly more im-portant role in the technological leapfrog and NIS development as the society's (including HR) perception of innovation and new technologies becomes crucial. Uneven distribution of social classes and demographics, the reduction of response speed and the growing importance of social power and capital require a wide range of foresight instruments focused on revealing the future, inducing personal readiness for transformations, and providing comfortable communication platforms (Table 2).

Societal challenges are becoming more frequently included in agendas of policymakers, NIS and foresight researchers, economics and innovations. The general switch from pure economics and "cost/benefit" principles to the ideas of sustainability induces the application of different methods that help understand society more deeply and broadly (e.g., AI). Businesses are the first wave of NIS players to face this need as companies require elaborate segmentation instruments relevant to at least the current status of their traditional and new consumers. In the nearest future, top-class research in this area could personalise the segmentation approach, literally, to each member of society regardless of age, nationality and other characteristics.

3.2. Business

The fundamental transformation of current business models, widespread in ecosystems, including digital, and encompassing different economic and market aspects (e.g., the economy of trust, the sharing economy, green or non-carbon economics, the silver economy, etc.) in one landscape reveals a real need for using foresight as an efficient instrument for competitive intelligence and forward-looking strategies. Significant reduction in the response time and the need to adjust, and agile, literally, the "online" drive of the business demand for foresight methods mostly connected with the integration into the decision-making process and the creation of proactive systems for strategic analytics, are more frequently based on predictive Big Data analysis and smart recommendation systems (Table 3).

Based on the above, foresight instruments could be divided into several types. The first type is simply adding new techniques and methods to traditional ones, e.g., conducting foresight sessions along with SWOT analysis or creating a BCG matrix. In this case, common results could be enhanced with a low synergy effect. Second, the opposite is more frequently used when modern decision-makers want to update everything. This includes AI, Bid Data analytics, etc. However, without expert validation, even the

Tab. 2. Applying blended foresight methods: society

Group 1	Group 2	Group 3	Group 4
Scanning for megatrends of social development, cultural and value transformation Scanning for global, national and regional trends connected with social and demographic changes Development of the social corporate responsibility Identifying and meeting ESG, ethics and other requirements and principles valuable for society Creating ecosystems for boosting demand-driven and inclusive innovations	Trend watching/environment scanning/trend monitoring STEEPVL analysis Identification of weak signals and wild cards (WIWE) connected with society, culture and values Stakeholder identification and mapping Statistical analysis Sociological monitoring and surveys based on representative samples Social futurology/ development of alternative scenarios	Open events (lectures, masterclasses, etc.) aimed at discussing foresight approaches and results Citizen panels Foresight fleet/ marathons/ hackathons Creating information signals for different (relevant) social groups and stakeholders Distributing foresight results using IT platforms and techniques (inc. mobile applications) White papers/memorandums/ analytical reports Creating social-oriented ecosystems and clusters based on foresight results	Creating different PR strategies aimed at different (relevant) social groups and stakeholders Social responsibility agenda setting, strategies, and action plans Reputation management including security, transparency, ESG and ethical issues

most profound model or software system only produces more picturesque figures. Third, a truly blended approach refers to fundamental changes to traditional strategic development instruments and their alignment to a complex fully-fledged methodology.

For example, in the Russian S&T Foresight 2030, to get more interesting and attractive results for the business and to increase their representativeness in the whole research, a methodology was created that combined marketing methods (e.g., the market pull approach, the identification of product and service-competitive characteristics) with traditional foresight instruments (e.g., the Delphi survey) and elaborated strategic sessions by adding results of the horizon scanning and stakeholder mapping (Gokhberg et al., 2017).

Nowadays, various businesses actually represent the "living laboratory" for testing different theoretical conceptions. As its role in NIS was changing, the demand for instruments dealing with the future was growing. Russia could be a good example of how a rapid and fundamental transformation could occur. For less than 15 years, Russian companies went from the "no need" position to the "must-have" imperative (Chulok, 2021).

3.3. Infrastructure and institutions

Global trends will result in a tremendous infrastructure change in the nearest future: while previously it was mostly physical, many aspects are becoming more digital, such as research and innovation development, generation and dispatching of knowledge, and logistics and supply chains. The cyber-physical embodiment of infrastructure reveals hidden capabilities of key NIS players, including small and medium enterprises, individual research and start-ups, and ensures multinational and multisectoral teams and conducted research, decreases transaction costs and develops transparency. Such changes demand a radical transformation of institutions that should be agile, open to new ideas and their implementation (e.g., within the so-called "sandbox" conception), and provide security in the broad sense, including cyber, product and mental (Table 4).

Infrastructural and institutional challenges become increasingly more crucial for creating the knowledge-based and digital economy and transforming to Industry 4.0 or further. The shortage of resources for the new industrial revolution, including natural, such as silicon for assembling semiconductors, electric energy for cybersports or AI learning, could put the infrastructural question on top. Rigidity and the increasing pace of changes create the demand for a new class of institutions. In this respect, different foresight instruments, such as trend watching and roadmapping could be useful. A good case of how they were applied is "International roadmap for devices and systems™", which unites stakeholders from different countries and elements of value chains and provides a communication platform for designing the future.

Tab. 3. Applying blended foresight methods: business

Group 1	Group 2	Group 3	Group 4
Scanning for megatrends of markets, consumer patterns and demand Scanning for global, national, regional and industrial trends Demand segmentation and searching for new market niches Description of prospective goods and services and assessment of the timing of their appearance on the market Identification of consumer characteristics of goods and services that determine their future competitiveness Identification of global and local value chains and their promising (high-margin) links Competitive intelligence/ identification of competitor's plans and agendas Identifying potential cost and profit centres New business model's identification Boosting demand-driven innovations Winner and loser analysis	Trend watching/environment scanning/trend monitoring, including business trends analytics STEEPVL analysis Analysis of five market forces by Porter/ industrial analysis Competition analysis Identification of WIWE Statistical analysis SWOT analysis BCG matrix Developing market scenarios including market volume and the CAGR forecast Delphi survey made by large expert samples Empirical surveys made by representative and statistically informative samples Market pull approach Econometric modelling Macroeconomic and industrial models Product life cycle assessment Imitation modelling/ developing scenarios Predictive analytics, including IT technologies and Big Data processing	Foresight-sessions/ industrial and business sessions aimed at creating a common vision and encouraging competitors to work together Interactive foresight platforms Creation of business ecosystems based on open innovation principles Expert panels White papers and memorandums	Mid- and long-term strategies Innovation and investment planning Setting priorities Technological, business and organisational roadmapping Win–win action plans Informing stakeholders and the CEO

3.4. Science

An increasing role of STI (science, technology and innovation) in national competitiveness, which was witnessed recently, was boosted by several wildcards — such as the pandemic and low oil prices. Growing expectations of finding Grand Responses for Global Challenges encourage deeper investigations into the nature of STI, all peculiarities of linkages, incentives and motivations inside this framework and create a fruitful discussion on different foresight instrument implementation. Among the most influential is a new wave of modelling and forecasting enhanced by IT technologies. Another important issue is using various communication instruments of foresight: the scientific language always differs from the vocabulary used by other NIS players; thus, translation is essential for a common vision and solution (Table 5).

Initially, foresight was applied for setting STI priorities. Today, its role is expanding and aims to identify research fronts and S&T frontiers, find areas for mutual collaboration at intercountry, intercultural, and multidiscipline arenas. To fulfil such demands, foresight itself goes to the edge, blending traditional forecast methods, based on statistics and hard data with experts' validation and their tacit knowledge, improving sociological and empirical instruments (e.g., online surveys, including Delphi, which can trace and count the response time) and applying Big Data analytics and AI.

3.5. Education

Education systems all over the world face difficult times caused by pre-pandemic challenges, such as digitalisation, spreading remote education, problems of retraction universities into research and innova-

Tab. 4. Applying blended foresight methods: infrastructure and institutions

Group 1	Group 2	Group 3	Group 4
Scanning for global, national, regional and industrial trends in the field of infrastructure and institutions Creation of a navigator or atlas describing different aspects of the future vision and demand for infrastructure and institutions Identification of the global and local value and logistics chains	Trend watching/trend monitoring Institutional analysis Statistical analysis Analysis of goods distributed within value and logistics chains based on databases (e.g., TiVA (Trade in Value-Added) or WIOD (World Input-Output Database)) SWOT analysis BCG matrix Benchmarking of suppliers institutional regimes Financial and business modelling ABC analysis/profit and loss analysis	Foresight session concentrated on b2b and b2g segments, procurement Creation of ecosystems/ integration in existing infrastructural or institutional ecosystems Creation and distribution of informational signals about the future vision and requests Engaging education and new skills for personnel employed in infrastructure and intuitional blocks of NIS	Creating a roadmaps action plan for infrastructure and institutional part of a common strategy Financial and procurement strategy and action plans Supply chains management Changes in risk assessment models and plans

Tab. 5. Applying blended foresight methods: science

Group 1	Group 2	Group 3	Group 4
Scanning for scientific megatrends and research fronts Scanning for global, national, regional and industrial trends with application to scientific development Defining characteristics and effects from radical and descriptive innovations and scientific discoveries Identification of long-term basic and applied science problems that can create a framework for the future (e.g., teleportation, space colonisation, nanoassembling) In-depth interviews	Identification of critical technologies and developing their portfolio (leading countries, centres of excellence, expenditures, effects, etc.) Statistical analysis Bibliometric and research fronts analysis including IT techniques Patent analysis including creating patent landscapes Technological benchmarking Technological audit Technology push approach Delphi surveys Assessment of technology readiness level (TRL) Product life-cycle analysis Genius forecast (with prominent researchers and visionaries, futurologists, Nobel prize winners etc.) Futurology/science fiction/ fantasy/ development of alternative scenarios Scientific and technological WIWE	Foresight session with leading science experts Focus groups and private talks Creation and support of departments, spinoffs and start-ups based at universities Creation of internal environment for knowledge and innovation generation, distribution and circulation Creation of systems and ecosystems embracing scientific and educational institutions and based on principles of open science and innovation	Scientific and technological roadmap Creating roadmaps for interconnection with scientific organisations and universities Developing various policy measures aimed at STI support, including the "policy mix" conception Creating national, industrial and regional systems for strategic foresight and planning and their initialisation (e.g., via special law or ministry mandate)

tions activities and changing society demands for education to be more agile, blended and offer "lighter" formats. After the global lockdown, the "old school" face-to-face communication was recognised as still desirable and live interaction has become a luxury good, but wherein some educational activities went online for a long time, at least to provide life-long learning for everybody. The third mission of universities and expectations from other NIS players open huge possibilities for foresight, especially for setting priorities for the future and creating efficient ecosystems around universities (Table 6).

Pandemic challenges forced fundamental transformation of education as a system, including not only universities and schools but also corporate learning systems and the institute of mentoring. No surprise, education sometimes is more inert than other systems and teachers and students have to pass through endless challenges. Under such conditions, the participative and communicative role of foresight is highly valued. As it stands upon the scientifically-based approach, it is more trusted than other conceptions, and its orientation for designing and forming a common vision is useful. Many world-known universities, such as the University of Manchester, Bialystok University of Technology or National Research University Higher School of Economics, used foresight for developing strategic agendas, educational and STI programmes.

3.6. Government

The role of government in establishing and supporting sustainable and efficient NIS was widely discussed since the occurrence of this concept in the mid-90s. Nowadays, the diversification of academic opinions and policy prescriptions differ from pure Adam Smith's invisible hand approach to total intervention into almost all NIS processes. Only time could judge which way was the most efficient, but what is common for all options is the increase of qualified clients among officials, growing demand for evidence-based foresight and policy instruments, interest in scenarios and gamification methods and expanding NIS conception to the ecosystemic approach (Table 7).

The horizon of strategic planning is changing dramatically. Several years ago, almost all foresight and forecasts explored the year 2030 or similar, and now we see a rapid leapfrog to 2050 in the European Policy Agenda (Green Deal 2050), Indonesia Vision 2045, China National Roadmap and Plan 2050, 11th Japan Foresight 2040–2050. To deal with such a long period, which is characterised by exponentially

Tab. 6. Applying blended foresight methods: education

Group 1	Group 2	Group 3	Group 4
Scanning for megatrends in education Scanning for global, national, regional and industrial educational trends Defining characteristics and effects from radical and descriptive innovations influencing education systems and universities Exploring the conception of the triple and quadruple helix to clarify the possible vision of education and universities Identification of possible directions for collaboration with scientific and business organisation In-depth interviews	Identification of critical technologies and developing their portfolio (leading countries, centres of excellence, expenditures, effects, etc.) Statistical analysis Bibliometric and research fronts analysis including IT techniques Patent analysis including creating patent landscapes	Foresight session with leading experts in science and education Focus groups and private talks Creation and support of departments, spinoffs and start-ups based at universities Creation of internal environment for knowledge and innovation generation, distribution and circulation Creation of systems and ecosystems embracing scientific and educational institutions and based on principles of open science and innovation Youth foresight, including various methods of communication with pupils and students (e.g., summer/ winter schools, seminars, masterclasses)	Scientific and technological roadmaps Creating roadmaps for interconnection with scientific organisations and universities Changes in educational standards and requirements due to results of foresight Educational policy Developing various policy measures aimed at STI support, including the "policy mix" conception

increasing uncertainty factors, foresight methods from the creativity group could be useful.

For all these requirements, foresight could suggest reliable instruments, especially in the field of integration into the decision-making process on an everyday basis and creating a fully-fledged foresight system at a national and industrial level as the one developing in Russia (Sokolov & Chulok, 2016).

Discussion and conclusions

To choose an efficient methodology for working with the future, it is important to understand the peculiarities of demands from key NIS players, which moves toward better quality and in-depth foresight. The most significant trends are the growing demand for more evidence, expanding variability, and the increasing role of priorities.

Evidence implies the existence of a solid scientifically grounded research base, transparent and validated methodology. Arguments "according to experts' estimates" or "the model showed" that satisfied decision-makers 10–15 years ago are no longer considered valid. Variability does not imply a description of the future according to one "base" or "target" scenario, but the characteristic of various alternative scenarios, e.g., simulation modelling or scanning for wild cards. Prioritising means not only ranking the recommendations in the field of markets, products, technologies or science directions. If earlier priorities often came using the "top-down" approach, and then their choice was supported by relevant arguments, now the process is increasingly more "bottom-up": first, a landscape of global trends should be elaborated, and then, depending on the criteria (social or ecological compliance, increase in revenue or marginality, meeting security and safety requirements, etc.) a list of priorities is formed.

The methodological model presented and applied in this article reveals several important trends which will appear in NIS and its key player transformation in the nearest 5–10 years.

Changing the NIS role as a system and its move toward an ecosystem framework, which implies more sophisticated linkages among participants, searching for a balance between manual regulation and free development and deeper integration into solving forthcoming global challenges, primarily connected with the ageing population, energy and climate change, recovery of biodiversity. We notice increasing expectations from NIS stakeholders and especially policymakers for a transformative role of NIS (Havas & Weber, 2017), which could help economic agents to adapt to the new reality, change business models, mindsets and obtain knowledge and skills needed for deeper integration into the new technological wave.

In this respect, foresight as a visionary basis could be very useful. A shift in academic and empirical research should also include creating or radically updating a statistical system that serviced the NIS conception from the static to the dynamic approach.

Tab. 7. Applying blended foresight methods: government

Group 1	Group 2	Group 3	Group 4
Scanning for megatrends of geopolitical transformations, agendas and strategies of leading innovation counties and unions Scanning for global, national and regional trends connected with regulation and policies Setting science, technology and innovation (STI) priorities for mid- and long-term Identification of forks and alternatives Stakeholder mapping, including a description of their incentives and strategies In-depth interviews Identification and description of key centres of STI excellence	Developing timelines for regulation and institutional changes, included in key strategic documents (e.g., agenda papers, memorandums, etc.) Benchmarking analysis with other NIS indicators Statistical analysis of key NIS indicators Empirical analysis (including questionnaire surveys) Policy scenarios Imitation models aimed at assessing effects from government actions within the "what if" conception	GR and foresight sessions, including policymakers Providing context dialogue between government and other NIS players Exploring possibilities of the e-government conception Creating and supporting institutional and regulatory framework for developing NIS and connected ecosystems	National roadmaps and plans Developing various policy measures aimed at STI support, including the "policy mix" conception Initiating ad supporting fully-fledged foresight exercises Creating national, industrial and regional systems for strategic foresight and planning and their initialisation (e.g., via special law or ministry mandate)

Redistribution of roles between key NIS players and the occurrence of newcomers, such as smart and megacities, regional and innovation clusters, virtual, garage and craft communities. We are witnessing how global trends are affecting incentives and strategies of key NIS players, and they are getting out of the frameworks and boundaries that were efficient in the past. Society becomes more miscellaneous, torn and inclusive, business moves from pure economic agenda to more complex, including social and environmental, infrastructure goes digital, institutions — more vulnerable, science and education face massive canopy of expectations for struggling with new threats and ensuring the development of human capital and government has to embrace these and provide a sustainable, transparent and efficient framework for the future. These innovations require revision of basic NIS conceptions, which have been set up previously, designing or updating the institutional basis. In this respect, foresight as communication and integration platform could be very useful.

Craftmanship of blending foresight methods is becoming increasingly more crucial for supporting the transformation of NIS and its key players. After conducting dozens of foresight projects at international, national, regional and industrial levels and investigating hundreds of similar research efforts all over the world, we can argue that there is no "silver bullet" for a "standard" foresight task. Four groups of possible foresight application types were investigated in this article, and more than 35 different methods were presented, creating a huge landscape of possibilities for further empirical implication and academic discussion on how to apply blended foresight methods for revealing incentives and future strategies of key NIS players applying the global trends approach. The following were the most significant methodological trends. Mutual integration of quantitative and qualitative methods allowing to compensate the disadvantages of one tool with the strengths of others. For example, using the results of mathematical modelling as input information for the work of expert groups and further "manual" verification, considering expert validation about those parameters or relationships that are impossible or difficult to model. Development of multidisciplinary and multicultural research, which allows getting closer to accurate assessment and forecasting of real processes. For example, the assessment of the prospects for the use of new materials in the energy sector or the application of neurobiological approaches to the analysis of the behaviour of economic agents requires the pooling of knowledge from many disparate areas. The widespread use of digital technologies, artificial intelligence, Big Data analysis creates a new class of future research. They can take different forms from visualisation (e.g., using augmented or virtual reality, allowing to get inside a semantic cluster of global trends and study everything in 3D) to predictive analytics based on machine analysis of documents, for which the development of a market consensus forecast is, literally, sense of a momentary matter.

This article contributes to the economic theory in several dimensions. The economic development, rising role of technological, ecological and institution innovations, the increasing pace of technological change and other global trends were embraced in the NIS conception by the theoretical model suggested in the article. To create appropriate recommendations for dealing with the future of six NIS key players, four groups of foresight implementations were suggested. Then, for each NIS player, a mix of foresight methods was elaborated, including universal and specific instruments. Such a methodological approach contributes to the general discussion of economic systems and their development and sets the scene for further enhancement and improvement. In terms of practical contribution, the article improves decision-making at national, industrial and corporate levels as it informs economic agents about precise global trends that can influence their future in the nearest 5–10 years, expands their toolkit for strategic development by suggested foresight instruments, and induces changes and transformations towards the desired vision. Its social impact could be as high as that of global trends, which could affect the society and almost each its member, depict their possible influence on different NIS players and their linkages. For experts and specialists in economic development, innovation, technological change and growth, this article provides a vast landscape for delving deep into the blending of foresight methods.

Future lines of research include conducting a more sophisticated literature review, including the description of cases, providing comparative and narrative analysis, engaging bibliometric software. The discussion of the research findings could be detailed in a separate book as research literature on NIS and foresight is extensive. The same further research could be done with the suggested methodological conception: defining six key NIS players at different levels and broadening their number. Finally, inter-country or intercultural research could be done as NIS is country-specific, and it could be interesting to implement the suggested methodology in different counties and then compare results.

Acknowledgements

The article was prepared in the framework of a research grant funded by the Ministry of Science and Higher Education of the Russian Federation (grant ID: 075-15-2020-928). The author would like to express his gratitude to two anonymous Reviewers for useful comments and suggestions.

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Engineering Management in Production and Services

Volume 13 • Issue 4 • 2021

received: 10 July 2021
accepted: 10 December 2021

pages: 174-188

Heat transfer and pressure drop analysis of automotive HVAC condensers with two phase flows in minichannels

Teodor Skiepko

ABSTRACT
The air cooled automotive condensers under study are of brazed aluminium tube and center, consisting of one row array of horizontal parallel multi-port flat tubes with louver fins on air side. Each tube is with a number of smooth parallel minichannels for internal flow of refrigerant. The analysis uses decomposition of the condenser along refrigerant flow path into specific different zones as follows: two single phase zones, namely: superheated and subcooled, and a few zones of two phase flow that can appear along some specific condensation paths to be: annular/intermittent/bubble or annular/annular-wavy/intermittent/bubble or annular/wavy/stratified. The approach presented is based on experimental correlations for heat transfer and pressure drop. The heat transfer prediction is performed using ε – NTU_o methodology. The results of the analysis refer to overall heat transfer rate, heat transfer in particular zones, pressure gradients heat transfer coefficients, vapour quality, condensation paths.

KEY WORDS
air cooled condenser, heat transfer and pressure drop analysis, minichannels

10.2478/emj-2021-0039

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Introduction

Vast fraction of passenger cars and trucks produced worldwide are vehicles equipped with air conditioning for which a refrigerant condenser is required to reject cycle energy gain to the environment. The condensers, like other automotive heat exchangers, subject to fulfil some specific automotive requirements such as compactness, low weight and low pressure drop. The compactness is of primary importance because of two reasons, small available chassis for the

Skiepko, T. (2021). Heat transfer and pressure drop analysis of automotive HVAC condensers with two phase flows in minichannels. *Engineering Management in Production and Services, 13*(4), 174-188. doi: 10.2478/emj-2021-0039

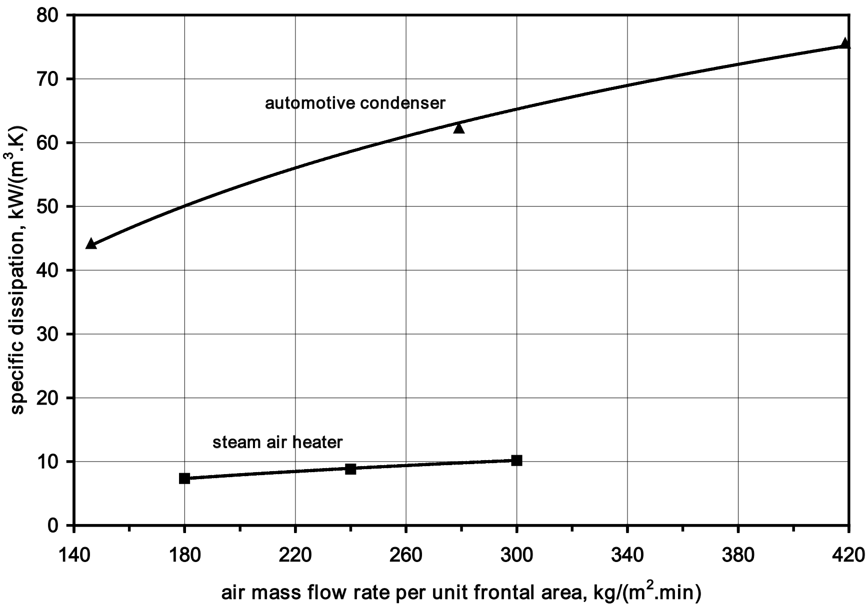

Fig. 1. Experimentally determined specific dissipation for a compact automotive condenser and steam air heaters

condensers as they are located in the vehicle engine compartment right behind the grill in front of the radiator and low weight significance because condenser weight contributes into total vehicle weight. To get a compact design the condenser high performance is necessary. Performance characteristics of automotive condensers, as being dependent on vehicle size and operation conditions, are the best presented if expressed by a specific figure of merit. Applicable to the case is the specific dissipation defined by heat rate dissipated per one degree of inlet temperature difference between the hot and cold fluid per volume of the exchanger core.

In Fig. 1 the specific dissipation as a function of air mass flow rate inflowing per unit frontal area of an aluminium condenser with minichannels for refrigerant flow is shown. For comparison purposes the corresponding data for an air heater by condensing steam assembled noncompact of one row finned steel round tubes arrangement are also presented. One can see in Fig. 1 that the specific dissipation for the condenser due to its compact design is on average six times higher than that for the heater.

The primary objective of this work is to present overall methodology to be purposed for thermal analysis of automotive condensers operating under mixed regimes in minichannels on the two-phase flow side of a vapour compression cycle with refrigerant R-134a as the working fluid.

1. Compact surfaces for automotive condensers

Because of the fact that compactness is the main feature of the condensers under study in this section we present an overview of compact heat transfer surfaces applied for automotive condensers. The condenser coil is composed of three main components: tubes, fins and side manifolds.

1.1. Air side

For automotive applications the air side thermal resistance contributes the most in overall resistance along the path of heat flow between the fluids. Hence particular attention is paid to improve performance of automotive exchangers by reduction the air side resistance. First of all extended surfaces of high compactness are employed. These surfaces by increasing the area for transfer can reduce the resistance by a factor of 3 ÷ 5 with respect to the resistance under air flow across bundles of small in diameter tubes. The other way leading for reduction the resistance is improvement of heat transfer coefficient on extended surfaces under air flow. Here shaped as well as interrupting surfaces are widely applied. These features of automotive exchangers are demonstrated in Figs. 2 and 3.

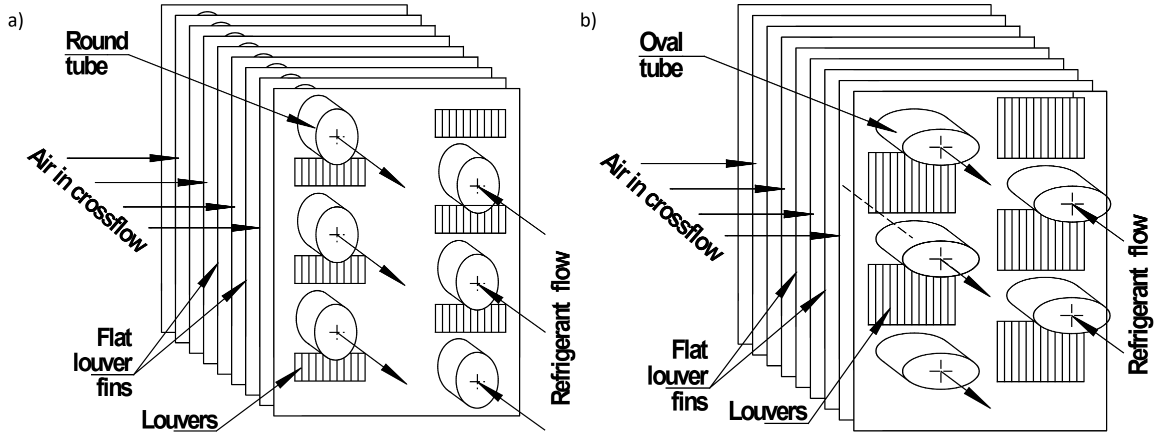

Fig. 2. Extended plain fin surfaces of interrupted geometry with multilouver fins: a) fins on round tubes; b) fins on oval (elliptic) tubes

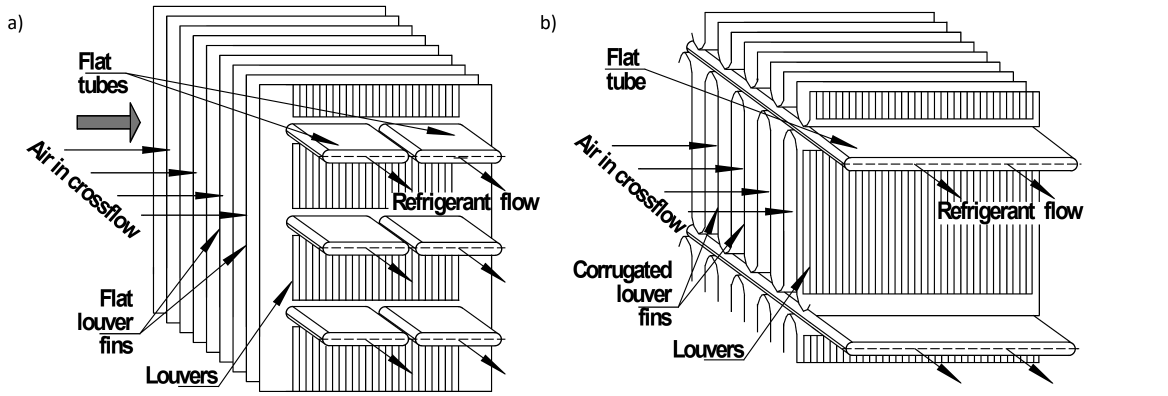

Fig. 3. Extended plain fin surfaces of interrupted geometry with multilouver fins: a) fins on two row flat tubes, b) fins on one row flat tubes

An ultimate design solutions are with the flat tubes with arrangement in one or a few rows, see in Fig. 3.

The designs with flat tubes, as shown in Fig. 3, can provide essential advantages such as:

- small wake zone that affects insignificantly the flow across louvers behind the tube,
- pretty high the average heat transfer coefficient for the overall finned surface because almost entire fin is louvered,
- much higher fin efficiency if fins are attached to the flat tube when compared to the round tube,
- lower aerodynamic drag because the exchanger can be designed with smaller frontal area,
- highest compactness of the exchanger core because of louvered fins are dense corrugated centers sandwiched in between the tubes and manifolds,
- easy way to make multi-port minichannels by extrusion.

Hence, the air cooled condensers with multilouver fins attached to the multiport flat tubes are very popular for automotive applications.

1.2. Refrigerant side

On the tube side there are three basic designs of plate fin-and-tube air cooled heat exchangers, namely: round tubes, oval tubes and flat tubes. The round tubes are in general of OD ~ 6 ÷ 16 mm by the tube wall thickness 0.3 ÷ 0.6mm. The inner tube surface can be smooth or covered with microfins in height of 0.1 ÷ 0.3mm at helical angle of 13° ÷ 25° to enhance the heat transfer coefficient during in tube condensation, see in Fig. 4.

The resultant enhance effect of the microfins is the heat transfer coefficient during in tube condensation of refrigerants increases by a factor 2 ÷ 3 over values of the coefficient for smooth tubes [1]. Availa-

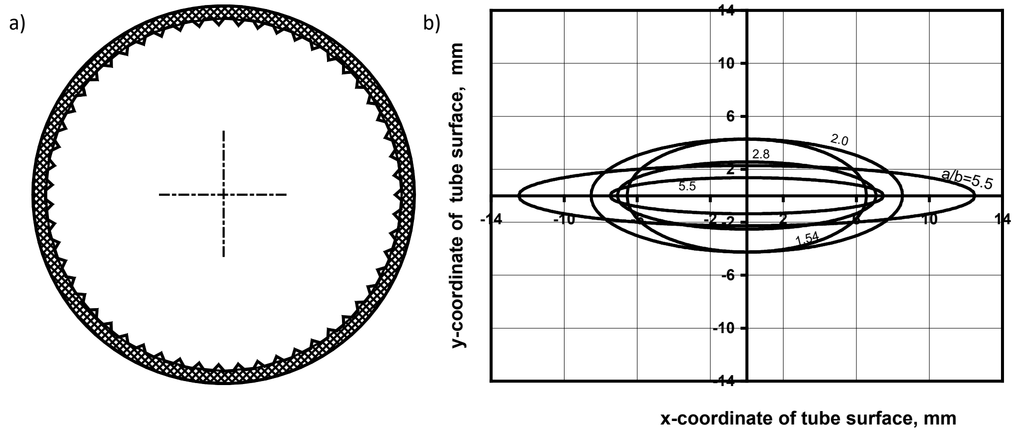

Fig. 4. Exemplary profiles of round and oval tubes applied with plain and louver fins: a) crossection of a round tube with internal microfins (magnification ~3x); b) oval tube profiles (a/b = longer semiaxis/shorter semiaxis)

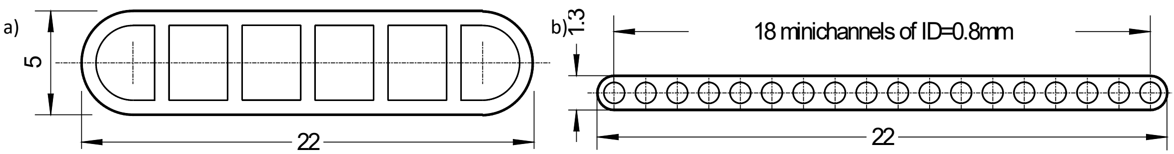

Fig. 5. The multiport extruded aluminium tubes: a) tube with square channels of medium size; b) tube with round minichannels

ble on the market are also multiport extruded aluminium tubes with the internal surface of mini channels smooth or enhanced by microfining. Such the tubes take advantage of low aluminium weight what results in profit from lower vehicle weight. Some exemplary profiles and mean dimensions are shown in Fig. 5.

Due to small inner diameter of the mini channels the inside flow occurs at low Reynolds numbers that values corespond to laminar flow regime. In turn, in tube heat transfer coefficient is higher for mini channels than for round tubes of medium size. This fact combined with dense packing of the core with aluminium flat tubes on air side permit to get much smaller units of equivalent condenser performance.

2. Previous works

Based on numerous references an overview of modelling for design of steam and refrigerant condensers is presented by Kakaç (1991) where considerations for air conditioning condensers are contributed by Pate (1991). Review of open literature shows that the first attempts on condensers design methodology were directed to steam turbine condensers (Šklover & Mil'man, 1985). More recently, the modelling for performance analysis of an automotive condenser is presented by Lee and Yoo (2000) where earlier attempts are also summarized. Their analysis is based on $\varepsilon - NTU_o$ methodology with each fin considered as a single transfer unit. Concerning the refrigerant flow (Lee & Yoo, 2000) assumed a simplified model of the condenser with the only annular regime on the two phase side. The condenser modelling which takes into account the annular and stratified flow regimes is presented by Bansal and Chin (2002). They determined condensation heat transfer coefficient for annular regime on correlation by Cavallini and Zecchin (1971) and by the Nusselt model (Kakaç, 1991) for stratified flow. In turn, by consideration only two flow regimes (Bansal & Chin, 2002) analysis is also limited because transition regime (wavy) that can occupy significant part (roughly about up to 20% of tube length) of condensation path is not included. For an automotive condenser with minichannels on the refrigerant side and louvered fins on the air side Jabardo and Mamani (2003) report the results of condenser modelling accompanied with experimental data related to. The model has been developed based on dividing the three pass condenser coil into three regions: the superheated vapor, the change of phase, and the subcooled liquid regions. Regarding the heat transfer coefficient on the refrigerant side that for single phase regions are determined in Jabardo and Mamani (2003) using well known Dittus and Boelter correlation and a correlation by Mamani (2001). His correlation is of the same form throughout all two phase region regardless two phase flow regimes occurring as the condensation progresses. In turn the analysis of two phase side proposed in Jabardo and Mamani (2003) is an approximation because one correlation cannot grasp different mechanisms of in tube condensation under different flow regimes. With respect to the air side Jabardo, Saiz and Mamani (Jabardo & Mamani, 2003) determine the heat transfer coefficient on correlation by Chang and Wang (1997).

With respect to thermal analysis of brazed aluminium condensers that use flat tubes with mini channels of small diameter for refrigerant flow under combined regimes annular/intermittent/bubble or annular/wavy/stratified or annular/wavy/intermittent/bubble no papers have been found to be published in open literature.

In the paper, at first an overview of heat transfer and pressure drop modelling applied for automotive condensers operating at mixed regimes on the two phase flow side is summarized. Then detailed solution procedure is outlined for the rating problem an automotive condenser using a specific set of input data and the results obtained are then presented.

3. Heat transfer modelling applied

We seek for heat transfer performance and pressure drop results for the condenser. To carry out the analysis a lumped approach is used with decomposition of the condenser coil along refrigerant flow into a number of zones established with respect to single phase and two phase flow regimes. In turn, the refrigerant flows (assuming at constant pressure) through either zone with its total mass flow rate, however, either zone is cooled in the crossflow with air stream of fractional mass flow rate that corresponds to total air mass flow rate via ratio the zone frontal area to total condenser frontal area. Since the refrigerant side heat transfer coefficients and pressure gradients can vary significantly along the flow the mean values within boundaries of each zone were calculated by integration.

3.1. The ε – NTU_o relations

The case of crossflow with both fluids unmixed is applied for single pass zones of no phase change so that the formula for effectiveness for the zones in point is given by (Incropera & DeWitt, 1996)

$$\varepsilon = 1 - exp\{NTU_o^{0.22} \cdot [exp(-C^* \cdot NTU_o^{0.78}) - 1]/C^*\} \quad (1)$$

Although, full mixing is assumed at either cros-section of individual minichannel, the assumption that the tubeside fluid is unmixed can be justified because usually number of parallel minichanels (rows) is significant. The shell side fluid is also considered unmixed. This assumption is commonly recommended to use for the case as well as also applied in data reduction procedures for heat transfer coefficients (Wang et al., 2000).

Regarding zones of two phase flow, note that $C^* = 0$ holds. Then the effectiveness is given by

$$\varepsilon = 1 - exp(-NTU_o) \quad (2)$$

In order to develop relationship describing parameter NTU_o of Eqs. (1) and (2) the total thermal resistance R_t in the path of heat flow between the fluids is required. The resistance Rt for the case is the sum of component resistances because the corresponding thermal circuit is along with resistances in series, hence

$$R_t = R_o + R_w + R_i \quad (3)$$

In turn, all the components of Rt envisioned in Eq. (3) need to be determined for either established zone of the condenser.

3.2. Component thermal resistances on the path of heat flow

The material of this section deals with the determination of individual resistances of Eq. (3) in which the main contributing considered in the paper are: convective resistances on the air and refrigerant sides and conductive resistance across the wall separating the fluids.

Thermal resistance on the air side. The resistance for a condenser zone of air side transfer area A_o extended by fins is determined on the following expression.

$$R_o = 1/(\eta_o \cdot h_o \cdot A_o) \quad (4)$$

Efficiency η_o of Eq. (4) is related to transfer areas A_o and A_f as well as fin efficiency η_f by

$$\eta_o = [1 - (A_f/A_o) \cdot (1 - \eta_f)] \quad (5)$$

where η_f is dependent on coefficient h_0 via the fin parameter. Hence, the most essential problem in determining R_0 is evaluation of heat transfer coefficient h_0 for extended surface with corrugated fins of louvered type brazed in between the flat tubes, as shown in Fig. 6. For the case with corrugated fins Chang and Wang (1997) proposed the following correlation describing the Colburn factor

$$j = Re_{L_p}^{-0.49} \cdot \left(\frac{\theta}{90}\right)^{0.27} \cdot \left(\frac{F_p}{L_p}\right)^{-0.14} \cdot \left(\frac{F_\ell}{L_p}\right)^{-0.29} \cdot \cdot \left(\frac{T_d}{L_p}\right)^{-0.23} \cdot \left(\frac{L_\ell}{L_p}\right)^{0.68} \cdot \left(\frac{T_p}{L_p}\right)^{-0.28} \cdot \left(\frac{\delta_f}{L_p}\right)^{-0.05} \quad (6)$$

An advantage of Eq. (6) is that it combines the Reynolds number and all the geometry parameters essential for fin design into an accurate formula developed based on fitting significant amount of experimental data for the louver fins.

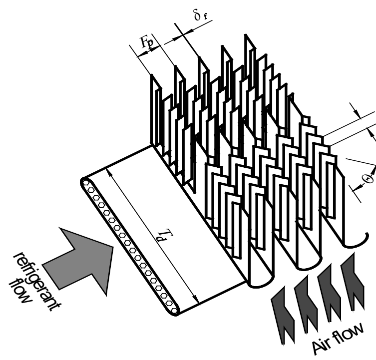

Fig. 6. Corrugated louver fins onto flat tube in a crossflow and associate dimensions

Correlation (6) determines the mean value of h_0 (note, η_o is not included into h_0) throughout all the extended surface (prime surface + fin surface) and is valid for air flow at Reynolds numbers bounded in between 50 ÷ 5000 for number of tube rows N = 1 and 2. It correlates experimental data on j factor at mean deviation ±7.55%.

Wall conduction resistance. The thermal resistance of the flat tube wall is determined by the conduction shape factor. To use available data defining the factors for transverse heat conduction a repeatable element of the tube crossection with a single circular minichannel is selected as shown in Fig. 7. The upper and bottom surfaces of the element as well as minichannel wall surface are diatermic but the left and right surfaces located in the middle of the wall between two adjacent minichannels can be considered as adiabatic (due to symmetricity).

For conducting system shown in Fig. 7 the conduction shape factor SL expressed per unit length of the element is given by (Zweidimensionale Wärmeleitung, 1984)

$$S_L = \frac{2 \cdot \pi}{\pi \cdot (D_m/2)/s + ln[(s/2)/(\pi \cdot D_i/2)]} \quad (7)$$

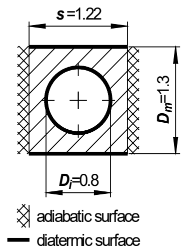

Fig. 7. Selected element of the flat tube with a single circular minichannel

Hence, for a zone of length L having N parallel flat tubes either with n mini channels the conduction resitance R_w can be expressed as

$$1/R_w = \lambda_w \cdot S_L \cdot L \cdot N \cdot n \quad (8)$$

Usually R_w values are the only a small fraction of R_t, order of ~1% or less. Consequently, idealization as shown in Fig. 7 affects the effectiveness insignificantly.

Thermal resistance on the refrigerant side. The scope of this paper is limited to mini channels of smooth inner surface. Because no fins are present onto this surface the thermal resistance either under single or two phase flow is given by

$$R_i = 1/(h_i \cdot A_i) \quad (9)$$

The heat transfer coefficient h_i in the foregoing expression is a complex function of flow and heat transfer conditions. For duct flows, as it is the case, there is a variety of available correlations that define coefficient h_i for single phase as well as two phase flows. The correlations proposed are all of recognized accuracy and have been selected as the most suitable for thermal analysis of automotive condensers.

Zones of single-phase flow. For zones of single-phase flow the correlation by (Gnielinski, 1976) is used to determine h_i so that the corresponding Nusselt number is given by

$$Nu_i = \frac{(Re_{D_i} - 1000) \cdot Pr_i \cdot (f_i/2)}{1 + 12.7 \cdot \sqrt{f_i/2} \cdot (Pr_i^{2/3} - 1)} \quad (10)$$

Correlation (10) is valid for fully developed internal flows in circular and noncircular (in this case use instead of) ducts under Reynolds numbers 3000 ÷ $5 \cdot 10^6$ and correlates experimental data at uncertainty of ±10% if Prandtl numbers are within $0.5 < Pr_i < 2000$, however if $2 < Pr_i < 140$ inaccuracy is lower to be ±6%.

Zones of two phase flow. Correlations for prediction coefficient hi for zones with the two phase flow refer to particular flow structure regimes that develop along the tube when the condensation progresses.

Hence, before setting up the correlations let us remind descriptively basic flow regimes for in horizontal tube condensation.

For condensers considered in the paper the refrigerant flows in minichannels of ID ~ 1 mm or a bit less so the surface tension forces can essentially affect the flow and in turn the flow regimes development. As influence of gravity decreases with decreasing tube diameter and at the same time the surface tension effect is progressively increasing one can expect in minichannels such flow regimes as annular, slug, plug and bubble (or transient regimes existing in between specified). These regimes are of mutual action of shear and surface tension forces. There are some experimental evidences confirming this conclusion. For example (Niño et al., 2003) recently reported that for two phase adiabatic flow in multiport minichannel test facility of 1.58 mm in hydraulic diameter of each port the flow regimes they observed are the following: annular, intermittent (slug and plug) and bubble. Hence, involving surface tension influence into recognition of flow regimes on the refrigerant side for the condenser under study is of primary importance. However, prevailing maps can be of used for predict flow regimes in tubes of larger diameters. Consequently, thermal analysis of condensers with minichannels should be based on new maps developed as specific for two phase flow regime evaluations in minichannels.

Steam traps are usually installed at the condenser exit or inlet to the subcooling pass permits only the liquid phase to flow through. In turn, the bubbly flow (or stratified regime at some flow conditions) ends the condensation with all the tube section filled with liquid phase. Concluding, variety of complex flow regimes precludes establishing a single correlation that can describe the heat transfer coeffcient hi along the complete condensation path.

Selecting appropriate correlations for heat transfer on the two phase flow side for purposes of the condenser design is influenced also by significance of thermal resistance on the two phase flow side R_i for total thermal resistance R_t of Eq. (3) when compared to significance of thermal resistance R_o on the coolant side, (Srinivasan & Shah, 1997). Preliminary evaluations done based on the condenser under study showed that for the zone with annular flow regime the resistances are: $R_i \approx 0.0004$ K/W, $R_o \approx 0.002$ K/W and $R_w \approx 0.000005$ K/W. Hence, one can see that the resistance on the air side does control accuracy of the condenser modelling.

Annular flow. This regime is generally regarded to be the dominant pattern existing over the most part of the condensing length. In turn, for the annular flow regime the correlation proposed by (Shah, 1979) of well recognized accuracy of ±15.4% has been used in a form as follows

$$h_{i,an}(x) = h_{\ell o} \cdot \left[(1-x)^{0.8} + \frac{3.8 \cdot x^{0.76} \cdot (1-x)^{0.04}}{p_r^{0.38}} \right] \quad (11)$$

where coefficient $h_{i,an}(x)$ refers to the inner tube surface at a crossection where the vapor mass fraction is x. Heat transfer coefficient $h_{\ell o}$ in expression (11) attributes to entire two phase flow (of liquid + vapor) as the liquid flow at saturated properties. Accordingly development of (Shah, 1979) coefficient $h_{\ell o}$ is calculated using a modified Dittus and Boelter equation (Winterton et al., 1998), hence

$$h_{\ell o} = 0.023 \cdot Re_{\ell o}^{0.8} \cdot Pr_{\ell}^{0.4} \cdot \lambda_{\ell} / D_i \quad (12)$$

Validity of correlation (11) refers to annular two phase flow at mass velocity of entire flow $G_i = m_i/A_i >$ 200 kg/(m²s). Accordingly Eq. (11) a local value of coefficient $h_{i,an}(x)$ depends essentially on the vapor mass fraction. Hence, mean value of coefficient $h_{i,an}(x)$ along a channel of length L is determined by the integration

$$h_{i,an} = \frac{1}{L} \cdot \int_0^L h_{i,an}(x) \cdot dz \quad (13)$$

where x = x(z). Relation x(z) can be found only by analysis of a distributed condenser model in which the condenser is divided into a number of small subexchangers along the refrigerant flow. However, if component thermal resistance on air side is much bigger than the other resistances of Eq. (3) then one can obtain reasonably accurate results of the condenser analysis assuming that x = x(z) is linear. Under this assumption, mean value of coefficient $h_{i,an}(x)$ is given by

$$h_{i,an} = \frac{1}{x_{o,an} - x_{i,an}} \cdot \int_{x_{i,an}}^{x_{o,an}} h_{i,an}(x) \cdot dx \quad (14)$$

where $x_{o,an} - x_{i,an}$ is the drop in vapor mass fraction under annular flow regime.

Wavy flow. Foregoing correlations refer to either pure annular or pure stratified flows. However there is a transition specified as the wavy flow in between those pure regimes. To find the heat transfer coefficient for such the transition under R134a flow Skiepko (2004) proposed to follow Jaster and Kosky (1976) proration developed for condensing steam flow. However, comparisons of experimental data and model evaluations showed that such the proration can result in increased inaccuracy of condenser performance data obtained from the modelling particularly at lower mass velocity of the entire two phase flow. Hence for this work we use a correlation for wavy regime proposed by Chato and Dobson (1998). The heat transfer coefficient (averaged over entire tube inner perimeter) for film condensation in the upper part of the horizontal tube is expressed (Chato & Dobson, 1998).

$$h_U\left(x\right)=\frac{0.23\cdot Re_{\upsilon o}^{0.12}}{1+1.11\cdot X_{tt}^{0.58}}\cdot\left(\frac{Ga\cdot Pr_{\ell}}{Ja_{\ell}}\right)^{0.25}\cdot\frac{\lambda_{\ell}}{D_i} \quad (15)$$

where the turbulent-turbulent Martinelli parameter X_{tt} is given by

$$X_{tt}=\left[(1-x)/x\right]^{0.9}\cdot\left(\rho_{\upsilon}/\rho_{\ell}\right)^{0.5}\cdot\left(\mu_{\ell}/\mu_{\upsilon}\right)^{0.1} \quad (16)$$

Intermittent and bubbly flow. Modeling of in tube condensation heat transfer lacks of relevant experimental data to be used for analysis if flow regime develops to be intermittent or bubbly. Hence, at present the corresponding contributions can be evaluated in approximate manners only. If such regimes occur at lower vapor qualities they contribute little in condenser overall heat transfer performance and due to this fact the approximations cannot significantly deteriorate in the final outcomes. If the intermittent regime develops at higher qualities the resistance on the refrigerant side is essentially lower than on the air side and hence approximations in determining heat transfer coefficient affect little the transfer. In turn, Cavallini et al. (2003) proposes to prorate linearly the heat transfer coefficient at the boundary down with respect to vapor quality to that for entire liquid flow, if after annular regime the slug flow develops, hence one gets

$$h_{i,int}=h_{i,\ell o}+\frac{x}{x_{an,o}}\cdot\left(h_{i,an}\Big|_{x=x_{an,o}}-h_{i,\ell o}\right) \quad (17)$$

Flow regime prediction. As aforementioned review shows, different types of correlations are necessary for prediction heat transfer coefficients in different two phase flow regimes. Hence, flow regime prediction is especially important for condenser heat-flow analysis. A simple way for regime predictions under condensation of steam during in tube flow is proposed by Jaster and Kosky (1976). Butterworth (1977) demonstrated consistency of their approach for condensation of refrigerant R-12. The main fault of method by Jaster and Kosky (1976) is its limited applicability only for a condensation path along annular – transition (wavy) – stratified regimes. More general method of flow regime prediction is by Taitel and Dukler (1976) map. Although this map refers to adiabatic two phase flows, Breber et al. (1980) showed that the parameters of the map Taitel and Dukler (1976) are indeed significant for condensation under horizontal flow. However, neither parameter of the original map Taitel and Dukler (1976) does take into account surface tension forces. Hence, application of the maps (Jaster & Kosky, 1976; Taitel & Dukler, 1976; Breber et al., 1980) for prediction two phase flow regimes in minichannles of small diameter is greatly limited unless some modifications are introduced. In this respect Dobson and Chato (1998) suggest to use of Taitel and Dukler (1976) map but with surface tension involved into prediction the flow regimes in a manner by Galbiatti and Andreini (1992). Their final result for the transition refers to annular – stratified regimes. Hence, involving of the surface tension as proposed by Galbiatti and Andreini (1992) is irrelevant for flow regime predictions in minichannels because the stratified in minichannel flows may marginal to occur, if any, what is a fact confirmed experimentally (Niño et al., 2003).

In turn, for the present work we use a new of two-phase flow map developed by Tabatabai and Faghri (2001). Their map accounts for the surface tension effects under two-phase flow in horizontal minichannelss. Basically, map Tabatabai and Faghri (2001) is split into two regions, namely: shear dominated and surface tension dominated. The transition boundary between shear dominated regimes (annular, mist, stratified, wavy) and surface tension dominated regimes (slug, plug, bubbly) has been determined on force balance resulted from mutual action of shear, bouyancy (due to gravity) and surface tension forces. Specifically, the transition from annular to slug/plug or bubble regime is developed based on instability of liquid collars in annular-wavy regime leading to formation of originating liquid slug. Hence, following Tabatabai and Faghri (2001) stabilizing influence of surface tension that augments stabilizing influence of gravity can be taken into evaluations of the flow regimes in ducts of small inner diameter.

3.3. Pressure drop evaluation

The pressure drop on the air side. The pressure drop in point is due to the following contributions: the friction effect, change in the momentum effect, and entrance and exit losses. To calculate the friction contribution a correlation for the Fanning friction factor developed by Chang et al. (2000) is proposed to employ. The main motivation for correlation is it involves not only various flow friction effects by terms dependent on the Reynolds number but also influence of the finned surface form drag (independent on Reynolds number) is accounted in by factors dependent on exhaustive design set of dimensionless geometry parameters of the louvered surface. Concluding, the friction factor for the case is given by

$$f = f_1 \cdot f_2 \cdot f_3 \quad (18)$$

where factor f_1 is described as

$$\text{if } Re_{L_p} < 150, \quad (19)$$

$$f_1 = 14.39 \cdot Re_{L_p}^{-0.805 \cdot F_p/F_\ell} \cdot \left\{ ln\left[1+\left(F_p/L_p\right)\right]\right\}^{3.04}$$

$$\text{and for } 150 < Re_{L_p} < 5000, \quad (20)$$

$$f_1 = 4.97 \cdot Re_{L_p}^{0.6049-1.064/\theta^{0.2}} \cdot \left\{ ln\left[\left(\delta_f/F_p\right)^{0.5}+0.9\right]\right\}^{-0.527}$$

Regarding factor f_2, the following expression is developed

$$\text{if } Re_{L_p} < 150, \quad (21)$$

$$f_2 = \left\{ ln\left[\left(\delta_f/F_p\right)^{0.48}+0.9\right]\right\}^{-1.435} \left(\frac{D_h}{L_p}\right)^{-3.01} \cdot \left[ln\left(0.5 \cdot Re_{L_p}\right)\right]^{-3.01}$$

$$\text{if } 150 < Re_{L_p} < 5000, \quad (22)$$

$$f_2 = \left[\frac{D_h}{L_p} \cdot ln\left(0.3 \cdot Re_{L_p}\right)\right]^{-2.966} \cdot \left(\frac{F_p}{L_\ell}\right)^{-0.7931 \cdot T_p/\left(T_p - D_m\right)}$$

Factor f_3, as below, completes necessary empirical information for air side pressure drop modelling, and hence

$$\text{if } Re_{L_p} < 150, \quad (23)$$

$$f_3 = \left(\frac{F_p}{L_\ell}\right)^{-0.308} \cdot \left(\frac{L}{L_\ell}\right)^{-0.308} \cdot \left(e^{-0.1167 \cdot T_p/D_m}\right) \cdot \theta^{0.35}$$

$$\text{if } 150 < Re_{L_p} < 5000, \quad (24)$$

$$f_3 = \left(\frac{T_p}{D_m}\right)^{-0.0446} \cdot \left\{ ln\left[1.2+\left(L_p/F_p\right)^{1.4}\right]\right\}^{-3.553} \cdot \theta^{-0.477}$$

Note also that correlation (18) does not include coefficients for the entrance and exit pressure losses. Therefore, these should be determined based on other sources, for the case using data charts presented by Kays and London (1984). In turn, based on the above information, the conventional pressure drop relation for compact heat exchangers described by Kays and London (1984) is applied for determining the pressure drop on the air side and due to this fact is not quoted here.

The pressure drop on the refrigerant side. Because the superheated vapor enters and subcooled liquid exits the condenser the overall pressure drop consists of the drop under single phase flow and drop under two phase flow. Note that the overall flow is horizontal throughout all the condenser tubing. In turn, either pressure drop, regardless single or two phase, is the sum of friction loss contribution, change in the momentum contribution and local pressure losses, if any. The pressure drop for the single phase duct flows includes friction and change in the momentum contributions and can be estimated using a variety of formulas presented elsewhere, e.g. in Gersten and Ducts (1998), hence not quoted here.

Under two phase flow for in tube condensation the pressure gradient along the flow varies significantly due to decreasing vapor quality. Hence, if one assumes that x depends linearly on coordinate z along duct length, then pressure change between outlet and inlet $\Delta p = p_o - p_i$ in a condenser duct of length L under two phase flow is given by

$$\Delta p = L \cdot \underbrace{\frac{1}{x_o - x_i} \int_{x_i}^{x_o} \frac{dp}{dz} \cdot dx}_{mean\ value\ of\ dp/dz} \quad (25)$$

Pressure gradient dp/dz of Eq. (25) is due to friction and change in momentum effects. Thus the gradient in point is

$$-\left(dp/dz\right) = \frac{2 \cdot f_{\ell o} \cdot G^2}{\rho_\ell \cdot D_i} \cdot \Phi_{\ell o}^2 + G^2 \cdot \frac{x_o - x_i}{L} \cdot \frac{d}{dx}\left[\frac{x^2}{\alpha \cdot \rho_\upsilon} + \frac{(1-x)^2}{(1-\alpha) \cdot \rho_\ell}\right] \quad (26)$$

The two phase flow pressure drop multiplier Φ_{lo}^2 is determined on an empirical correlation by Friedel (1979), due to space limitation not quoted here. The void fractions required in formula (26) have been calculated with constant C_o given by Thome (2003) as

$$C_o = 1 + 0.12 \cdot (1 - x) \quad (27)$$

An advantage of Friedel's correlation is that it involves the influence of the ratio of inertia to surface tension forces on pressure drop multiplier Φ_{lo}^2. Hence, for in tube two phase flow, evaluation of the frictional contribution into the presuure gradient by Friedel correlation is regarded Cavallini et al. (2002) as one of the best prediction of available experimental data. Eq. (27) completes necessary empirical information applied in evaluation of pressure drop on the refrigerant side of the condenser.

4. Condenser under study

A condenser of R134a considered for this work is cooled in crossflow with air as shown in Fig. 8. The air inlet temperature, pressure, humidity and mass flow rate are: 35°C, 1.01325bar, 60% and 2.5kg/s, respectively. The refrigerant (R134a) inlet temperature is 25°C above its saturation temperature at pressure of 1.52MPa. On R134a side the condenser is of two pass horizontal flow arrangement where the second pass is predicted for subcooling. The air flows across corrugated louver fins brazed onto one row array of flat aluminium tubes having internal circular minichannels where R134a flows. As shown in Fig. 8 the refrigerant enters the header, flows through minichannels along the first pass and condenses. Then the opposite header turns the liquid flow into the second pass in back direction along the subcooling zone towards the exit.

a)

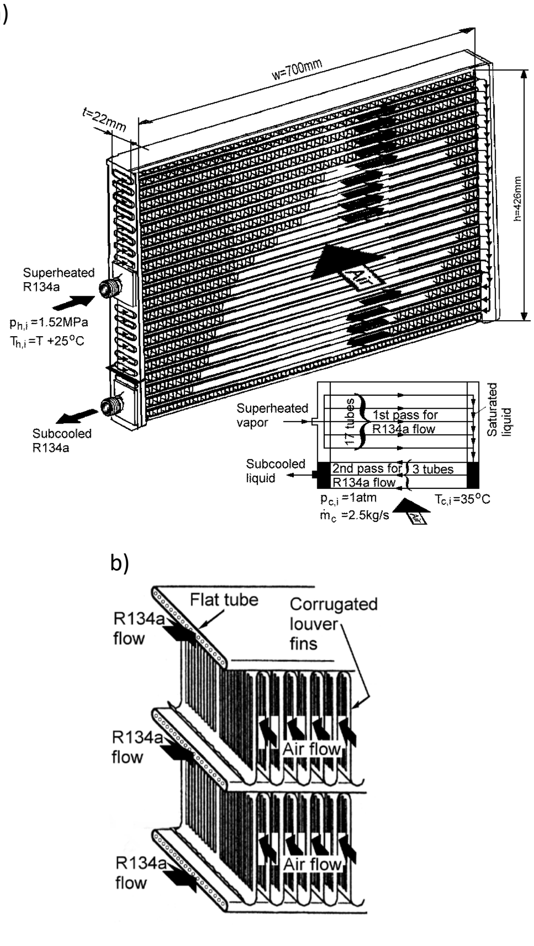

Fig. 8. Basic dimensions and flow arrangement of the condenser under study:
a) view of the condenser assembling, and flow arrangement;
b) view of brazed fins onto flat tubes of the condenser

On input, condenser core geometry configuration data are given in Table 1. For needs of the present study thermodynamic properties of R134a are quoted from Lemmon et al. (2005) and air properties from Kakaç (1991).

Tab. 1. Condenser core geometry configuration data

Configuration quantity	Data value
Height, h, [mm]	426
Width, w, [mm]	700
Depth, t, [mm]	22
Number of passes	2
Number of flat tubes in condensation pass, N_{cd}	17
Number of flat tubes in subcooling pass, N_{sc}	3
Number of flat tubes in air flow direction, N	1
Tube material thermal conductivity, λ_w, [W/m.K]	204
Flat tube	
Major flat tube dimension, T_d, [mm]	22
Minor flat tube dimension, D_m, [mm]	1.3
Flat tube pitch, T_p, [mm]	21.3
Minichanel diameter, d_o, [mm]	0.8
Number of minichannels in one flat tube, n_r,	18
Fins	
Fin pitch, F_p, [mm]	2.0
Fin thickness, δ_f, [mm]	0.075
Fin length between tubes, F_ℓ, [mm]	20
Louver length, L_ℓ, [mm]	18.0
Louver angle, ϑ, [°]	28.0
Louver pitch, L_p, [mm]	1.5
Fin length in air flow direction, L, [mm]	22.0
Free flow area to frontal area ratio	0.902
Heat transfer area/total volume, Y, [m^2/m^3]	1089.6
Hydraulic diameter on air side, D_h, [mm]	3.31
Fin transfer to total transfer area ratio	0.911

4.1. Flow regimes evaluation

Because correlations for prediction coefficient h_i as well as for multiplier $\Phi_{\ell 0}^2$ refer to particular flow structure regimes the primary step in condenser heat-flow analysis is evaluation of the regimes that can develop along the tube when condensation progresses. For needs of this presentation the flow regimes have been identified with the use of the map (Tabatabai & Faghri, 2001) developed for two phase flows in minichannels because this map involves the surface tension into evaluation of the flow regimes. In this map the transition boundary between the annular and intermittent (slug) regimes occurs if the liquid volume flow rate fraction determined based on superficial velocities j_ℓ and j_υ of the liquid and gas phase, respectively, is

$$\dot{\varepsilon}_\ell = \frac{j_\ell}{j_\ell + j_\upsilon} = 0.06 \tag{28}$$

For comparison purposes let us provide some data on terminal vapor quality for the annular regime at the transition evaluated with the use of criterion Jaster and Kosky (1976), maps Taitel and Dukler (1976) and Tabatabai and Faghri (2001). The results of this evaluation are shown in Table 2. One can see in Table 2 that the terminal point for the annular regime is essentially affected by inclusion the surface tension into considerations. Hence, accordingly Tabatabai and Faghri (2001) the condensation flow under annular regime terminates at x = 0.531 when the surface tension is included when compared to x = 0.151 if one neglects the surface tension. This result does mean that the annular regime terminates at about four times higher vapor quality when the condensation is affected by the surface tension forces.

As the condensation continues down under the slug and then plug regimes, the vapor quality x decreases what results in decreasing the ratio of vapor superficial velocity j_υ to liquid superficial velocity j_ℓ. At the same time the void fraction α is also decreasing what, in accordance with Tabatabai and Faghri (2001), makes the increase in pressure gradient due to surface tension. However, due to decrease in vapor quality the shear pressure gradient also decreases. In turn, the condensation path on map Tabatabai and Faghri (2001) continues down right into the region of slug and plug regimes because ratio j_υ/j_ℓ decreases below 15.7 (value resulted from m = = 0.06) and ratio $(dp/dz)_{surface\ tension}/(dp/dz)_{shear}$ increases. This conclusion indicates that nor wavy neither stratified regimes can occur for the case considered at entire flow mass velocity G_h = 421.3 kg/(m²s). Hence, the only possible post intermittent regime is the bubble flow. To determine the transition between the intermittent and bubble regimes use on their map the same boundary as proposed by Taitel and Dukler (1976). In turn, intersection of $T_{TD}(X)$ values determined for horizontal flows from

$$T_{TD} = \left\{ \left(\frac{dp}{dz} F \right)_\ell \Big/ \left[(\rho_\ell - \rho_\upsilon) \cdot g \right] \right\}^{0.5} \tag{29}$$

with boundary D(X) of map Taitel and Dukler (1976) provides value of the Martinelli parameter X at the transition. Then solving formula for X

$$X = \sqrt{\left[\frac{(dp/dx)_\ell}{(dp/dx)_\upsilon} \right]} \tag{30}$$

with respect to vapor quality provides x_D value at the transition.

Experimental evidences (see e.g. Collier & Thome, 1994) show that the slug regime always preceeds plug flow as x decreases (corresponding X values increase). Hence, at first slug flow is formed for the case as condensation progresses after the annular regime. The liquid slugs coalescence locking large vapor bubbles (plugs) within liquid what forms the plug flow regime. As the plugs of vapor continue along the flow, condensation continues also what reduces the size of plugs. Then the bubble flow is formed when turbulent fluctuations can break the plugs into small bubbles what is the transition of intermittent to bubble regime as described above. For the case it occurs at X_{tt} = 70.9 what corresponds to x = 0.00262 and α = 0.0261. The bubble flow condensation continues with disappearing smaller and smaller bubbles by the end of condensation.

Development of this condensation scenario is depicted in Fig. 9 that illustrates how flow regimes can vary along the flow length (see also data in Table 2) accompanied by decreasing vapor quality. Note in Fig. 9 that as condensation starts at x = 1 the first flow regime is annular, as expected. After that the intermittent flow develops, initially the slug and then plug. The flow regime becomes bubbly as condensation continues down the intermittent regime.

The following observations can be made based on Fig. 9. Hence, when the surface tension is disregarded one can see in Fig. 9 a) the length of the annular flow regime is the biggest in the zone of two phase flow. The intermittent flow spans on the length by four 4 times shorter that the that for the annular

Tab. 2. Vapor quality and liquid volume flow rate fraction at termination point of the annular regime

Steam, surface tension neglected (Jaster & Kosky, 1976)	R134a, surface tension neglected (Taitel & Dukler, 1976)	R134a, surface tension included (Tabatabai & Faghri, 2001)
x = 0.127	x = 0.151	x = 0.531
$\dot{\varepsilon}_\ell$ = 0.332	$\dot{\varepsilon}_\ell$ = 0.289	$\dot{\varepsilon}_\ell$ = 0.06

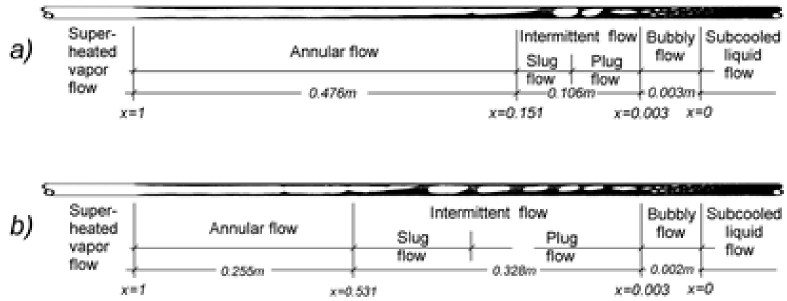

Fig. 9. Two phase flow regimes for the condenser under study determined based on (note: length and x scales are not preserved):
a) map (Taitel & Dukler, 1976) at G = 424.7 kg/(m^2s) with surface tension neglected;
b) map (Tabatabai & Faghri, 2001) at G = 421.3 kg/(m^2s) with surface tension included

and the bubbly flow occurs at negligible length almost directly at the minichannel exit port. On the contrary, it is shown in Fig. 9 b) that the surface tension essentially affects development of the flow regimes under condensation in minichannels. In turn, the biggest length is under the intermittent flow and the annular flow preceding the intermittent takes the length shorter by about 20% when compared to the former one. Insignificant length is of the bubbly flow of the same order if one disregards the surface tension. One can also see in Fig. 9 that regardless the surface tension is included or not the stratified regime is not present. This result is in accordance with aforementioned experimental observations done by Niño et al. (2003).

4.2. Overall calculation scheme

The input data for the calculations are: core geometry data and design conditions such as the air inlet temperature, pressure, humidity, air mass flow rate and the refrigerant inlet temperature and pressure. To manage the task a computational strategy has been developed which performs the analysis taking into considerations zone after zone along the refrigerant in tube flow. Calculations are iterative because the refrigerant mass flow rate should be initially guessed. Because of complexity of the expressions involved into the modelling presented an extensive spreadsheet Excel has been prepared to be used in calculations after passing thorough checking for its convergence and accuracy.

4.3. Results of the analysis

The results of the analysis are presented in tabulated and graphical forms. Table 3 shows the most essential outcomes. All the computed values presented in Table 3 have been obtained with inclusion of the surface tension into the analysis.

One can see in Table 3 the significance of transfer processes in particular zones for the overall condenser performance and pressure drop on the refrigerant side. In this respect the intermittent flow regime zone contributes the most providing ~39% of the overall condenser heat transfer. The corresponding figure for annular regime zone is lower by ~4% to be about ~35%. The zone of the bubble regime contributes in overall heat rate transfer by the only a small fraction ~0.2%. Hence, the bubble flow may not be distinguished for the case and the entire two phase region can be regarded as composed of the annular and intermittent zones only. A interesting comment arises if one compares the above figures evaluated at inclusion the surface tension with those presented in Breber et al. (1980) where the influence of surface tension is disregarded. For this case the corresponding figures are: ~63% (zone of the annular regime), ~11% (zone of the intermittent regime), ~0.2% (under the bubble regime). In turn, the surface tension promotes the transfer under intermittent regime and reduces contribution the annular flow zone in the transfer. The bubble regime contribution is insensitive on the surface tension.

Regarding pressure drop, the biggest contribution of ~73% is under single phase flow of subcooled liquid. For two phase flow region the biggest contribution of ~13% in overall pressure drop is under annular flow. All pressure drop in the two phase flow zone is ~0.2bar what means ~21% of that by overall condenser. This drop can decrease the saturation temperature by ~0.6oC what changes the mean temperature difference air – R134a in zone of two phase flow by ~1.6%, hence negligibly. By comparing thermal resistances on refrigerant and air sides given in Table 3, one can see that the accuracy of heat transfer prediction for two phase flow region of the condenser is controlled by accuracy of the air side modelling.

In Fig. 10, referenced to the annular flow regime, the variations of heat transfer coefficient $h_{i,an}$(x) and

Tab. 3. Elected results of condenser analysis with annular, intermittent and bubble regimes (surface tension included)

Property	Super-heated zone	Annular regime zone	Intermittent regime zone	Bubble regime zone	Sub-cooling zone
$T_{h,i}$,°C	80.8	55.8	55.8	55.8	55.8
$T_{h,o}$,°C	55.8	55.8	55.8	55.8	42.6
$x_{h,i}$	-	1.0	0.531	0.00298	-
$x_{h,o}$	-	0.531	0.00262	0	-
G,kg/(m²s)	421.3	421.3	421.3	421.3	2387.4
$T_{c,i}$,°C	35.0	35.0	35.0	35.0	35.0
$T_{c,o}$,°C	40.5	40.6	39.9	38.1	38.5
C_h , W/K	77.85	∞	∞	∞	100.83
C_c , W/K	356.0	790.7	1017.9	8.0	383.3
C^*	0.2187	0	0	0	0.2631
R_i , K/W	$7.28\,10^{-3}$	$6.97\,10^{-4}$	$1.06\,10^{-3}$	$4.51\,10^{-1}$	$1.59\,10^{-3}$
R_w , K/W	$2.11\,10^{-5}$	$9.50\,10^{-6}$	$7.38\,10^{-6}$	$9.38\,10^{-4}$	$1.96\,10^{-5}$
R_o , W/K	$7.46\,10^{-3}$	$3.36\,10^{-3}$	$2.61\,10^{-3}$	$3.32\,10^{-1}$	$6.98\,10^{-3}$
NTU_o	0.8705	0.3112	0.2671	0.1594	1.1546
ε	0.5463	0.2675	0.2344	0.1473	0.6322
L , m	0,1147	0,2548	0.3280	0.00240	0.70
Δp_h , Pa	4074	12136	7411	9	66194
	Refrigerant side pressure drop : 91182 Pa				
$\dot{Q}$, kW	1.9479	4.3942	4.9571	0.0245	1.3245
	Overall condenser heat transfer rate: 12.65 kW				

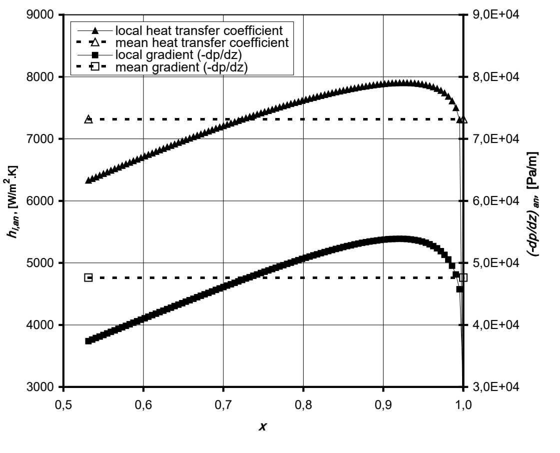

Fig. 10. Variation of heat transfer coefficient and pressure gradient with vapor quality for annular flow at G = 421.3 kg/(m²s)

pressure gradient $(dp/dz)_{an}$ with vapor quality are shown. Here coefficient $h_{i,an}(x)$ has been determined on correlation by Shah (1979) and gradient $(dp/dz)_{an}$ was evaluated using Eq. (26).

As forced convection driven by vapor shears is the only mechanism under this regime, note strong nonlinear variability in $h_{i,an}(x)$ as well in $(-dp/dz)_{an}$ with vapor quality so that both the curves are like parallel. There are also remarkably higher values of $h_{i,an}$ and (-dp/dz)an for the case considered of D_i = 0.8 mm in tube inner diameter when compared to cases with larger D_i values order of a few mm. There is a maximum also in coefficient $h_{i,an}$ as well as in gradient $(-dp/dz)_{an}$, either at about x ~ 0.9.

Conclusions

In the paper at first modelling of horizontal flow in tube condensers is summarized with particular attention on evaluation of refrigerant flow regimes in minichannnels with the use of two phase flow regime map accounting for the surface tension. Based on the modelling a computerized spreadsheet has been developed for design analysis of the condensers. Then, results of numerical experiments generated with the use of the spreadsheet are presented for a crossflow automotive condenser with R134a flow in minichannels of 0.8mm in inner diameter.

Presentation of the results begins with flow regimes predictions where effects of surface tension are also included. The condensation path for assumed input data of the condenser under study goes through the annular regime, then passes intermittent (slug and plug) regime and ends with bubble regime. Evaluations of thermal resistances show that the accuracy of heat transfer prediction for two phase flow region of the condenser is controlled by accuracy of the air side modelling. Regarding pressure drop, on R134a side the biggest contribution of ~73% in overall pressure drop is under single phase flow of subcooled liquid and for two phase flow region the biggest contribution of ~13% is under annular flow. The overall pressure drop under two phase flow results in change the mean air – R134a temperature difference in zone of two phase flow by ~1.6%, hence negligibly. Two additional remarks arise also from the results. The first is that involving surface tension into flow regime predictions for minichannels is necessary. In this respect map (Tabatabai & Faghri, 1979) directed on two phase flow regime predictions in minichannels has been employed in the paper. Worthy also to mention is lack of experimental data that can be used for modelling of condensation under intermittent flow regime.

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