ORESTA

ISSN: 2620-1607

eISSN: 2620-1747

DOI: 10.31181/oresta190101s

OPERATIONAL RESEARCH IN ENGINEERING SCIENCES: THEORY AND APPLICATIONS

EUROPEAN CENTRE FOR OPERATIONAL RESEARCH - (ECOR)

REGIONAL ASSOCIATION FOR SECURITY AND CRISIS MANAGEMENT - (RABEK)

Volume 3, Issue 3

ISSN: 2620-1607

eISSN: 2620-1747

DOI: 10.31181/oresta190101s

Published: December 2020

OPERATIONAL RESEARCH IN ENGINEERING SCIENCES: THEORY AND APPLICATIONS

Publishers:

EUROPEAN CENTRE FOR OPERATIONAL RESEARCH - (ECOR)

REGIONAL ASSOCIATION FOR SECURITY AND CRISIS MANAGEMENT - (RABEK)

Address of editorial office:
Regional Association for Security and crisis management (RABEK) –
European centre for Operational research (ECOR)
Cerska 76a, 11000 Belgrade, Serbia
Tel. +38165-2503-213
e-mail: zeljkostevic88@yahoo.com, editor@oresta.rabek.org
http://oresta.rabek.org

CONTENTS

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 1-12
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta2030301b

SELECTION OF THE BARRIERS OF SUPPLY CHAIN MANAGEMENT IN INDIAN MANUFACTURING SECTORS DUE TO COVID-19 IMPACTS

Tapas Kumar Biswas*, Manik Chandra Das

Department of Automobile Engineering, MCKV Institute of Engineering, Howrah-711204, India

Received: 22 June 2020
Accepted: 10 August 2020
First online: 29 August 2020

Research Paper

Abstract. *The coronavirus (COVID-19) pandemic is having a clear impact on the supply chains of virtually all manufacturers. Whether frozen foods and grocery items or emergency items, or even the services, the supply chain has been facing multiple obstacles. For manufacturing industries with complex supply chains, it is indeed critical to identify strategies to deal with such a crisis. With demand high and supply unavailable, some products became more desirable causing price hikes and price extorting because the manufacturing sectors are facing some barriers during lockdown. This research has identified the five essential barriers of supply chain such as lack of man power, local laws enforcement, lack of transportation, scarcity of raw materials and deficiency in cash flow for Indian manufacturing sectors during lockdown. This paper proposed a methodology based on a fuzzy analytical hierarchy process (Fuzzy-AHP) with use of triangular fuzzy numbers for the pairwise comparison matrices. It has been seen that lack of man power is a higher weight barrier than others. Moreover, the managerial implication about the results is also provided, which will be useful for manufacturing sectors to take suitable decisions to overcome these obstacles.*

Keywords: *COVID-19, Manufacturing sectors, Barriers, Fuzzy AHP, SCM*

1. Introduction

At present time, the world is facing the coronavirus disease known as Covid-19. The first case of the coronavirus was reported in December, 2019 in the Wuhan city of China which is known as the major transportation hub of China (Mayo clinic, 2020). Many countries have shut down their sea docks and airports after the spread of the virus. They have banned the import and export activities. World Health Organization (WHO) has declared the COVID-19 outbreak as a global pandemic on March 11, 2020 (Cucinotta & Vanelli, 2020). The virus has affected the lives of many

* Corresponding author.
tapasbiswasmckv@gmail.com (T. Biswas), cd_manik@rediffmail.com (M. Das)

people and also affecting the global economy more than that happened during the outbreak of severe acute respiratory syndrome (SARS) (WHO, Situation Report-92, 2000). The first case of Covid-19 in India was reported in January 30, 2020. On 23rd of March, 2020, the Government of India has declared the lockdown in the whole country to minimize the spread of Covid-19 (Jamwal et al., 2020). Within a month, unemployment has risen from 6.7% on 15 March to 26% on 19 April (Vyas, 2020). During the lockdown, estimated 140 million people lost employment while salaries were cut for many others (Goyal, 2020). More than 45% of households across the nation have reported an income drop as compared to the previous year (Research, Centre for Policy, 2020). Since the last couple of months, the fast spread of the COVID-19 disease is creating huge uncertainty and indefinable disruptions in the global supply chain. According to WHO (2020), the global supply chain is experiencing a big challenge to keep smooth supplies of food and medical instruments including masks and medicine highly required to the treatment, protection, and control of the pandemic. In India, the supply chain (SC) has also been put under stress with the lockdown restrictions which disrupted the SC across the nation (Chaudhry, 2020). Major companies in India such as Larsen & Toubro, Bharat Forge, UltraTech cement, Grasim Industries, Aditya Birla Group, BHEL and Tata Motors have temporarily suspended or significantly reduced operations. Young startups have been impacted as funding has fallen (Singh, 2020). Fast-moving consumer goods companies in the country have significantly reduced operations and are focusing on essentials. The Indian Express, 2020 showed that stock markets in India posted their worst losses in history on 23 March 2020. Almost all two-wheeler and four-wheeler companies put a stop to production till further notice. Hindustan Unilever, ITC and Dabur India shut manufacturing facilities except for factories producing essentials (Mudgill, 2020). Foxconn and Wistron Corp, iPhone producers, suspended production following the 21-day-lockdown orders (Wu, 2020). Following the lockdown, certain essential supply chains (SCs) broke down. Britannia Industries, supporting the lockdown, urged the government to ensure inter-state movement of the raw material for the food processing industry was not hampered. During the lockdown, inter-state logistics has been banned, it does not apply to essentials, and in places like Maharashtra, the state police are yet to streamline the process and disrupt the SCs. (Parth, 2020). Vidya Krishnan writes in The Atlantic that due to the lockdown, even movement of medical goods were affected (Krishnan, 2020). On 29 March, 2020, the government of India permitted the movement of all essential goods across the country during the lockdown. The milk and newspaper SCs are also allowed to function. Chemicals, automotive, electronics and other industries are shut down due to supply disruption and restriction of logistics/shipment (Kumar et al., 2020). On another note, the pandemic control measures taken by countries worldwide have interrupted flows of finished goods and raw materials from plants to many parts of the world. For instance, Wuhan, the epicenter of the COVID-19 outbreak, is an automobile factory hub with global brands such as General Motors, Hyundai, and Toyota (Yu & Aviso, 2020). Aside from these car manufacturing plants, multinational companies such as Apple, Alphabet, Starbucks, McDonald's, and Proctor & Gamble have closed production facilities. Presently, the country is suffering from recession in the third quarter of fiscal year (FY) 2020. The economic impact of the 2020 coronavirus pandemic in India has been largely disruptive. India's growth in the fourth quarter of the FY 2020 went down to 3.1% according to the Ministry of Statistics. In India, manufacturing industry is totally hampered due to lack of man power, logistics and SC due to lockdown restrictions. Although many companies are embracing more online shopping activities to deal with low foot traffic and extensive closure of many showrooms completely by trying to meet car buyer needs virtually. Changes in business models and the use of innovative practices and technologies also lead to changes in existing SC structures and relationships. Micro, small and medium-sized enterprises (MSME), the United Nations Industrial Development Organization in India, communicated 85 enterprises and enquired about the challenges they are facing and their expectations and plans for the revival of their businesses once the lockdown is lifted. The survey was conducted by telephone during the period 9-13 April, 2020 and included enterprises engaged in the automotive components, bicycle, paper, textile, ceramic, foundry, tea and rice milling sectors (rice milling sector where production has reportedly dropped by half) in clusters across the country. Some communications, sales, administrative and other support activities are being undertaken from home but on a limited scale. Workers who come from different states of India have returned in large numbers to their hometowns. In this situation, some manufacturers are involved in the manufacturing of ventilators, but small quantities and small fraction of its regular workforce. The movement of materials (raw materials/finished goods) is standstill. The disruption of the flow of materials and goods is having negative implications on other aspects of business, in particular an abrupt end to incoming cash flows and the migration of workforce across all skill levels. The blockage of people and material movement disrupted every SC.

There are different critical barriers found out which affected the SCs in India during this period. It is expected that this paper will be helpful to the manufacturing sectors to overcome this issue. Covid-19 pandemics suddenly projected those SC change scenarios onto a level of dramatic uncertainty. The susceptibility to which regional and global SCs are subjected to extreme events raises several concerns in terms of analysis and transport and logistics scenarios. Irrespective of significant benefits, the implementation of supply chain management (SCM) is stimulating, and industries continue to meet barriers that prevent them from implementing effective SCM (Meehan & Muir, 2008). Benefits of SCM execution can be achieved when companies are able to identify and overcome these barriers to stay competitive in today's changing environment (Stank et al., 2011). These barriers are complex in nature, and thus it is crucial for industries to understand them well. Therefore, multi criteria decision making (MCDM) techniques may be used in selecting the best one among criteria. In the present paper, quality of performance of five critical barriers of SCM such as lack of man power, local laws enforcement, lack of transportation, scarcity of raw materials and deficiency in cash flow in Indian manufacturing sectors has been analyzed using a modified Fuzzy AHP method (Shaw et al., 2012), (Arikan, 2013) for their subsequent ranking. In this paper, we use the Fuzzy AHP method to determine the weights associated with criteria under study.

The paper is organized as follows: after the introduction and barriers of SCM in manufacturing environment, section 3 presents the Fuzzy AHP methodology with mathematical formulation of the method. Section 4 contains the application of Fuzzy AHP method for calculating the weights. Section 5 presents the discussion and concluding remarks, and directions for future research is presented in section 6.

2. Barriers of supply chain management (SCM) due to COVID-19

As reported in literature (Moktadir et al., 2018), (Sirisawat & Kiatcharoenpol, 2018), SCM barriers are lack of top management commitment and support, an unclear organizational objective, employee empowerment and training, insufficient funds, poor corporate culture, mistrust among employees and SC partners, lack of education and training to employees and suppliers, poor information and communication technology infrastructure, unwillingness to implement SC practices, lack of integration among SC partners, lack of collaboration among SC partners, lack of responsiveness, lack of customer satisfaction index, etc. These barriers are complex in nature, and thus it is crucial for decision makers to understand them well, so that the barriers can be curtailed. It has been seen that supply chains are always influenced by some barriers. Now in India, Covid-19 has disrupted the supply chain in manufacturing sectors. The barriers for the Indian SC caused by the Covid-19 are found out with the discussion with academic experts and industrial experts and they sort out many barriers of SCM in manufacturing sectors like lack of man power, lack of raw materials, unavailability of imported goods, a bottleneck in last mile delivery, lack of transportation, slow movements of goods, restriction on overseas transportation, lack of buyers, lack of cash flow, slow credit flow from the financial sectors and local laws enforcement. In this study, five serious barriers are considered which are further discussed in Table 1 because these five barriers are the most important in this pandemic situation and these five barriers are directly or indirectly connected with all other barriers. The five barriers are lack of man power, local laws enforcement, lack of transportation, scarcity of raw materials and deficiency in cash flow in the market, found out as critical in the SCs in India. It is expected that this study will be helpful for the researchers to develop the conceptual models to overcome this issue. These barriers have a great influence on Indian SC. Although these issues in the SC are very generalized, which needs further study, the prioritization of these barriers will help the industries to overcome the SC issues due to the Covid-19.

Table: 1 Description of the barriers

Barriers	Description of the variables
Lack of man power	Man power in any sectors is defined by the supply of people who are able to work. Any sector suffers from a lack of man power. This is an important variable or criterion for any industry or service sectors and it directly affects the productivity, which reduces the revenue and profit.
Local laws enforcement	Government of India is taking all necessary steps against the spread of CORONA Virus 19. The most important factor in preventing the spread of the Virus locally is to empower the citizens with the right information and taking precautions as per the advisories being issued by government. In India, the government has decided a nationwide lockdown to battle the spread of the Covid-19 virus.
Lack of transportation	Due to COVID 19, India has restricted or stopped the transport system in the country and globally, which

	directly affects the SC of manufacturing sectors.
Scarcity of raw materials	Industries in the country are facing shortages of raw materials because of the graded lifting of the ongoing nationwide lockdown. Due to restricted capacity at the main ports in India, both for sea and air freight, industries are facing a scarcity of import of material for which a locally-produced alternative is extremely difficult to find.
Deficiency in cash flow in the market	A lockdown of this magnitude puts immediate pressure on the cash flow and pandemic has significantly impacted the cash flow at organizations.

3. Methodology

There are a number of multiple criteria decision making (MCDM) tools, such as AHP, ENTROPY, CRITIC (Saaty, 1980), (Biswas et al., 2019), (Biswas et al., 2020), etc., available for prioritization of criteria in a set. In this paper, the fuzzy AHP method has been used to determine the weights/performance evaluation of the different barriers. This method works with the development of pairwise comparison matrix to determine the subjective weights or relative importance of each criterion. To capture the vagueness or imprecision in the judgments rendered by decision makers, triangular fuzzy membership function has been used (Chang, 1996) with AHP theory. There are a good number of advantages of this method such as: it is simple to understand and comprehend, it can capture imprecision in judgments, it can return to a crisp value at the end, etc. A fuzzy scale as proposed by Chang (1996) has been considered for pairwise comparisons of one criterion over another and the same is shown in Table 2.

Table 2. Fuzzy Scale

Preference of pairwise comparisons	Fuzzy numbers
Equal	(1,1,1)
Moderate	(0.67,1,1.5)
Strong	(1.5,2,2.5)
Very strong	(2.5,3,3.5)
Extremely Strong	(3.5,4,4.5)

In this work, the extent fuzzy AHP (Chang, 1996) is utilized for defuzzification.

4. Data and Computation

In order to rank the different barriers of SCM due to COVID-19 for Indian manufacturing sectors, 15 respondents were contacted and their demographic information was collected. It has been seen that the majority of the respondents are Bachelor degree, Master's degree or PhD degree holders. All the respondents comprised are in manufacturing sectors, SC sectors and professors/associate professors in colleges/universities. All the academicians involved in the survey either teach engineering or management and by virtue of their profession, they have practical experiences in dealing with SC activities in Indian manufacturing industries. It has been observed that all the respondents have working experiences of 5 years or more. So, overall, it can be concluded that all the respondents participated in the present survey have sufficient expertise in SC management.

After identification of evaluation barrier, with the help of expert committee, fuzzy linguistic values are used to determine weights of criteria.

4.1 Priority of criteria

Considering the feedback of the experts from various fields, we form a pairwise comparison matrix of 5 criteria to get their relative weight over others. Table 3 shows the fuzzy evaluation of the criteria.

Table 3. Pairwise comparison matrix

Criteria	Lack of man power	Local laws enforcement	Lack of transportation	Scarcity of raw materials	Deficiency in cash flow in the market
Lack of man power	(1,1,1)	(1.5,2,2.5)	(0.67,1,1.5)	(2.5,3,3.5)	(0.67,1,1.5)
Local laws enforcement	(0.4,0.5,0.67)	(1,1,1)	(0.67,1,1.5)	(0.67,1,1.5)	(1.5,2,2.5)
Lack of transportation	(0.67,1,1.5)	(0.67,1,1.5)	(1,1,1)	(0.67,1,1.5)	(2.5,3,3.5)
Scarcity of raw materials	(0.29,0.33,0.4)	(0.67,1,1.5)	(0.67,1,1.5)	(1,1,1)	(1.5,2,2.5)
Deficiency in cash flow in the market	(0.67,1,1.5)	(0.4,0.5,0.67)	(0.29,0.33,0.4)	(0.4,0.5,0.67)	(1,1,1)

Using the steps of extent fuzzy AHP mentioned in the literature (Chang, 1996) and fuzzy evaluation values in Table 3, we determine the triangular fuzzy number (TFN) values of five criteria as follows:

S_1(Lack of man power)
$=(6.33,8.00,10.00) \otimes (1/37.30,1/29.17,1/22.94)$
$=(0.17,0.27,0.44)$
S_2(Local laws enforcement)
$=(4.23,5.50,7.17) \otimes (1/37.30,1/29.17,1/22.94)$
$=(0.11,0.19,0.31)$
S_3(Lack of transportation)
$=(5.50,7.00,9.00) \otimes (1/37.30,1/29.17,1/22.94)$
$=(0.15,0.24,0.39)$
S_4(Scarcity of raw materials)
$=(4.12,5.33,6.90) \otimes (1/37.30,1/29.17,1/22.94)$
$=(0.11,0.18,0.30)$
S_5(Deficiency in cash flow in the market)
$=(2.75,3.33,4.23) \otimes (1/37.30,1/29.17,1/22.94)$

=(0.07,0.11,0.18)

Similarly as mentioned in literature (Chang, 1996), the degree of possibility of $S_j=(l_j,m_j,u_j)\geq S_i=(l_i,m_i,u_i)$ can be computed by comparing the values of S_i as determined above. Table 4 shows the values of $V(S_j\geq S_i)$.

Table 4. Values of $V(S_j\geq S_i)$

V(Sj≥Si)	Value	V(Sj≥Si)	Value	V(Sj≥Si)	Value
V(S1≥S2)	1.000	V(S2≥S1)	0.636	V(S3≥S1)	0.880
V(S1≥S3)	1.000	V(S2≥S3)	0.762	V(S3≥S2)	1.000
V(S1≥S4)	1.000	V(S2≥S4)	1.000	V(S3≥S4)	1.000
V(S1≥S5)	1.000	V(S2≥S5)	1.000	V(S3≥S5)	1.000
V(S4≥S1)	0.590	V(S5≥S1)	0.059		
V(S4≥S2)	0.950	V(S5≥S2)	0.467		
V(S4≥S3)	0.714	V(S5≥S3)	0.187		
V(S4≥S5)	1.000	V(S5≥S4)	0.500		

Calculate the minimum degree of possibility d′ (i) of V $(S_j\geq S_i)$ for i,j=1,2,3,....k.

$D'(1)=\min V(S_1\geq S_2,S_3,S_4,S_5) = \min(1.000, 1.000, 1.000, 1.000)=1.000$

$D'(2)= \min V(S_2\geq S_1,S_3,S_4,S_5) = \min(0.636, 0.762, 1.000, 1.000)=0.636$

$D'(3)= \min V(S_3\geq S_1,S_2,S_4,S_5)= \min(0.880, 1.000, 1.000, 1.000)=0.880$

$D'(4)= \min V(S_4\geq S_1,S_2,S_3,S_5)= \min(0.590, 0.950, 1.000, 1.000)=0.590$

$D'(5)= \min V(S_5\geq S_1,S_2,S_3,S_4)= \min(0.059, 0.467, 0.187, 0.500)=0.059$

Therefore, the weight vector becomes

$W'= (1.000, 0.636, 0.880, 0.590, 0.059)^T$

Normalizing the weight vector, we get

$W= (0.316, 0.201, 0.278, 0.186, 0.019)^T$

Therefore, the final weights of lack of man power, local laws enforcement, lack of transportation, scarcity of raw materials and deficiency in cash flow in the market become 0.316, 0.201, 0.278, 0.186 and 0.019 respectively. The relative weights which are non-fuzzy numbers are described in the following figure (Figure 1).

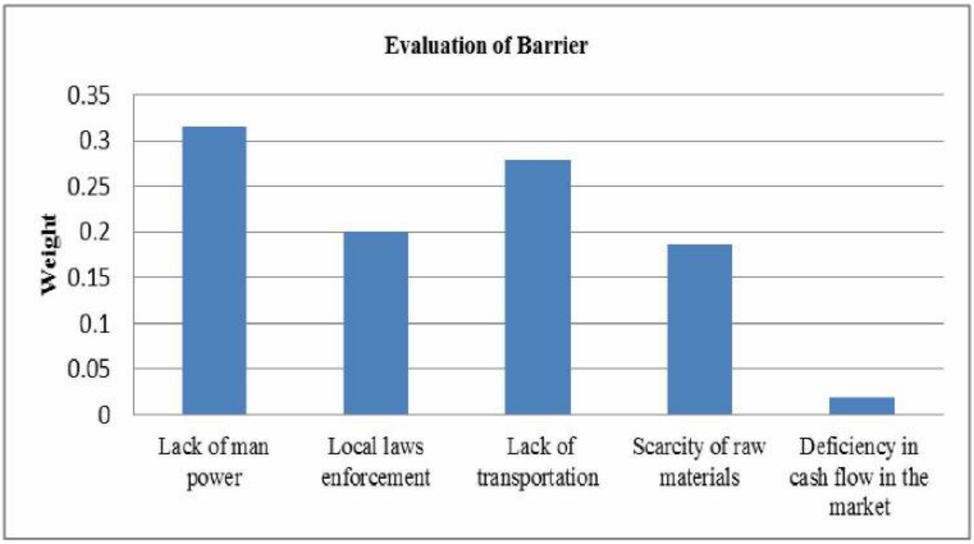

Figure 1: Relative weights for evaluation of barriers

5. Result and Discussion

As mentioned above, the five essential barriers of SCM implementation in different manufacturing sectors were identified and subsequently validated by academicians and practitioners in order to see the importance of the different barriers of SCM in manufacturing sectors. The majority of the expert respondents belongs to either academic or industry area. All the academicians involved in the survey are aware of operations management and marketing management by virtue of their profession, and they have practical experiences in dealing with SC activities. So, overall, it can be concluded that all the respondents participated in the present survey have sufficient expertise in SC management. The figures also show the priorities of the factors compared. For clarity purpose, the five barriers and their corresponding priorities and ranks are shown in Fig. 1. It is observed that the five most critical barriers are (arranged in a descending order of criticality) the following:

1. Lack of man power,
2. Lack of transportation,
3. Local laws enforcement,
4. Scarcity of raw materials,
5. Deficiency in cash flow in the market.

From Figure 1, it is found that the most serious barrier is "Lack of man power" and the least critical barrier is "Deficiency in cash flow in the market". This does not mean that 'deficiency in cash flow in the market' is not serious; it merely shows that the other barriers considered are more serious compared to it because deficiency in cash flow directly or indirectly depends on logistics and SCM. Lack of man power affects production directly. Presently, the production level is already low due to unavailability of the raw materials because of the irregular transportation system. In this present scenario, local law enforcement has played a major role in implementation of “the lockdown”. So, the entire distribution channel is hampered and does not meet the demand supply equation. As a result, there is a scarcity of raw material items in the market. These emergency items are unnecessarily being stocked by some classes of people as they are thinking that there may be a crisis in the near future. Therefore, it widens the gap between demand and supply in the local market. As most of the businesses were entirely stopped due to the lockdown countering this pandemic, it resulted in the downfall of the economy and an increase in the unemployment level as well. It has been noticed that many people had lost their jobs in different sectors and some employees did not get their remuneration fully. Due to the loss of job, these people are having difficulties to meet their necessities. Consequently, all the above mentioned points directly affect the cash flow. It has been observed from the literature review that manufacturing industry has been hit in many ways due to the Corona effect. To begin with, lower production due to lack of raw materials, employees stop coming in to work due to government directives, thereby reducing the scale of operations, with a consequent effect on quality, cost and production volumes. Over a period, this adversely affects the turnover, which slows down to a drop. The uncertainties in the logistics leads to a flowing effect; transporters struggle to not only place vehicles for loading; they also are under pressure to adjust their quotes for carrying goods, as it also faced lower attendance, with their operational risks increasing steeply. Another side, the slower rate of banking operations, shorter working hours and jammed & overloaded communication lines lead to delayed money transactions, thereby elevating monetary risks.

Hence, the main challenges for restarting manufacturing industries can be started, although COVID-19 will remain around and create a high degree of uncertainty in all aspects in manufacturing sectors. In particular, the need to avoid the further spread of COVID-19 in the workplace or through the movement of people and materials may result in further restrictions and a potential return to lockdown. When restrictions are lifted, the market is expected to be very tight and extremely cash-constrained. This is largely due to extreme uncertainties with regard to demand for manufacturing and consequent low or non-existing business income while expenses for labor, energy, rent and other business inputs will still be suffered.

Now, the different Indian govt. organizations (MSME, Confederation of Indian Industry) may consider the followings:

1. Manpower will be a constraint due to maintaining social distancing, therefore some percentage of workers have to bring back from their hometowns due to uncertainties of job and loss of income during the lockdown. Now, it will be a challenge to convince staff to return or to hire new staff for operation. Even though engagement with industrial training institutes and hiring of temporary workers on walk-in basis.
2. Machinery and stocks of raw materials, work in progress and final products become tainted. It needs to undertake outstanding maintenance and service, and clean out wasted stocks, before they can resume operations, at a significant cost and with likely write-offs of stocks currently trapped on-site.

3. Ensuring timely supplies of essential inputs without price hikes is a matter of concern. Those are sometimes critically dependent on specialized parts from other states or from abroad express concerns about their susceptibility to supply shortages.
4. Some emergency product industries had already started pre-lockdown with some measures for COVID-19 infection prevention and control, particularly through awareness-raising and communication (on hygiene, physical distancing, etc.) and, in some cases, the provision of hand sanitizers, masks and gloves. This forms the basis for stepping up preventive measures for post-lockdown. Common measures under consideration are health checks at the factory entrance, the provision of personal protective equipment (PPE), staggering of shifts and break times to minimize congestion of people, maintaining physical distancing during work and compulsory use of Aroygya setu app (COVID-19 contact tracing app launched by the Government).
5. Currently, the most immediate concerns are cash flow and working capital. Most are concerned that survival is only possible with a substantive financial and/or fiscal support package from the government.
6. Build digital SC & logistics and mandate and further drive digital payments.

6. Conclusion

The panic-stricken country has come to a standstill with nationwide lockdowns, mandatory quarantine, home confinement, job losses and economic woes. However, these restrictions have a severe impact on SCM in Indian manufacturing sectors. Notably, the restrictions disrupted the raw materials and finished goods SC that in turn made to experience huge losses and growth of market are facing too much problems. Adding to that, immense post losses due to shortage of labors and transportation bottlenecks were observed. In this paper, we have focused on five main barriers of SCM in manufacturing sectors and used the Fuzzy-AHP model to evaluate the weightage of different barriers due to COVID-19. It has been seen that lack of man power is the most serious barrier and the least weightage barrier comparing to others is deficiency in cash flow in the market because it depends upon the other barriers. This study can be extended by considering the other barriers with different multi-criteria decision making approaches. The proposed paper provides some useful information to manufacturing sectors in checking out the action plans in order to overcome those barriers. Once the barriers are overcome, the manufacturing sectors can start their production and continue in contributing to the country's GDP substantially.

References

Arikan, F., (2013). An interactive solution approach for multiple objective supplier selection problem with fuzzy parameters. Journal of Intelligent Manufacturing, DOI: 10.1007/s10845-013-0782-6.

Biswas, T., Chaki, S. & Das, M.C. (2019). MCDM technique application to the selection of an Indian Institute of Technology. Operational Research in Engineering Sciences: Theory and Applications, 2(3), 65-76.

Biswas, T., Chatterjee, P. & Choudhuri, B. (2020). Selection of commercially available alternative passenger vehicle in automotive environment. Operational Research in Engineering Sciences: Theory and Applications, 3(1), 16-27.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operations Research, 95, 649–655. DOI:10.1016/0377-2217(95)00300-2.

Chaudhry, S. A. (26 March 2020). Covid-19 puts India's food supply chain to a stress-test. The Hindu @businessline. Retrieved 26, March 2020.

Cucinotta, D., & Vanelli, M. (2020) WHO Declares COVID-19 a Pandemic. Acta Biomed, 91:157-160.

Goyal, M. (22 March 2020). "Covid-19: How the deadly virus hints at a looming financial crisis". The Economic Times. Retrieved 23, March 2020.

Jamwal, A., Bhatnagar, S., & Sharma, P. (2020). Coronavirus Disease 2019 (COVID-19): Current Literature and Status in India.

Krishnan, V. (2020). "The Callousness of India's COVID-19 Response". The Atlantic. Retrieved 2 April 2020.

Kumar, S.,Thombare, P. B., & Kale, P. A. Impact of coronavirus (COVID-19) on Indian economy. ISSN: 2581-8317, 2 (4), April 2020.

Mayo clinic. Coronavirus disease 2019 (COVID-19). 2020.

Md. Moktadir, A., Mithun Ali, S., Rajesh, R., & Paul, S. K. (2018). Modeling the interrelationships among barriers to sustainable supply chain management in leather industry. Journal of Cleaner Production, 181, 631-651

Meehan, J., & Muir, L. (2008). SCM in Merseyside SMEs: Benefits and barriers". The TQM Journal, 20:223-232.

Mudgill, A. (25 March 2020). "How will India lockdown play out for economy & markets: 4 scenarios". The Economic Times. Retrieved 25 March 2020

Parth, M.N. (26 March 2020). "Coronavirus Outbreak: In Maharashtra, police disrupting farm produce supply chains impairs farmers, lack of labour stalls harvest". Firstpost. Retrieved 26 March 2020.

Research, Centre for Policy. "Podcast: How has India's lockdown impacted unemployment rates and income levels?". Scroll.in. Retrieved 24 April 2020.

Saaty, T. L. (1980). The analytic hierarchy process (1st ed.). New York: McGraw-Hill.

Shaw, K., Shankar, R., Yadav, S.S., & Thakur, L.S., (2012). Supplier Selection Using Fuzzy AHP and Fuzzy Multi Objective Linear programming for developing low carbon supply chain. Expert Systems with Applications, 39(9), 8182-8192.

Singh, S. (1 April 2020). Covid-19 Pandemic Spoils Indian Startup Funding Party, Growth Stage Worst Hit in Q1 2020. Inc 42 Media. Retrieved 1, April 2020.

Sirisawat, P. & Kiatcharoenpol, T.(2018). Fuzzy AHP-TOPSIS approaches to prioritizing solutions for reverse logistics barriers. Computers & Industrial Engineering, 117, 303-318.

Stank, T.P., Dittmann, J.P. & Autry, C.W. (2011). The new supply chain agenda: A synopsis and direction for future research. International Journal of Physical Distribution & Logistics Management; **4**(10): 940-955.

The Indian Express. 23 March 2020. Stock markets post worst losses in history; Sensex crashes 3,935 points amid coronavirus lockdown". Retrieved 23, March 2020.

Vyas, M. (21 April 2020). "Unemployment rate touches 26%". Centre for Monitoring Indian Economy (CMIE). Retrieved 24 April 2020.

WHO. Coronavirus disease 2019 (COVID-19) Situation Report-92. 2020.

Wu, Debby (25 March 2020). "iPhone Makers Suspend India Production Due to Lockdown". Bloomberg. Retrieved 25 March 2020.

Yu, K.D.S., & Aviso, K.B. (2020). Modelling the Economic Impact and Ripple Effects of Disease Outbreaks. Process Integr Optim Sustain. https://doi.org/10.1007/s41660-020-00113-y.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 13-28
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303013s

AN APPLICATION OF METAHEURISTIC OPTIMIZATION ALGORITHMS FOR SOLVING THE FLEXIBLE JOB-SHOP SCHEDULING PROBLEM

Aleksandar Stanković*, Goran Petrović, Žarko Ćojbašić, Danijel Marković

Faculty of Mechanical Engineering, University of Niš, Serbia

Received: 11 June 2020
Accepted: 10 August 2020
First online: 24 September 2020

Original scientific paper

Abstract. *The Flexible Job Shop Planning (FJSP) problem is another planning and scheduling problem. It is a continuation of the classic problem of scheduling jobs, where each operation can be performed on different machines, while the processing time depends on the machine being used. FJSP is a difficult NP problem that consists of two sub-problems, scheduling problems and scheduling operations. The paper presents a model for solving FJSP based on meta-heuristic algorithms: Genetic algorithm (GA), Tabu search (TS) and Ant colony optimization (ACO). The efficiency of the approach in solving the aforementioned problem is reflected in the flexible search of space and the choice of dominant solutions. The results of the computation are graphically represented on the Gantt chart.*

Keywords: *Scheduling, Flexible job-shop, Genetic algorithm, Tabu Search, Ant Colony Optimization, Local search.*

1. Introduction

The planning of production and production processes has a very important role in the successful functioning of production. Planning and scheduling problems occur in almost every field of economics, engineering, up to industrial production. One of the most important production issues is the planning and scheduling of operations. A key reason for scheduling and planning operations is to increase production productivity. Scheduling and planning operations can be very easy, but it can also be one of the most difficult scheduling problems, depending on the type of problems and planning conditions. A problem where there is more than one machine available for each operation, where there is flexibility in selecting a machine from a set of alternative machines is called the Flexible Job Shop Problem (FJSP). According to the

* Corresponding author.
aleksandar.stankovic@masfak.ni.ac.rs (A. Stanković), goran.petrovic@masfak.ni.ac.rs (G. Petrović), zcojba@ni.ac.rs (Ž. Ćojbašić), danijel.markovic@masfak.ni.ac.rs (D. Marković)

JSP action routine, each job is processed on a machine with a defined processing time, and each machine can only process one operation. In practice, a machine may have the flexible ability to perform more than one type of operation, leading to the modification of the JSP in the FJSP. As Pinedo (2008) stated his book, the definition of FJSP can be expressed as a generalization of the workplace and the parallel environment of machines. Instead of *m* machines in a row, there are *c* centers for working with each work center in parallel with the same number of identical machines. Each job has its own route to follow throughout the shop; job *j* requires processing in each work center on only one machine and each machine can run. If a business on its way through the store can visit the work center more than once, then the *b*-field contains the *rcrc* entry for recirculation.

The aim of this paper is to test and compare tree meta-heuristic optimization methods in order to minimize the amount of time spent planning and scheduling operations on the available set of machines. The results obtained using different approaches should help managers to identify an appropriate method for this class of problem.

There are different approaches to solving FJSP available in the literature, and that will be reviewed in the next section. In the earlier years of research into planning and scheduling problems, exact methods were used in the allocation of resources. Today, methods such as constraint programming and simulation methods are being used more and more in the planning world. The objective of this paper is reflected in the application of several meta-heuristic methods, namely Tabu Search (TS) algorithm, Ant Colony Optimization (ACO) and Genetic Algorithm (GA) and their comparison in the speed of the convergence and accuracy of the solutions. The basic idea is to assess which of the applied algorithms is most applicable for solving FJSP.

2. Literature review

Resource planning and scheduling, as well as the methods used to solve scheduling problems, are gaining ground in many areas of logistics, planning, search, and routing, where this methodology is very significant and applicable. Speaking of scheduling (Brucker & Schile, 1990), they are one of the first scientists to develop a graphical algorithm for planning and scheduling. The algorithms most commonly used today to solve scheduling problems within the FJSP are meta-heuristic algorithms: Genetic Algorithm (Fraser, 1957; Bremermann, 1958; Holland, 1975), Ant Colony Optimization (Dorigo et al., 2006), Simulated Annealing (Kirkpatrick et al., 1983), Tabu Search (Glover & Laguna, 1997), Particle Swarm Optimization (Kennedy & Eberhart, 1995) and others. In the continuation of the work in Figure 1, methods are presented on the basis of which it is possible to solve the problems of planning and scheduling resources.

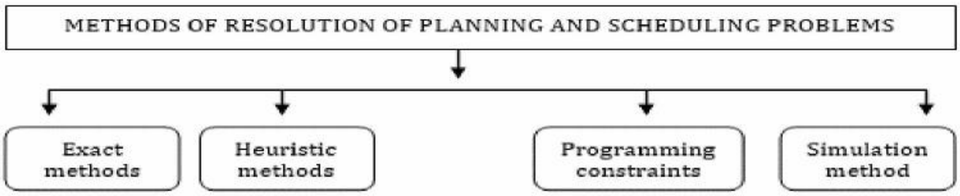

Figure 1. Methods for solving scheduling problems

Exact methods: The basic feature of exact methods is the accuracy in defining mathematical model as well as finding optimal solutions depending on the size of the data tested. One of the major drawbacks of exacting methods is solving robust models. This group of methods includes some of the basic techniques used to solve scheduling and planning problems: nonlinear, linear, dynamic, integer, and disjointed programming techniques. There are many exact algorithms in the research literature that are used to solve such research problems, such as Branch and Bound methods (Lomnicki, 1965), and they can be defined through various techniques for determining the lower and upper bounds.

Klein & Scholl (1996), as well as Blazewicz, et al., (1996) present, in their works, the Branch and Baund method in the example of resource planning, and the main aim of their work is to assign tasks to a certain number of machines in order to achieve maximum productivity. Liu, et al. (1996) and Thomalla (2001) present, in their papers, the problem of scheduling by the Lagrangian relaxation method, where they prove that the scheduling and planning problem can be successfully solved by this method. Robson (1986) worked to refine an algorithm he had already developed to improve temporal complexity. Ostergard (2002) proposed a Branch and Baund algorithm that defines each node with a different color to distinguish the nodes from each other, which at that point is a new tagging methodology. Vandaele (2000), Hasan & Arefin (2017), and Aslan et al. (2017) show, in their papers, the problem of planning and scheduling and the success in solving these problems by an integrated method of planning.

Heuristic methods: Alan Turing is probably the first to use heuristic algorithms when he broke the German Enigma code during World War II. The next significant step in the evolution of evolutionary algorithms was (Holland, 1975) and his associates at the University of Michigan in the 1960s and 1970s. Such search methods do not guarantee finding the optimal solution, but effectively finding a good enough solution. Heuristics are divided into: heuristics that give only one solution within the search and heuristics that give results during the search through a series of iterative solutions. In the works, (Sentlelro, 1993), (Lagodimos & Leopoulos, 2000), (Spyropoulos, 2000), (Xing & Zhang, 2000), we can see a heuristic approach to solving planning and scheduling problems, and also based on the obtained results, it can be seen that this approach gives optimal results. Kung & Chern (2009) show another way to solve planning problems. In this paper, we can see a scheduling heuristic approach that focuses on solving factory planning and scheduling operations for different job (product) structures. For this planning problem, a heuristic algorithm is proposed, and is referred to in the paper as the factory planning heuristic algorithm, abbreviated as HFPA. Xing & Zhang (2000) use a method of heuristic approach to solve the problem of planning and scheduling on the problem of M parallel machines with minimal total cost. Sobeyko & Mönch (2016) present a heuristic approach to solving scheduling problems in large-scale flexible operations. Based on the results obtained in this paper, we can conclude that the proposed heuristics arrive at satisfactory solutions quickly.

Programming constraints: This problem-solving approach belongs to the group of NP-hard problems, and the basic feature is the programming of constraints on problem solving in industrial planning and scheduling systems. There are a number of different software applications used in this troubleshooting category that can be used to program scheduling constraints. This approach originated in the field of artificial intelligence. The programming languages most commonly used today to solve artificial intelligence planning and scheduling problems are: MatLab, Python, C ++, C #, Java, and more. When it comes to programming time, constraints planning, and scheduling problems are meta-heuristic methods largely presented.

One example of solving scheduling problems can be seen in (Stanković, et al., 2019). It should be noted that two approaches are presented in the literature: the deterministic approach and the stochastic approach (Pinedo, 2008). The time of completion of the scheduling of operations (products) in the scientific literature is indicated by C_{max} which represents the total criterion value of the function. Examples of solving problems of planning and scheduling can be seen in (Jamili, 2018); (Fan, et al., 2019). Solving FJSPs based on meta-heuristic algorithms with programming constraints in the form of time constraints, periods of unavailability can be seen in the papers (Zhang, et al., 2011); (Stanković, et al., 2019).

Tamssaouet, et al. (2018) compares several meta-heuristic algorithms with their associates with periods of machine unavailability in the form of preventive and corrective machine maintenance. Liaw, (2000) presents the application of a hybrid algorithm with a basic genetic algorithm. Further research includes a local tab-based search enhancement process. The results obtained show optimality compared to other search algorithms.

Simulation methods: Simulation modeling has a great ability to present complex systems in a multitude of details, which is its main advantage over other methods. Simulation-based planning is used for many operations and system controls, and as a final output, a detailed work plan is obtained. Simulation-based planning models need to be more detailed than other typical simulation models. Many models in practice with this type of problem can only be solved by the simulation-based optimization method, an approach in which the simulation model is integrated with meta-heuristic search methods such as GA and TS (Laguna, et al., 2003).

The Kanban method is used to increase the productivity of product flow through a single production system and eliminate potential errors at the end of a cycle. Kanban is a system that controls the flow of material (resources) through a number of multiple optimization processes. Kanban system was developed by Toyota engineers - Taiichi Ohno (Industrial Engineer and Businessman) to optimize their manufacturing process. The implementation and success of solving the problems of planning and scheduling operations in small and medium-sized enterprises can be seen in many professional papers. Schaefers et al., (2000) is one example of solving product planning and flow problems as well as cost optimization. Problems were identified, analyzed and optimized based on the Kanban method. Japanese industry management technique has been applied in many western countries.

Graver & Price (1987) present the Kanban method in their work and use it to solve JSP planning and scheduling problems in the form of simulation, and the final results of the simulation show a significant improvement of the system over previous planning practice. Kumar & Panneerselvam (2007) present the Kanban system and 100 state-of-the-art research papers as well as suggestions for further research.

The Work Load Control (WLC) method involves three models: planning, control, and scheduling. The basic task of this method is to solve the problem of production load. In many cases, when planning and selecting a job, the rules of job priority are used, depending on the delivery time of a certain type of product, which is one of the most important factors during the planning process in small and medium-sized enterprises. Such methods are of great use in the form of simulations and in solving planning and scheduling problems, which can be seen in papers (Thürer et al., 2012); (Thürer et al., 2017).

3. Methodology

Accurate and heuristic methods are used to solve planning and scheduling problems. The application of exact methods is limited to simple problems, while more complex meta-heuristic methods are used for complex real systems. The term meta-heuristics was first proposed by Fred Glover in 1986, while the same author defined meta-heuristics many years later as a high-level problem-independent algorithmic framework that provides a set of guidelines or strategies to develop heuristic optimization algorithms (Sörensen & Glover, 2013). Meta-heuristics are designed to solve complex optimization problems when other optimization methods fail to effectively solve the optimization problem.

These methods are nowadays recognized as one of the most important practical approaches to solving many complex problems, and this is especially important for solving many real combinatorial optimization problems, hence the application for the FJSP problem. In general, meta-heuristics can be said to be higher level heuristics. Below, we present three meta-heuristic methods that have been applied in solving the problems of allocation and scheduling of FJSP operations.

3.1. Tabu Search

The Tabu Search (TS) algorithm was first mentioned by a famous scientist Glover, (1986). The TS algorithm is a meta-heuristic search method that uses local search methods. Search implementation uses structural models that describe average places, that is, possible solutions, or use sets that the user defines as the initial parameters of the problem under consideration. This means that if a potential solution was previously visited at some point in the search or if the set search rules were exceeded, then it will be marked in the tab list. So, the TS algorithm does not take the same solution multiple times as possible solutions during search.

Tabu searches during previous research have proven to be the optimal search method in a wide range of classic and practical planning problems, and even in the field of neural networks, as can be seen in papers (Nowicki & Smutnicki, 2005); (Zhang et al. 2007). To avoid problems during the search, the size of the taboo list during the search needs to be modified (Talbi, 2009). Tabu list size is crucial during this type of search. For a taboo list that is too small, a search will tend to cycle through the same possible solutions multiple times, whereas if the taboo list is too large, the lack of available moves can lead to possible errors during the search. The TS algorithm is represented by a pseudocode in Table 1 (Glover, 1989).

Table 1. Pseudocode of Tabu Search

Pseudocode of Tabu Search

sBest ← s0
bestCandidate ← s0
tabuList ← []
tabuList.push(s0)
While (not stoppingCondition())
sNeighborhood ← getNeighbors(bestCandidate)
for (sCandidate in sNeighborhood)
if ((not tabuList.contains(sCandidate)) and (fitness(sCandidate) > fitness(bestCandidate)))
bestCandidate ← sCandidate
end for
end if
if (fitness(bestCandidate) > fitness(sBest))
sBest ← bestCandidate
end if
tabuList.push(bestCandidate)
if (tabuList.size > maxTabuSize)
tabuList.removeFirst()
end if
end While

3.2. Ant colony optimization

The Ant Colony Optimization (ACO) method was first proposed by Dorigo (1992). Ant colony optimization is a population-based meta-heuristic that can be used to find approximate optimal solutions for different test cases. The algorithm is inspired by the behavior of ants in nature. The basic characteristic of the collective behavior of ants is that all members of the colony exchange information about their environment indirectly or directly, i.e. the phenomenon of collective intelligence. It has been discovered in nature that each ant leaves a trail behind, releasing a certain amount of a chemical called a pheromone. The more ants go in one path, the more pheromones, and that is, for each subsequent ant, positive information about the correctness of that path. In this way, the ants indirectly communicate with each other via pheromones. All ants start with a value of 0, which means that no operations are scheduled before the search begins. All nodes have an initial pheromone 1. The pheromone will decrease after each round of search. Local search depends on the number of pheromones and the search time, and the total time is calculated based on the extra time required to activate the next O_{ij} operation on the available M_n machine. A random value is generated for comparison with r_0. If the rand value is less than r_0, the local search will select the planning route with the maximum amount of pheromone. Only the best ants can deposit the pheromone on the path from point A to point B. The total amount of pheromone deposited is calculated based on the expression $\Delta\tau = 1 / (best\ cost)$. The pseudocode of the ACO algorithm is presented in Table 2 (Yang, 2010).

Table 2. Pseudocode of Ant Colony Optimization

Pseudocode of Ant Colony Optimization

Objective function f (x), x = (x1,...xn)T
[or f (xij) for routing problem where (i, j) € {1, 2, ... n}]
Define pheromone evaporation rate $^{\gamma}$
while (criterion)
for loop over all n dimensions (or nodes)
Generate new solutions
Evaluate the new solutions
Mark better locations/routes with pheromone $^{\delta\varphi}$ij
Update pheromone: $^{\varphi}$ij – (1-$^{\gamma}$) $^{\varphi}$ij + $^{\delta\varphi}$ij
end for
Daemon actions such as finding the current best
end while
Output the best results and pheromone distributions

3.3. Genetic algorithm

Genetic Algorithm (GA) is an optimization technique used to solve nonlinear or non-differential optimization. The GA was developed by Holland in the 1970s of the last century (Holland, 1975). The genetic algorithm is characterized by several stages in solving a defined problem, in this case of planning and scheduling.

The algorithm mimics the natural selection process, while changes in the genetic structure are possible by mutation of genetic material, the essence of which is to expand the search area and overcome local extremes. Crossing in solving GA is a process of combining several units to get a new unit selected, and this type is compared to a natural process like parents and their offspring. New individuals inherit their parents' genes. When it comes to solving planning and scheduling problems, the most common examples are based on a genetic algorithm. One of the most common solutions is based on a coded job scheduling matrix used for scheduling problems on more than one machine, an example of such a matrix can be seen in Figure 2.

M1: O_{11}; O_{13}; O_{12} → M1: J_1; J_3; J_2
M2: O_{22}; O_{23}; O_{21} → M2: J_2; J_3; J_1
M3: O_{31}; O_{32}; O_{33} → M3: J_1; J_2; J_3

Figure 2. Job scheduling matrix

The mutation involves a random change in the genes of the individuals. Mutation achieves uncontrolled alteration of genetic material. By changing the genetic structure, completely new solutions are achieved. The basic goal is to get an individual that cannot be obtained in other stages.

This random value initiates a search across the entire allowed domain. The mutation rate should be small from about 0.001% to 0.01% in order to avoid a random, stochastic and uncontrolled procedure. The pseudocode of GA is presented in Table 3 (Yang, 2010).

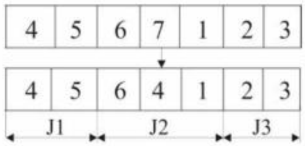

Figure 3. Mutation in the case of scheduling machine

Table 3. Pseudocode of GA

Pseudocode of GA
Objective function f(x), x= $(x_1,....,x_n)^T$
Encode the solution into chromosomes (binary strings)
Define fitness F (eg, F ∞ f(x) for maximization)
Generate the initial population
Initial probabilities of crossover (p_c) and mutation (p_m)
While (t < Max number of generations)
Generate new solution by crossover and mutation
If p_c > rand, Crossover;
end if
If p_m > rand, Mutate;
end if
Accept the new solutions if their fitness increase
Select the current best for new generation
end while
Decode the results and visualization

4. Case study

This section presents a method for solving FJSPs based on three proposed meta-heuristic algorithms. The first part of the case studies presents a model for testing algorithms on a classic data set. The efficiency of the algorithms is reflected in the speed of the convergence solution through a series of iterations. The input parameters consist of 25 jobs and 10 machines with a defined processing time of each operation on an individual machine. The mathematical model of solution optimization with objective function and time constraint is represented by the following notation:

- J – number of jobs,
- M – number of identical machines,
- $p_{i,j,k}$ – the processing time of each operation.

Constraints:

$$J > M > 1,\; J, M \in Z^+ \tag{1}$$

$$\forall\, p \in T,\;\; p \in Z^+ \& 1 \le p \le M \tag{2}$$

Cost function:

$$f(x)=max_i f(i), \quad i=1,2,..., M \tag{3}$$

The input parameters as well as the results of the optimization problem for all three meta-heuristic algorithms are presented in Table 4.

Table 4. Input parameters and results: TS, ACO and GA

TS parameters		
MaxIter	J	M
1000	25	10
Time for TS algorithm for which an optimal solution is found [s]		
Local best found for 1000 iterations	187	
ACO algorithm parameters		
MaxIter	J	M
1000	25	10
Time for ACO algorithm for which an optimal solution is found [s]		
Local best found for 1000 iterations	182	
GA parameters		
MaxIter	J	M
1000	25	10
Time for GA for which an optimal solution is found [s]		
Local best found for 1000 iterations	176	

Based on the results presented in Table 4, it can be concluded that TS, ACO and GA give satisfactory results, but that GA gives the most favorable results. On the basis of the obtained results, GA was used in the FJSP case study of planning and scheduling operations in an industrial environment.

The case study covers the planning and scheduling of production cycles related to the FJSP solution. The basic structure of the problem being solved relates to a set of jobs that need to be done on the machines, and each job is allocated to a list of activities that are processed in the order. The essence of the problem and the defined activity is to keep the total completion time as low as possible in accordance with the planned operations with defined time of each operation individually. The set of operations performed to make one job complete and therefore a finished product. The mathematical model of FJSP can be represented as follows (Özgüven et al., 2010).

It is necessary to schedule *n* products $J = \{J_1, J_2, ..., J_n\}$, with each job J_j (j = 1,2, ... n) having a predetermined order of operations *nj* (O_1, *j*, O_2, *j* ,. ... They, *j*), should be realized in the order given in *m* machines $M = \{M_1, M_2,..., M_m\}$. For a completely flexible problem, each machine can perform only one operation at a time, and the processing time of each operation depends on the machines available and is represented by *p, i, j, k* (processing time of the operation O_i, *j* on the machine M_k). The goal of the problem observed is to assign each operation to a corresponding machine and then determine the arrangement of all the machines assigned to the operations to reduce the target function, in this case minimizing the manufacturing process based on GA. An example of the problem examined is presented in Table 5.

Table 5. Input matrix of partial FJSP

Jobs	Operations	M_1	M_2	M_3	M_4	M_5	M_6
	O_{11}	7	-	1	5	-	-
	O_{21}	3	-	-	5	-	8
J_1	O_{31}	-	6	-	7	-	10
	O_{41}	7	-	5	7	-	-
	O_{51}	-	5	-	-	6	3
	O_{61}	7	-	-	-	6	3
	O_{12}	-	8	-	8	-	9
	O_{22}	5	-	5	-	-	4
J_2	O_{32}	10	-	11	-	10	-
	O_{42}	8	-	7	-	-	10
	O_{52}	10	-	-	10	-	12
	O_{62}	-	7	15	4	-	-
	O_{13}	8	-	5	-	7	-
	O_{23}	-	4	-	4	6	-
J_3	O_{33}	-	-	-	-	-	8
	O_{43}	9	-	8	-	7	-
	O_{53}	-	3	-	5	-	3
	O_{63}	-	5	6	-	7	-
	O_{14}	-	5	-	6	-	9
	O_{24}	5	-	4	-	8	-
J_4	O_{34}	9	-	5	-	-	10
	O_{44}	5	11	-	3	-	-
	O_{54}	15	-	9	-	8	-
	O_{64}	-	10	-	11	-	9
	O_{15}	9	-	9	-	9	-
	O_{25}	-	3	6	-	8	-
J_5	O_{35}	-	6	7	-	5	-
	O_{45}	-	6	-	5	-	4
	O_{55}	3	-	4	-	4	-
	O_{65}	-	8	-	6	-	9
	O_{16}	-	3	-	5	-	4
	O_{26}	8	-	-	3	6	-
J_6	O_{36}	7	-	8	-	-	9
	O_{46}	10	-	8	9	-	-
	O_{56}	-	9	-	10	4	-
	O_{66}	7	-	6	-	8	-

It should be noted that not all machines need to be able to perform all the operations as can be seen in the attached Table 5. This troubleshooting approach is called partial troubleshooting or partial flexibility where some operations can only be performed on specific machines. Such examples are much more common in real-world cases during optimization of production processes. Table 5 of the problem described can show 6 jobs and 6 machines, job 1 has 6 operations, the first operation can only be processed by one machine and that machine is M_3 with a processing time of 1. We can see the graphical results of the first investigated case of partial research flexibility in Figure 4 in the Gantt chart.

One of the most common means of presenting a result in the case of production planning is Gantt charts and as they are called in the research literature, Gantt charts. Gantt chart is a diagram in a coordinate system in which the horizontal axis is time, and the vertical axis shows the planning tasks on which to determine: the beginning, total duration and end of the cycle, which is the main problem in determining the planning and scheduling in this case of machine and work. Another examined case of planning and scheduling is called total FJSP, with each operation being deployable on any of the available *m* machines, as all machines are capable of performing each operation at a specified time during a specified processing time of each operation. An example of the problem examined is presented in Table 6.

Table 6. Input matrix of total FJSP

Jobs	Operations	M_1	M_2	M_3	M_4	M_5	M_6
	O_{11}	7	11	9	7	8	9
	O_{21}	3	6	12	10	5	7
J_1	O_{31}	5	6	6	11	7	10
	O_{41}	5	5	7	7	8	7
	O_{51}	9	5	10	9	6	3
	O_{61}	10	3	11	8	6	7
	O_{12}	7	8	7	5	7	7
	O_{22}	4	7	5	10	9	8
J_2	O_{32}	5	7	9	10	10	9
	O_{42}	3	5	11	10	9	10
	O_{52}	10	7	9	9	6	6
	O_{62}	3	9	5	4	11	10
	O_{13}	5	6	5	7	8	9
	O_{23}	2	5	9	4	8	9
J_3	O_{33}	8	5	9	10	10	8
	O_{43}	9	5	9	10	11	8
	O_{53}	7		7	10	7	9
	O_{63}	7	9	9	10	7	11
	O_{14}	7	5	7	8	9	10
	O_{24}	5	5	7	9	9	9
J_4	O_{34}	5	9	5	10	6	10
	O_{44}	6	7	8	3	9	3
	O_{54}	2	5	9	9	8	10
	O_{64}	7	9	9	10	11	9
	O_{15}	9	5	9	8	10	11
	O_{25}	6	5	5	8	10	6
J_5	O_{35}	9	5	9	10	5	9
	O_{45}	5	9	10	11	12	4
	O_{55}	3	5	5	6	9	11
	O_{65}	9	8	9	8	10	7
	O_{16}	2	3	9	8	10	7
	O_{26}	2	5	9	3	9	7
J_6	O_{36}	2	5	9	9	10	9
	O_{46}	10	9	10	9	9	10
	O_{56}	9	5	10	6	4	9
	O_{66}	10	5	9	4	9	8

Table 6 shows the input parameters of the test problem where we have 6 jobs (products) where each of these 6 jobs has 6 operations, each of which defined operations with machine processing time in minutes can be performed on each machine. As we can see in the previous part of the paper, we call this case complete flexibility. Graphical results of the survey can be seen in Figure 5. As for the implementation of GA, the experimental results were tested in python and the numerical values were derived on standard MS Windows based PC platform.

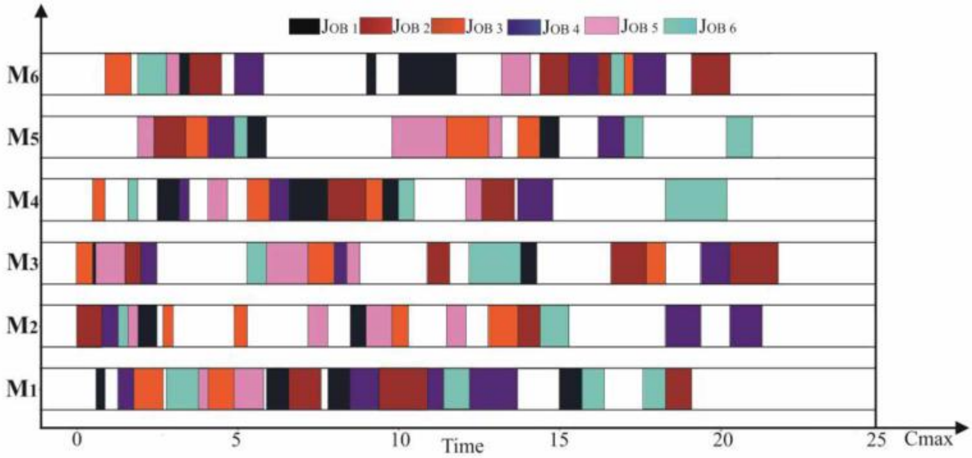

Figure 4. Graphical representation of the results for the first case in Table 5

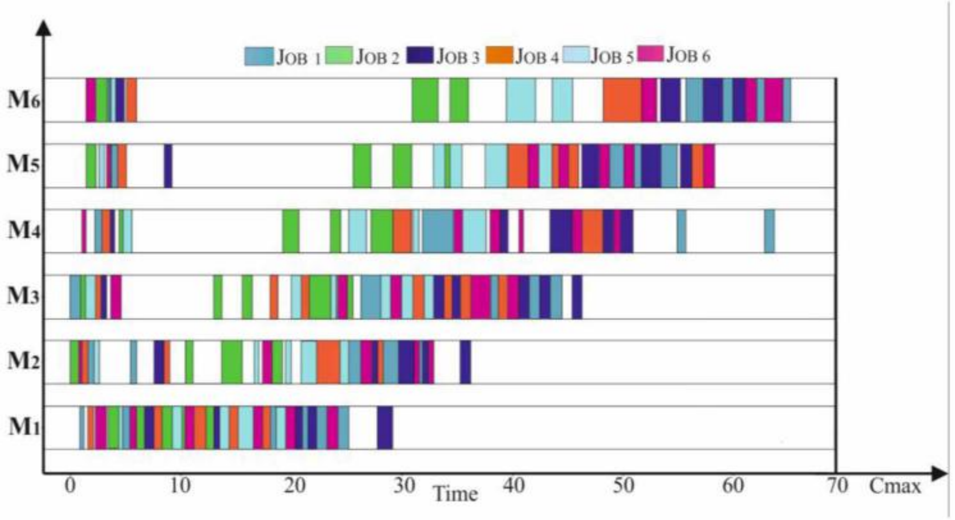

Figure 5. Graphical representation of the results for the second case in Table 6

5. Results and discussion

After introductory discussions and clarification of the FJSP, as well as a review of the research literature on the topic of planning, a specific set-up of the problems and results of the planning was made. It is important to note that the tested test data is randomly given. As can be seen in the previous part of the paper, two cases of planning and scheduling were tested, which was at the same time the aim of this problem. Table 5 shows that not every machine can perform every operation during the planning and scheduling of operations. Partial flexibility is one of the most common causes that can be encountered in manufacturing, it is often the case that not every machine can perform every operation to get the job (product) done. The results of the input data in Table 5 are graphically presented in the chart in Figure 4 for the first case of partial flexibility. In Figure 4, we can see the layout of operations on individual machines depending on the initial constraints. *J* defines each job in a different color to differentiate jobs (products). On the horizontal axis, time is presented with the criterion function value C_{max} = 218 units in minutes. Regarding testing, it was noted that the search was performed by Genetic algorithm with MaxIter = 500. GA based search in a python programming language, that is, total planning and scheduling time is 41.63 seconds for the first case tested. On the vertical axis, we can see all 6 machines that are linearly aligned. With regard to the second case examined, it is presented in Table 6 and is clearly different from the first case examined. In Table 6, based on the input data presented, it is possible to see complete flexibility where each machine can perform each operation with defined time.

Also, in this case, we have *J* = 6 jobs (products) and each of the jobs has O_{ij} = 6 operations that can be performed on each machine depending on the schedule of operations with a defined processing time of each operation individually. On the horizontal axis, we can see the total time represented by the value of the criterion function C_{max} = 652 units in minutes. The value of the criterion function representing the total time of completion of all operations and the completion of the planning process is represented by the C_{max} mark, which could be seen in the previous part of the paper and is presented in minutes. The Gantt chart presents a detailed schedule of operations that will be performed on machines. The machines are represented linearly on the vertical axis. The total simulation time based on GA in a python programming language is 90.89 in seconds. The objective of the examined problem of planning and scheduling operations was successfully realized, as can be seen from the attached results. The results obtained confirm the success of the genetic algorithm in solving FJSP.

Regarding the proposal for further research, the FJS problem can be further expanded by observing available workers who participate in the realization of production activities. In this problem, workers and machines are limited, and the problem is called the Dual Resource Constrained Flexible Job Shop.

Acknowledgment

This research was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

References

Aslan, E., Şimşek, T., & KarkacieR, A. (2017). A binary integer programming model for exam scheduling problem with sSeveral departments, 13th International Conference on Knowledge, Economoy and Management, Bilgi Ekonomisi ve Yönetimi Dergisi, 12 (2), 169-175.

Blazewicz, J., Domschke, W., & Pesch, E. (1996). The job shop scheduling problem: Conventional and new solution techniques. European Journal of Operational Research, 93, 1-33.

Bremermann, H. J. (1958). The evolution of intelligence. The nervous system as a model of its environment, Technical Report No. 1, Department of Mathematics, University of Washington, Seattle, WA.

Brucker, P., Schile, R. (1990). Job-shop scheduling with multi-purpose machines. Computing, 45(4), 369–375.

Dorigo, M. (1992). Optimization, learning and natural algorithms (in italian), Ph.D. dissertation, Dipartimento di Elettronica, Politecnico di Milano, Italy.

Dorigo, M., Birattari, M., & Stutzle, T. (2006). Ant Colony Optimization. IEEE Computational Intelligence Magazine 1(4):28-39, DOI: 10.1109/MCI.2006.329691

Fan, K., Wang, M., Zhai, Y., & Li, X. (2019). Scatter search algorithm for the multiprocessor task job-shop scheduling problem. Computers & Industrial Engineering, 127, 677–686.

Fraser, A. S., (1957). Simulation of genetic systems by automatic digital computers. II: Effects of linkage on rates under selection, Austral. J. Biol. Sci. 10:492–499.

Glover, F. W. (1989). Tabu Search – Part 1. ORSA Journal on Computing. 1 (2): 190–206. doi:10.1287/ijoc.1.3.190.

Glover, F. W., & Laguna, M. (1997). Tabu Search. Springer US.

Graver, M., Price, W. L. (1987). Using the Kanban in a job shop environment. International Journal of Production Research, 26(6):1105-1118, DOI: 10.1080/00207548808947921

Hasan, M., & Arefin, R. (2017). Application of Linear Programming in Scheduling Problem. Dhaka University Journal of Science, 65(2): 145-150.

Holland, J. H. (1975). Adaptation in Natural and Artificial Systems. University of Michigan Press, Ann Arbor.

Jamili, A., (2018). Job shop scheduling with consideration of floating breaking times under uncertainty. Engineering Applications of Artificial Intelligence, Volume 78, 28-36.

Kennedy, J., & Eberhart, R. (1995). Particle Swarm Optimization. Proceedings of IEEE International Conference on Neural Networks. IV. pp. 1942–1948. doi:10.1109/ICNN.1995.488968.

Kirkpatrick, S., Gelatt Jr, C. D., Vecchi, M. P. (1983). Optimization by Simulated Annealing. Science. 220 (4598): 671–680.

Kumar, C. S., Panneerselvam, R., (2007). Literature review of JIT-KANBAN system. International Journal of Advanced Manufacturing Technology 32(3):393-408, DOI: 10.1007/s00170-005-0340-2.

Kung, L. C., & Chern, C. C. (2009). Heuristic factory planning algorithm for advanced planning and scheduling. Computers&OperationsResearch, 36(9), 2513—2530.

Lagodimos, A. G., & Leopoulos, V. (2000). Greedy heuristic algorithms for manpower shift planning, International Journal of Production Economics, 68, 95-106.

Laguna, M., Marti, R., & Marti, R. C. (2003). Scatter Search: Methodology and Implementation in C. New York: Springer.

Liaw, C. F. (2000). A hybrid genetic algorithm for the open shop scheduling problem. European Journal of Operational Research, 124(1):28-42.

Liu, G., Luh, P.B., & Resch, R. (1996). Scheduling permutation flow shop using the lagrangian relaxation technique. IAFC 13th Triennial World Congress. San Francisco. USA, la-Ol 6.

Lomnicki, Z. A. (1965). "Branch-and-Bound" Algorithm for the exact solution of the three-machine scheduling problem. J Oper Res Soc 16, 89–100. https://doi.org/10.1057/jors.1965.7

Nowicki, E., & Smutnicki, C. (2005). An advanced tabu search algorithm for the job shop problem. Journal of Scheduling, 8(2), 145–159.

Ostergard, P. R. J. (2002). A fast algorithm for the maximum clique problem, Discrete Applied Mathematics, 120(1-3):197-207.

Özgüven, C., Özbakır, L., Yavuz, Y. (2010). Mathematical models for job-shop scheduling problems with routing and process plan flexibility, Applied Mathematical Modelling, 34, 1539–1548.

Robson, J.M., (1986). Algorithms for maximum independent sets. Journal of Algorithms, 7(3):425-440.

Schaefers, J., Briquet, M., & Colin, J. (2000). A generic KANBAN based push-pull schedule in a job shop. IFAC Proceedings Volumes, 33(17):585-590

Sentlelro, J. J. S., (1933). Planning and scheduling: non-classic heuristic, 12th Triennial World Congress. Sydney. Australia.

Sobeyko, O., & Mönch, L. (2017). Integrated process planning and scheduling for large-scale flexible job shops using metaheuristics. International Journal of Production Research, 55:2, 392-409, DOI: 10.1080/00207543.2016.1182227

Sörensen, K., & Glover, F. (2013). Metaheuristics. Encyclopedia of Operations Research and Management Science. Springer, New York.

Spyropoulos, C. D., (2000). AI planning and scheduling in the medical hospital environment. Artificial Intelligence in Medicine, 20(2):101-111.

Stanković, A., Marković, D., Petrović, G., Ćojbašić, Ž. (2019). Simulated annealing and particle swarm optimization for the vehicle routing problem and communal waste collection in urban areas, 14th International Conference on Accomplishments in Mechanical and Industrial Engineering, DEMI 2019, 497-505, isbn: 978-99938-39-84-2.

Talbi, E. G. (2009). Metaheuristics: From design to implementation, John Wiley & Sons.

Tamssaouet, K., Dauzère-Pérès, S., & Yugma, C. (2018). Metaheuristics for the job-shop scheduling problem with machine availability constraints. Computers & Industrial Engineering, 125:1-8.

Thomalla, C. (2001). Job shop scheduling with alternative process plans. International Journal of Production Economics 74(1-3):125-134 DOI: 10.1016/S0925-5273(01)00119-0

Thürer, M., Huang, G., Stevenson, M., Silva, C., & Filho, M. (2012). The performance of due date setting rules in assembly and multi-stage job shops: an assessment by simulation. International Journal of Production Research, 50(20), 5949–5965.

Thürer, M., Land, M. J., Stevenson, M., & Fredendall, L. D. (2017). On the integration of due date setting and order release control. Production Planning & Control, 28(5), 420–430.

Vandaele, N. J. (2000). An integrated, hierarcmcal framework for planning, scheduling and controlling job shop. IFAC Proceedings Volumes, 30(14):121-126.

Xing, W., & Zhang, J. (2000). Parallel machine scheduling with splitting jobs. Discrete Applied Mathematics, 103(1-3):259-269.

Yang, X. S., (2010). Engineering Optimization: An introduction with metaheuristic applications. University of Cambridge, United Kingdom.

Zhang, C. Y., Li, P. G., Guan, Z. L., & Rao, Y. Q. (2007). A tabu search algorithm with a new neighborhood structure for the job shop scheduling problem. Computers & Operations Research, 34(11):3229-3242

Zhang, G., Gao, L., & Shi, Y. (2011). An effective genetic algorithm for the flexible job-shop scheduling problem, Expert Systems with Applications, 38(4):3563–3573.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 29-47
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303029a

A SYSTEMATIC REVIEW AND ANALYSIS OF RISK ASSESSMENT IN HIGHWAY CONSTRUCTION PROJECTS

Ismail Nur Ariyanto [1], Humiras Hardi Purba [2], Aleksander Purba [3]

[1] Civil Engineering Department, Mercu Buana University, Jakarta, Indonesia
[2] Industrial Engineering Department, Mercu Buana University, Jakarta, Indonesia
[3] Civil Engineering Department, Lampung University, Lampung, Indonesia

Received: 20 June 2020
Accepted: 10 August 2020
First online: 24 September 2020

Review paper

Abstract: *Before planning and managing risks to reduce the causes of severe risks associated with road construction, it is very important to conduct an evaluation first. Aspects related to risk are convoluted in several steps from design to planning to project fulfillment. This research aims to implement a complete risk management process for highway construction projects. Through this process, there will be a list of risks in the highway construction project (risk identification) and the definition of the most significant risk through the application of the evaluation process (applying risk analysis and valuation). To successfully improve the performance of road projects, it is necessary to identify and assess various risk factors in a project for efficient project fulfillment. The research method begins by reviewing at least 50 articles to find a list of the main risk factors that might be encountered during highway construction. This analysis involves the identification, classification, and assessment of various risks involved in the construction of a highway project.*

Keywords: *Risk, Highway Project, Road, Construction, Pavement.*

1. INTRODUCTION

Progress in development in various fields continues to develop at any time, especially infrastructure development. In general, various types of construction are carried out by a contract involving various service providers in the construction sector. With a contract system, the implementation of development projects can be carried out effectively and can be accounted for, both in terms of quality and administration. In the implementation of construction, projects will not be separated from big risks and small risks. Project accuracy in implementing risk management is

* Corresponding author
farjashis@gmail.com (I. Nur Ariyanto), humiras.hardi@mercubuana.ac.id (H. Hardi Purba), purbaynu@gmail.com (A. Purba)

needed for the smoothness and success of a project. A smaller potential risk will benefit the project in terms of time, cost, and quality of construction. The larger the scale of the project, the greater the risk that will be faced and will affect the performance of project implementation if not handled properly. Like other construction projects, this highway construction project is an infrastructure project that is not free from various risks that may occur. Therefore, to reduce the risk of impacts that occur, we need a risk management system that includes identification, analysis, response, and monitoring of various risks that may occur during the development period. From the risk analysis, it can predict what risks will occur in the future based on the probability of the risk that has occurred and also other factors that will be very helpful for future projects. Research related to project risks in road construction is necessary and important to do, especially those related to road structure work. This article aims to determine and analyze important factors that pose risks in the implementation of construction projects and to find out how they affect the implementation of project risks. With risk assessments, these tasks can be prioritized for the smooth completion of road construction projects.

In completing research, there are various data and source collection methods commonly used. On this occasion, the research will be discussed further about data collection strategies through the literature review. This paper is based on a literature review from a trusted source that discusses the identification of risks and risk management in road construction, then obtained 50 articles selected and reviewed. Risks are identified through a literature review, identified risks are then assessed in terms of the impact and priority risks that are dominant so that a rating is obtained based on risk factors.

2. Research method

The writing of this article is based on a literature review conducted online including various scientific articles relating to risk analysis on road construction projects, which are then reviewed and synthesized to provide comprehensive information. The research framework of this research of articles is shown in Figure 1 bellow:

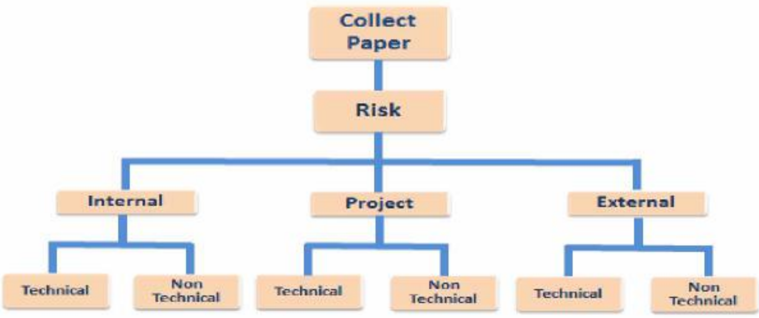

Figure 1. Research Framework

The list of articles selected and analyzed from the aspect of risk assessment in the highway construction project is shown in Table 1.

Table 1. Summary literature review of risk assessment in highway construction projects

No	Article	Risk Category						Result
		Internal		Project		External		
		Tech	Non-Tech	Tech	Non-Tech	Tech	Non-Tech	
1	(Nasir et al., 2003)	x	x	x	✔	x	x	Evaluating Risks in the Construction Model is carried out to develop a schedule risk model that discusses pessimistic and optimistic estimates of the duration of activities based on project characteristics.
2	(Wang & Chou, 2003)	x	✔	x	x	x	x	When deciding on risk management strategies, a contractor must consider many aspects, including risk responsibilities, risk patterns, risk management capabilities, etc.
3	(Molenaar, 2005)	x	x	x	✔	x	x	Provide estimates for road project cost estimates, which provide more transparent estimation, estimates and the significant and direct benefits of this process are the ability to increase high-risk items and potential mitigation measures that can be taken to improve safety.
4	(Shiraki et al., 2007)	x	x	✔	x	x	x	Combines earthquake and transportation engineering techniques to better characterize the system risk curve for the highway system.
5	(Damnjanovic & Zhang, 2008)	x	x	x	✔	x	x	A general and flexible framework for measuring risk-based performance with numerical examples where premium costs are estimated for various preventive maintenance and rehabilitation strategies and contract specifications.
6	(Gharaibeh & Shirazi, 2009)	x	x	x	✔	x	x	The risk-based model presented here to fill the price gap of warranty offers is often estimated subjectively due to the lack of a systematic methodology for measuring warranty service costs for road infrastructure assets with WCEM, estimated warranty costs, taking into account the PF of guaranteed goods as defined in the warranty clauses and costs which is projected to correct the failure.
7	(Li & Bai, 2009)	x	x	✔	x	x	x	The facts show that there is room to increase the effectiveness of traffic control currently used in high-risk work zones and help engineers to understand these risk factors and how they can increase the likelihood of death when severe accidents occur in work zones.
8	(Li & Madanu, 2009)	x	x	x	✔	x	x	Using the project-level life cycle benefits estimated by the uncertainty-based analysis approach results in a higher percentage of the level of conformity with actual programming practices compared to the level of conformity using the project benefits calculated by the risk-based analysis approach.

9	(Le et al., 2009)	x	x	✓	x	x	x	The development and testing of the APRA method is an innovative tool that can help the project team to improve the road development process through the definition of proactive scope and risk management.
10	(Zhao et al., 2009)	x	x	✓	x	x	x	The results show that the risk of fatigue cracking is not possible at the surface layer for properly designed asphalt pavement with a semi-rigid base if all layer interfaces are fully bound.
11	(Creedy et al., 2010)	x	x	x	✓	x	x	That the arbitrary application of a base contingency percentage figure, such as 10%, to accommodate project risk can lead to those projects reporting a substantial budget overrun.
12	(Sarkar & Dutta, 2010)	x	x	✓	x	x	x	Efforts have been made to design and implement new cumulative addition procedures for the ready-mix concrete industry, which address the risks involved and related to concrete production.
13	(Hall et al., 2011)	x	x	✓	x	x	x	Can be drawn: (1) Risk analysis is illustrated to help pavement engineers; (2) The AHP method makes it possible to compare the importance of parameters not only in each category, but also between categories.
14	(Honjo et al., 2011)	x	x	✓	x	x	x	The results are (1) The probability of the relative failure risk of each slope successfully estimated; (2) The absolute failure probability of each slope is estimated by calibrating the relative failure probability.
15	(Hu & Huang, 2011)	x	x	x	✓	x	x	Some conclusions: (1) Risks may be serious when the shielding machine advances under the cement concrete pavement; (2) Loss of risk and pavement condition index associated with maximum settlement due to tunneling; (3) There are about 10 accidents that will occur in the construction of several subways.
16	(Pantelidis., 2011)	x	x	✓	x	x	x	The risk value for each embankment examined derives from the failure hazard and consequence value following the well-known definition of risk.
17	(Heravi & Hajihosseini, 2012)	x	x	x	✓	x	x	The identification of the most important risks and their allocation and funding can be used by other parties who seek to attract private investment for large infrastructure projects in developing countries.
18	(Mukhopadhyay et al., 2012)	x	x	✓	x	x	x	Reducing the risk of injury, death, and property damage in the highway work zone for employees who carry out operations/maintenance and the community of road users.
19	(Tran & Molenaar, 2012)	x	x	x	✓	x	x	Conduct a risk analysis at the beginning of the project development process, but also serves as an input to the risk-based framework for selecting the appropriate project delivery method.
20	(Yasamis-Speroni et al., 2012)	✓	x	x	x	x	x	An evaluation of the contractor's quality performance, combined with an evaluation of the technical and financial performance of the contractor, can result in a better understanding of the contractor's overall capabilities.

21	(Cruz & Marques, 2013)	x	x	x	x	x	✔	This investigation revealed evidence that showed that although contracts became increasingly complex over time, the public sector assumed more production and commercial risks in the road development process.
22	(Lu et al., 2013)	x	x	✔	x	x	x	Theory and method support in terms of sensible traffic organization to improve traffic safety as well as prevent traffic jams on-road working zones on urban freeways.
23	(Azambuja & Chen, 2014)	x	x	✔	x	x	x	Mode failure methodology and criticality analysis (FMECA) is an alternative scenario recommended for ready-mix concrete plants to achieve the desired balance between having more than enough resources and avoiding risks and disruptions in the supply chain on time.
24	(Ghorbani et al., 2014)	x	x	x	x	x	✔	Time and costs are subject to adverse deviations that lead to the highest priority risk from time delays and cost overruns.
25	(Kaleem et al., 2014)	x	x	x	✔	x	x	The risk of overtime resulting from various factors is the most cardinal problem which ultimately leads to cost overruns and hence triggers turbulence in the estimated cost and initial time.
26	(Pineda & Arboleda, 2014)	x	✔	x	x	x	x	The aggregate effect of increasing cost of emergency response, uninsured calamities, third party, and user influence on indicator results, shows a particular risk arising from the indicator-based model and the interaction with road safety policies.
27	(Tran & Molenaar, 2014)	x	x	x	✔	x	x	The results indicate that seven delivery selection risk factors have the most influence on DB delivery selection: (1) scope risk; (2) third-party and complexity risk; (3) construction risk; (4) utility and right-of-way (ROW) risk; (5) level of design and contract risk; (6) management risk; and (7) regulation and railroad risk.
28	(Wang et al., 2014)	x	x	✔	x	x	x	Pavement engineers need to establish corrective measures such as building superior grooving textures, installing traffic signs at the right speed, etc. to avoid traffic accidents due to hydroplaning.
29	(Yan et al., 2014)	x	x	✔	x	x	x	The lowest evaluative criteria of the road operating environment are given to improve the design of road facilities and intensify the environmental safety risks of the operation of basic road facilities.
30	(El-Sayegh & Mansour, 2015)	x	x	x	✔	x	x	Inefficient planning is the most significant risk in the highway construction with a probability of moderate to high, inefficient planning weighed the highest among other risks, highway projects require efficient and accurate planning.
31	(Hanna et al., 2015)	x	x	x	✔	x	x	Designed to identify the top misallocated risks in the highway construction industry and to provide recommendations to more appropriately allocate these risks on highway construction projects.

32	(Tran & Molenaar, 2015)	x	✓	x	x	x	x	Based on the probabilistic risk analysis process, a risk-based project delivery model selection workshop utilizes probabilistic risk-cost estimation concurrently with the project delivery decision process.
33	(Xiao et al., 2015)	x	x	✓	x	x	x	The traffic risk on the rural highway in general, all of the risk factors can be classified as the four factors and natural environmental factors.
34	(Chu & Fwa, 2016)	x	x	✓	x	x	x	The risk analysis procedure aims to overcome the inadequacy of the current asphalt pavement design methods, specifically the asphalt mix design, concerning the functional safety requirements of road operations.
35	(Fontán-Pagán et al., 2016)	x	x	x	✓	x	x	The use of a hybrid contract method produces a significant reduction in costs when compared with the unit price contracting method for this particular construction project.
36	(Louhghalam & Ulm, 2016)	x	x	✓	x	x	x	The model presented here is only a first-order approach towards a paradigm shift from current strength-based designs to fracture-based designs that are consistent to increase pavement resistance to various risks of distress mechanism, which ultimately aims to reduce maintenance costs and to improve environmental footprint from the aging infrastructure.
37	(Tran & Bypaneni, 2016)	x	x	x	✓	x	x	The findings from this paper provide some guidelines for highway agencies to better perform a more accurate risk cost estimate.
38	(Diab et al., 2017)	x	x	x	✓	x	x	Inadequate constructional reviews have a significant influence in determining owner contingencies, while changes in owner demand affect the number of owner and contractor contingencies, and also have a significant impact on project schedules.
39	(Liu et al., 2017)	x	x	✓	x	x	x	A comprehensive evaluation model of construction site risk based on the fuzzy mathematical method by establishing a construction risk index rating system derived from AHP, using risk management methodologies, and considering the risk probability and the severity of the consequences.
40	(Tokiwa & Queiroz, 2017)	x	x	x	✓	x	x	In PPP projects on the road, it is important to identify risks and allocate responsibilities for risks identified between the public and private sectors specifically, allocating risks related to income is very important because it involves uncertainty for future demand.
41	(Nguyen et al., 2018)	x	x	x	✓	x	x	Provide practitioners implementing or considering the implementation of public-private partnerships with a comprehensive overview of risk allocation practices and contractual language across a variety of public-private partnership project characteristics.
42	(Nguyen et al., 2018)	x	x	x	✓	x	x	Inadequate constructional reviews have a significant influence in determining owner contingencies, while changes in owner demand affect the number of

								owner and contractor contingencies, and also have a significant impact on project schedules.
43	(Yuan & Li, 2018)	x	✓	x	x	x	x	Empirical evidence and simulation results have shown that P3 pavement assets significantly outperform PSC pavement assets in terms of service life, probability and duration of maintenance delays, and remaining life after the concession period.
44	(Bypaneni & Tran, 2018)	✓	x	x	x	x	x	Decision-makers must have a clear understanding of how risks impact each delivery method to select the most suitable delivery method for their projects.
45	(Castro-Nova et al., 2018)	x	x	✓	x	x	x	Statistically significant differences in perception of the importance of geotechnical risk factors between public institutions and the Design Built industry.
46	(Andrić et al., 2019)	x	x	x	✓	x	x	Risk considerations for BRI projects are complex tasks requiring efficient tools that provide complex information about financial issues, to bridge this coverage, new methods developed and applied to complex, scattered and large-scale infrastructure project financial reports.
47	(Firouzi & Vahdatmanesh, 2019)	x	✓	x	x	x	x	By using the Bermudan collar option, the company will be able to make a more accurate estimate of the total operational costs at the pre-construction stage of the project thereby reducing the risk of failure.
48	(Guo et al., 2019)	x	x	✓	x	x	x	Use risk assessments to provide risk specifications for operating rural mountain roads and decide on priority safety precautions.
49	(Zheng et al., 2019)	x	x	x	x	✓	x	The relationship between the risk of the likelihood of a collision and related factors is nonlinear and indicates that the independent variables are not completely independent of each other.
50	(Nicholson, 2020)	x	x	x	✓	x	x	Risk communication and consultation will need to take account of variations between risk management specialists and the public, as well as variations between members of the public, in the understanding and interpretation of qualitative and quantitative probability terms.

Remarks: ✓=discussed x=not discussed

Based on the analysis of 50 articles in the above table, that in Figure 2 shows the distribution of literature reviews from the aspect of risk assessment in highway construction projects.

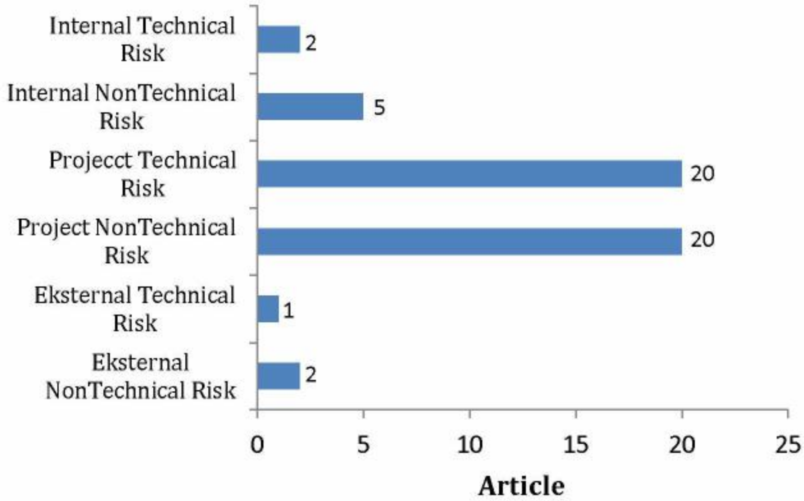

Figure 2. Distribution of literature reviews

3. Risk Identification

3.1. Internal Technical Risk

This article introduces a contractor quality performance evaluation model (CQP) which measures the quality performance of a pavement contractor that the DOT that is in the process of selecting a pavement contractor for a project will benefit from the CQP evaluation model because this system allows clients to quickly assess the quality performance of potential pavement contractors in the list of their offers (Yasamis-Speroni et al., 2012). Cronbach's alpha test and correlation analysis were carried out to verify internal consistency, interdependence, and the reliability of delivery risk factors. The ranking of risk factors and their impact on each method of project delivery can help the road agency to increase appropriate risk allocation and risk-taking wisely, which can result in more efficient project delivery (Bypaneni & Tran, 2018).

3.2. Internal Non-Technical Risk

The contractor's ability in risk management is a key factor for project performance when deciding on a risk management strategy, the contractor must consider many aspects, including risk responsibilities, risk patterns, risk management capabilities, etc. (Wang & Chou, 2003). Performance analysis finds risks in the relationship between the owner and the concessionaire, revealing weaknesses in the indicator mechanism and dispute resolution. This analysis also reports that force majeure events are not easily distinguishable between insured and non-insured events. This shows a failure in guarantee management with separate incentives in premium costs, risk coverage, and the effect of moral hazard (Pineda & Arboleda, 2014). This article shows that this same team member can assist in the selection of project submissions. Based on the probabilistic risk analysis process, a risk-based project delivery model selection workshop utilizes probabilistic risk-cost estimation concurrent with the project delivery decision process (Tran & Molenaar, 2015). Empirical evidence and simulation results have shown that P3 pavement assets significantly outperform PSC pavement assets in terms of service life, probability and duration of maintenance delays, and remaining life after the concession period. While the average lifetime of a PSC residual is only 6.3 years, the average residual life of a P3 partner is 13.5 years (Yuan & Li, 2018). From numerical results, this article found that, by using the Bermudan collar option traded in OTC, the company would be able to make a more accurate estimate of the total operational costs at the pre-construction stage. It was also found that limiting future purchase prices could reduce the likelihood of unexpected cost overruns during the project construction phase. It can be concluded that using the Bermudan OTC collar option can reduce the risk of construction material prices (Firouzi & Vahdatmanesh, 2019).

3.3. Project Technical Risk

This article combines earthquake and transportation engineering techniques to better characterize the risk curve system for the Los Angeles and Orange County, California highway systems. Knowledge of seismic hazards must be combined with a means to adequately model system performance (Shiraki et al., 2007). Comprehensive knowledge about risk factors found from damage data, therefore, becomes important to reduce the level of risk and prevent severe accidents in the work zone (Li & Bai, 2009). It presents the development and testing of the APRA method, which is an innovative tool that can help the project team to improve the highway development process through proactive scope definition and risk management (Le et al., 2009). Asphalt pavement fatigue behavior with semi-rigid bases: crack Fatigue cracking is not possible in the AC layer for well-designed asphalt pavement with semi-rigid bases if the semi-base is rigid in good condition and all interface layers are fully bound (Zhao et al., 2009). RACUSUM and CUSUM can detect that a change has occurred in the process, but cannot predict the cause of the change. This research can be extended by applying the RACUSUM technique to monitor quality in other sectors of the construction industry such as precast and modular manufacturing units including modular formwork and scaffolding, the highway industry including hot mix asphalt plants, units for manufacturing fly ash bricks, block pavers, and other related products (Sarkar & Dutta, 2010).

The risk analysis method is applied to analyze the flexible pavement design using a mechanistic-empirical method. Based on this research, the following conclusions can be drawn: (1) Risk analysis is illustrated to help pavement engineers. The steps of risk analysis include risk identification using Holographic Hierarchical Modeling (HHM), risk ranking using Analytical Hierarchy Process (AHP), risk assessment, and risk management. (2) The AHP method makes it possible to compare the importance of parameters not only in each category, but also between categories (Hall et al., 2011). The conclusions that can be drawn from the analysis are as follows: (1) The probability of the relative failure of each slope is successfully estimated based on the SAT data; (2) The absolute failure probability of each slope is estimated by calibrating the relative failure probability based on RFAR data (Honjo et al., 2011). Some conclusions are drawn from the analysis and case studies in this paper as follows: (1) Risks may be serious when the shielding machine advances under a cement concrete pavement. This results in a lot of damage such as cracks, breakages, crashing, potholes and explosions, etc., which affect the pavement operation performance and traffic capacity; (2) Loss of risk and pavement condition index associated with maximum settlement due to tunneling; (3) There are around 10 accidents that will occur in the construction of several subways in China. Also, the risk of tunneling has received high attention in recent years (Hu & Huang, 2011). This system consists of three main stages, (1) quantification of the danger of failure of the road embankment, (2) calculation of the geometric characteristics of the possibility of failure, and (3) quantification of the consequences. The risk value for each embankment inspected originates from the hazards and the consequence values follow a known risk definition (Risk = Hazard x Consequences) (Pantelidis., 2011).

Intuitively, any process that reduces risk must improve worker safety, reduce agency costs, improve services to the public who are traveling, and lead to more efficient procedures in the long run (Mukhopadhyay et al., 2012). With the application of REMRUE into the risk evaluation of sample road work zones on the Beijing toll road, the difference in operating speed between neighboring parts of the road work zone is analyzed to check whether there is a risk of traffic safety and the value of the Traffic performance Subdivision in the road work zone related to the average operating speed calculated to evaluate the operational risk of traffic (Lu et al., 2013). Presenting an effective failure mode methodology and criticality analysis (FMECA) combined with a simulation modeling approach for Just-in-Time supply chain risk management. FMECA and discrete event simulation can be used to model the dynamic nature of Just-in-Time supply chain networks. Several alternative scenarios are recommended for ready-made concrete plants to achieve the desired balance between having more than enough resources and avoiding risks and disruptions in their timely supply chain (Azambuja & Chen, 2014). MTD, transverse, longitudinal slope, tire pattern, and rainfall intensity are important factors for hydroplaning prediction. This paper uses a volumetric measurement method based on 3D laser imaging technology to estimate MTD and to measure the texture depth of all paths. Besides, directly using the IMU to measure cross slope cannot guarantee good accuracy due to the dynamic movement of the data collection vehicle (Wang et al., 2014). By assessing four aspects of the road operating environment including climate, roads, transportation, and administration, it provides road facilities with functions such as early warning before an accident, feedback in emergencies and quick repairs after a disaster, so that the safety of road operations is greatly enhanced (Yan et al., 2014). ISM is an effective method used to analyze and uncover complex structures, which transform complex and scattered relationships between various elements into a clear multilevel hierarchical structure model (Xiao et al., 2015).

Frameworks and procedures have been presented to include consideration of road slip resistance and hydroplaning in the asphalt mixture design. The proposed framework and analysis procedures aim to address the inadequacy of the current asphalt pavement design methods, specifically asphalt mix designs, concerning the functional safety requirements of road operations (Chu & Fwa, 2016). The proposed mechanics-based model links the risk of concrete pavement fractures that experience different pressure mechanisms on the material and its structural properties. In addition to classic design recipes such as increasing pavement thickness and reducing joint spacing, both of which reduce the rate of release of energy, the results allow the following conclusions: (1) For fixed pavement structures, increasing fracture toughness and reducing material stiffness reduce the risk of fractures; (2) Increasing the horizontal stiffness of the subgrade will improve the performance of concrete pavement that experiences autogenous shrinkage at an early age by reducing the rate of structural energy release; (3) For cases of pavement undergoing a thermal cycle, special attention must be paid to the ratio of the rate of release of dimensionless energy due to bending and axial contributions to ensure that fractures will not occur during transient conditions immediately after the application of sudden temperature changes (Louhghalam & Ulm, 2016). This paper proposes a comprehensive evaluation model of construction site risk based on the fuzzy mathematical method by building a construction risk rating system derived from AHP, using risk management methodologies, and considering risk probabilities and severity of consequences. The accuracy of the evaluation model is validated through calculation examples, so that it can provide theoretical and practical guidance to reduce the risk of road project construction (Liu et al., 2017). The results prove that there is an optimism bias in the DB highway project and that there are statistically significant differences in geotechnical risk perception (Castro-Nova et al., 2018). Introducing the application procedure and GHSLPE risk assessment model, then, with data on traffic accidents, road conditions, and traffic volume from typical rural mountain roads, the risk of traffic accidents (TAR), and the risk of traffic operations (TOA) are calculated; the difference between TOA and post-TAR predictions is compared based on actual conditions (Guo et al., 2019).

3.4. Project Non-Technical Risk

The resulting model is referred to as ERIC-S. This is the first risk-schedule construction model known by the author to measure the relationship between variables. This model is tested on large projects where target completion dates are monitored. The results are almost identical to those of project participants except that the data from experts took 6 weeks while incorporating project characteristics into the ERIC-S model only took 2 hours, indicating that the model was effective and efficient (Nasir et al., 2003). The model described in this paper is a first-order model in which uncertainty is represented by using averages of each uncertain variable, and risk events are modeled as independent events - uncorrelated events because they are actually possible. One possible improvement for the risk modeling process is to build a second-order model in which uncertainty is modeled by the mean and standard deviation of the uncertain variable, including the delay variable. Such a model will produce more accurate results in the outermost range of the distribution of costs and time (Molenaar, 2005). The premium pricing model developed can be used to assist transport agents and contractors in estimating the "fair" value for PSMC. This paper presents a conditional reliability function which can be developed by entering information about in-service pavement conditions using indirect methods. Besides, the formulation of boundary-state functions and the application of the moment method allow for direct consideration of different design approaches, as well as the different effects of preventive maintenance and rehabilitation measures. Finally, this paper illustrates a framework with numerical examples in which premium costs are estimated for various PM&R strategies and contract specifications (Damnjanovic & Zhang, 2008).

The case article results revealed that using project-level life cycle benefits estimated by the uncertainty-based analysis approach resulted in a higher percentage of conformity with actual Indiana DOT programming practices compared to the level of compliance using project benefits calculated by risk-based analysis approaches (Li & Madanu, 2009). The risk-based model presented here to fill the price gap of warranty offers is often estimated subjectively because of the lack of a systematic methodology for measuring warranty service costs for road infrastructure assets. Under WCEM, the cost of guarantee is estimated, taking into account the PF of the guaranteed item as defined in the warranty clause and the projected costs to correct the failure (Gharaibeh & Shirazi, 2009). Regression analysis shows a weak correlation between the size of the highway project, as measured in indexed programmed costs and measures of excess costs. Correlations develop after data transformation is carried out to improve the model. It can also be concluded from research that the arbitrary application of a basic contingency percentage rate, such as 10%, to accommodate project risks can cause projects that report substantial budget overruns (Creedy et al., 2010). Some conclusions: (1) Risks may be serious when the shielding machine advances under the cement concrete pavement; (2) Loss of risk and pavement condition index associated with maximum settlement due to tunneling; (3) There are about 10 accidents that will occur in the construction of several subways (Hu & Huang, 2011). Lessons from two PPP case studies are used to improve the contract organization of the Tehran-Chalus Toll Road project. The findings from this case article on the identification of the most important risks and their allocation and funding can be used by others who are trying to attract private investment for large infrastructure projects in developing countries (Heravi & Hajihosseini, 2012).

The findings from this article not only encourage decision-makers to carry out risk analysis at the beginning of the project development process, but also function as an input for a risk-based framework for selecting appropriate project delivery methods in high industries (Tran & Molenaar, 2012). The mathematical relationship between the duration of the highway project, the planned costs, and the type of project are shown in this paper by using various time correlation models flooded with potential risk factors investigated including attributes such as project type, costs, and geographic location. This paper identifies several significant risk variables and their severity that contribute to extensive delays and the consequences exceeding the planned time estimate (Kaleem et al., 2014). The results of this test indicate that the risk preferences between public owners and designers and contractors towards the choice of DB delivery method do not differ significantly in the scope of risk, third party risk, and complexity risk, utility risk and, ROW, level of design risk and contract risk, management risk, or regulatory and railroad risk, but statistically different in construction risk (Tran & Molenaar, 2014).

External risks have little effect on the UAE highway construction industry. Research shows clearly that internal risks threaten projects more than external risks (El-Sayegh & Mansour, 2015). This flowchart acts as a guideline to assist contractors and owners in designing contracts that are transparent and that efficiently allocate risk to the parties best suited to bear it. By designing contracts with appropriate risk allocation strategies, the project will perform better from a cost and schedule perspective by eliminating activities that do not add value. Contract disputes and litigation are examples of activities that did not add value to the project participants who were forced to do when the risk of misallocation. This research has revealed the pitfalls of improper risk allocation in the highway construction industry and offers practical considerations that, if combined from the beginning of the project, will result in higher performance projects (Hanna et al., 2015). The use of the hybrid contract method results in a significant cost reduction when compared to the unit price contract method for this particular construction project. This article concludes the effectiveness of assigning contractors to risks associated with variations in the amount. Implementation of items for unexpected possibilities shows benefits for both parties, the owner, and the contractor. Contracting contingency estimates can be reduced by showing a higher chance of becoming the lowest bidder (Fontán-Pagán et al., 2016). Simulation results show the importance of viewing data from a practical point of view. However, in this case, the difference is small and will not affect funding decisions. Users are warned not to neglect the correlation between related inputs because that would result in underestimation of the total cost variance with the effect of cancellation during the simulation between uncorrelated variables (Tran & Bypaneni, 2016).

The models developed and discussed in this paper can help deal with risks in road construction projects by looking at RI, CI, and SI ratings of risk drivers and allocating appropriate contingency percentages for use (Diab et al., 2017). Potential PPP road projects in developing countries may want to take advantage of one or more financial instruments, such as the World Bank Partial Risk Guarantee and Political Risk Insurance, even more, developed countries, such as France and Spain, have subsidized projects, changing them into successful PPP projects, such as the Perpignan-Figueras Rail Concession (Tokiwa & Queiroz, 2017). This article has introduced practical guidelines for conducting detailed assessments of the impact of risks on the financial viability of PPP projects in developing countries. Finally, this paper focuses on risk and the preferred allocation mechanism for PPP toll road projects in Vietnam, recognizing that the risk allocation mechanism in PPP projects is dynamic and depends on several contextual variables at the country level (Nguyen et al., 2018). The allocation results show that some risks are managed by the public sector such as changes by public authorities, but most of the 31 risks are transferred to the private sector or shared, practitioners who apply or consider implementing PPP, a comprehensive review of risk allocation practices and contract language in various project characteristics PPP in the US (Nguyen et al., 2018). BRI's project risk assessment demonstrates the application of the fuzzy logic method proposed for large-scale, complex, and geographic infrastructure projects. Fuzzy logic-based methods are proven to be a systematic, efficient, and practical tool for infrastructure project risk assessment (Andrić et al., 2019). Transportation risk management will be improved if greater attention is given to so-called human factors, including risk perception, risk acceptance (including the factors that influence it and the relative importance of those factors), and the nature of the changes in driver behavior with perceived risk changes. (Nicholson, 2020).

3.5. External Technical Risk

The results prove that the NN model is a powerful tool for predicting and explaining HRGC crashes with the ability to reveal a continuous function relationship between the likelihood of an accident and contributors. The results showed that the relationship between the likelihood of a collision and related factors was nonlinear, and showed that the independent variables were not completely independent of each other (Zheng et al., 2019).

3.6. External Non-Technical Risk

Concessions were developed using completely different contract models, although certain features are common among these models, especially the duration of the contract and the conditions that must be met to trigger a mechanism to restore financial balance through renegotiation, the uncertainties and negative results of renegotiation lead to changes in risk allocation which have generally transferred commercial risk from the concession from the concessionaire to the grantor. Re-negotiated contract clauses generally guarantee that their returns will not change, even though their risks are significantly reduced (Cruz & Marques, 2013). The PPP Toll Road Project in Iran observes that the basic performance indicators of these projects due to time and cost may be subject to adverse deviations that lead to the highest priority risk of time delays and excessive costs, the risk of high inflation also results in excessive cost overruns (Ghorbani et al., 2014).

4. Result

The results of the research article analysis based on risk factors are shown in Table 2.

Table 2. Mapping research articles analysis based on risk factor

Factor	Research Article
Internal Risk	
Finance	(32) (47)
Contractor Experience	(2) (20)
Client Service	(26) (43) (44)
Project Risk	
Material	(12) (23)
Duration	(1) (25)
Finance	(3) (6) (8) (9) (11) (37) (38) (40) (42)
Construction Method	(13) (22) (33) (34) (39) (45)
Structure Construction	(4) (10) (14) (15) (16) (28) (36)
Project Management	(17) (29) (30) (31) (35) (46)
Contract	(5) (19) (27) (41)
Field Condition	(7)
K3	(18) (48) (50)
External Risk	
Socio-Economic Conditions	(49)
Government	(21) (24)

Based on the analysis of risk sources above, it is found that the risk aspect in the construction of highways that has the highest percentage is financial factors, as shown in Figure 3 below:

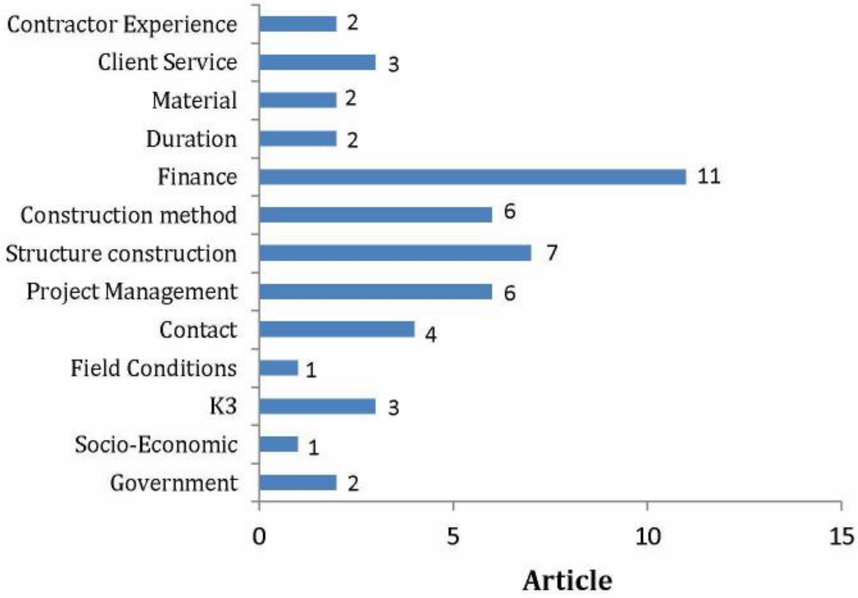

Figure 3. Barchart analysis of research articles based on risk factors

5. Conclusion

This article concludes that there is one source of risk that is very influential, namely the risks originating from the project itself, both technically and non-technically. The potential risk weights of a project are based on the frequency parameters of the occurrence of risks and negative consequences due to the occurrence of these risks for project objectives. The results obtained show that from 50 identified risks, there are 11 risks originating from financial factors consisting of 2 internal risks and 9 project risks. Finance is the highest risk percentage of the article analyzed. This shows that finance is an important factor in the implementation of construction projects, project financing must be managed properly to avoid problems during project implementation. Contractors who do not have adequate finance and poor financial planning will have an impact on project implementation starting from delays in the realization of work, and poor quality of work. By knowing the main risks in a road project, this article is expected to assist the contractor in recognizing and investigating the effect of risk allocation on contractors' risk management decisions, so that prevention can be carried out earlier. This research is expected to assist future research in investigating rigorous analytical methods to verify project financial estimates and also must examine how to consider the effects of correlations on other risk analysis frameworks in the construction industry.

References

Andrić, J. M., Wang, J., Zou, P. X. W., Zhang, J., & Zhong, R. (2019). Fuzzy Logic-Based Method for Risk Assessment of Belt and Road Infrastructure Projects. Journal of Construction Engineering and Management, 145(12), 1–12.

Azambuja, M., & Chen, X. (2014). Risk Assessment of a Ready-Mix Concrete Supply Chain. Construction Research Congress 2014 ©ASCE 2014, 1695–1703.

Bypaneni, S. P. K., & Tran, D. Q. (2018). Empirical Identification and Evaluation of Risk in Highway Project Delivery Methods. Journal of Management in Engineering, 34(3), 1–9.

Castro-Nova, I., Gad, G. M., Touran, A., Cetin, B., & Gransberg, D. D. (2018). Evaluating the Influence of Differing Geotechnical Risk Perceptions on Design-Build Highway Projects. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 4(4), 1–11.

Chu, L., & Fwa, T. F. (2016). Incorporating Pavement Skid Resistance and Hydroplaning Risk Considerations in Asphalt Mix Design. Journal of Transportation Engineering, 142(10).

Creedy, G. D., Skitmore, M., & Wong, J. K. W. (2010). Evaluation of risk factors leading to cost overrun in delivery of highway construction projects. Journal of Construction Engineering and Management, 136(5), 528–537.

Cruz, C. O., & Marques, R. C. (2013). Risk-sharing in highway concessions: Contractual diversity in Portugal. Journal of Professional Issues in Engineering Education and Practice, 139(2), 99–108.

Damnjanovic, I., & Zhang, Z. (2008). Risk-based model for valuation of performance-specified pavement maintenance contracts. Journal of Construction Engineering and Management, 134(7), 492–500.

Diab, M. F., Varma, A., & Panthi, K. (2017). Modeling the Construction Risk Ratings to Estimate the Contingency in Highway Projects. Journal of Construction Engineering and Management, 143(8), 1–9.

El-Sayegh, S. M., & Mansour, M. H. (2015). Risk assessment and allocation in highway construction projects in the UAE. Journal of Management in Engineering, 31(6).

Firouzi, A., & Vahdatmanesh, M. (2019). Applicability of Financial Derivatives for Hedging Material Price Risk in Highway construction. Journal of Construction Engineering and Management, 145(5), 1–13.

Fontán-Pagán, J. J., González-Quevedo, S. L., & González-Quevedo, A. (2016). Use of a Hybrid Bidding Method for Costs and Risk Reduction in Highway Construction. Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan - Proceedings of the 2016 Construction Research Congress, CRC 2016, 759–769.

Gharaibeh, N. G., & Shirazi, H. (2009). Risk-Based model for pricing highway infrastructure warranties. Journal of Infrastructure Systems, 15(4), 378–382.

Ghorbani, A., Ravanshadnia, M., & Nobakht, M. B. (2014). A Survey of Risks in Public Private Partnership Highway Projects in Iran. ICCREM 2014: Smart Construction and Management in the Context of New Technology - Proceedings of the 2014 International Conference on Construction and Real Estate Management, 482–492.

Guo, G.-G., Tian, B.-J., Hu, C.-Y., & Yang, W.-C. (2019). The Applicability Analysis of

"Technical Guide for Implementation of Highway Safety and Life Protection Engineering" in Risk Assessment of Mountainous Rural Roads. CICTP 2019, 3797–3809.

Hall, K. D., Xiao, D. X. P., A., E. W., & CP, K. (2011). Risk Analysis Of Mechanistic-Empirical Pavement Design Methods. ICTE 2011 © ASCE 2011, 2151–2156.

Hanna, A. S., Blasier, K., & Aoun, D. G. (2015). Risk Misallocation on Highway Construction Projects. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 7(4), 04515002.

Heravi, G., & Hajihosseini, Z. (2012). Risk allocation in public-private partnership infrastructure projects in developing countries: Case article of the Tehran-Chalus toll road. Journal of Infrastructure Systems, 18(3), 210–217.

Honjo, Y., Otake, Y., Moriguchi, S., & Hara1, T. (2011). Road Slopes Risk Assessment of the Northern Part of Gifu Prefecture Japan. GeoRisk 2011 © ASCE 2011, 988–996.

Hu, Q. F., & Huang, H. W. (2011). Quantified Risk Assessment of Shield Tunneling Effects on Urban Cement Concrete Pavement. GeoRisk 2011 © ASCE 2011, 915–922.

Kaleem, S., Irfan, M., & Gabriel, H. F. (2014). Estimation of highway project duration at the planning stage and analysis of risk factors leading to time overrun. T and DI Congress 2014: Planes, Trains, and Automobiles - Proceedings of the 2nd Transportation and Development Institute Congress, 612–626.

Le, T., Caldas, C. H., Gibson, G. E., & Thole, M. (2009). Assessing scope and managing risk in the highway project development process. Journal of Construction Engineering and Management, 135(9), 900–910.

Li, Y., & Bai, Y. (2009). Highway work zone risk factors and their impact on crash severity. Journal of Transportation Engineering, 135(10), 694–701.

Li, Z., & Madanu, S. (2009). Highway project level life-cycle benefit/cost analysis under certainty, risk, and uncertainty: Methodology with case study. Journal of Transportation Engineering, 135(8), 516–526.

Liu, H., Shan, Y., Ge, X., & Lu, J. (2017). The Research on Construction Risk Evaluation in Mountainous Roads. CICTP 2017, 5101–5109. https://doi.org/https://doi.org/10.1061/9780784480915.526

Louhghalam, A., & Ulm, F. J. (2016). Risk of pavement fracture due to eigenstresses at early ages and beyond. Journal of Engineering Mechanics, 142(12), 1–12.

Lu, F., Qian, S., & Wang, Y. (2013). Article on risk evaluation methods of road work zone on urban expressway. ICTIS 2013: Improving Multimodal Transportation Systems - Information, Safety, and Integration - Proceedings of the 2nd International Conference on Transportation Information and Safety, 178–184.

Molenaar, K. R. (2005). Programmatic cost risk analysis for highway megaprojects. Journal of Construction Engineering and Management, 131(3), 343–353.

Mukhopadhyay, S., Shane, J. S., & Strong, K. C. (2012). Safety risk analysis and proposing risk mitigation strategies for operations and maintenance activities in highways: A qualitative method. Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress, 525–534.

Nasir, D., McCabe, B., & Hartono, L. (2003). Evaluating Risk in Construction-Schedule Model (ERIC-S): Construction schedule risk model. Journal of Construction

Engineering and Management, 129(5), 518–527.

Nguyen, A., Mollik, A., & Chih, Y. Y. (2018). Managing Critical Risks Affecting the Financial Viability of Public-Private Partnership Projects: Case Article of Toll Road Projects in Vietnam. Journal of Construction Engineering and Management, 144(12).

Nguyen, D. A., Garvin, M. J., & Gonzalez, E. E. (2018). Risk Allocation in U.S. Public-Private Partnership Highway Project Contracts. Journal of Construction Engineering and Management, 144(5), 1–13.

Nicholson, A. (2020). Road Safety: Risk Management Perspective. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 6(1), 1–10.

Pantelidis., L. (2011). An innovative landslide risk assessment system: Application to highway embankments. Geotechnical Special Publication, 224 GSP, 1012–1019.

Pineda, G., & Arboleda, C. A. (2014). Assessing Operational Risks in Road Projects under the PPP Framework in Colombia. Construction Research Congress 2014 ©ASCE 2014, 1811–1820. Sarkar, D., & Dutta, G. (2010). Design and application of risk adjusted cumulative sum for strength monitoring of ready mixed concrete. Journal of Construction Engineering and Management, 136(6), 623–631.

Shiraki, N., Shinozuka, M., Moore, J. E., Chang, S. E., Kameda, H., & Tanaka, S. (2007). System risk curves: Probabilistic performance scenarios for highway networks subject to earthquake damage. Journal of Infrastructure Systems, 13(1), 43–54.

Tokiwa, N., & Queiroz, C. (2017). Guarantees and Other Support Options for PPP Road Projects: Mitigating the Perception of Risks. Advances in Public-Private Partnerships - Proceedings of the 2nd International Conference on Public-Private Partnerships, 624–632.

Tran, D., & Bypaneni, S. (2016). Impact of Correlation on Cost-Risk Analysis for Construction Highway Projects. Construction Research Congress 2016, 668–678.

Tran, D., & Molenaar, K. (2012). Critical risk factors in project delivery method selection for highway projects. Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress, Dbia 2010, 331–340.

Tran, D., & Molenaar, K. R. (2014). Impact of risk on design-build selection for highway design and construction projects. Journal of Management in Engineering, 30(2), 153–162.

Tran, D., & Molenaar, K. R. (2015). Risk-Based Project Delivery Selection Model for Highway Design and Construction. Journal of Construction Engineering and Management, 141(12), 1–9.

Wang, K. C. P., Luo, W., & Li, J. Q. (2014). Hydroplaning Risk Evaluation of Highway Pavements based on IMU and 1 mm 3D Texture Data. T&DI Congress 2014, 511–522.

Wang, M. T., & Chou, H. Y. (2003). Risk allocation and risk handling of highway projects in Taiwan. Journal of Management in Engineering, 19(2), 60–68.

Xiao, H., Jiang, H., & Zhang, Z. (2015). Analyzing the Risk Factors of Guangdong Province's Rural Highway Using Interpretative Structural Model. CICTP 2015 - Efficient, Safe, and Green Multimodal Transportation - Proceedings of the 15th COTA International Conference of Transportation Professionals, 2876–2886.

Yan, M., Zhong-yin, G., Hua, G., & Yong-gang, X. (2014). Risk Assessment of Road Operation Environment Under Atrocious Weather Condition. ICCTP 2009: Critical

Issues in Transportation Systems Planning, Development, and Management ©2009 ASCE, 683–692.

Yasamis-Speroni, F., Lee, D.-E., & Arditi, D. (2012). Evaluating the Quality Performance of Pavement Contractors. J. Constr. Eng. Manage, 1114–1124.

Yuan, X. X., & Li, Y. (2018). Residual value risks of highway pavements in public-private partnerships. Journal of Infrastructure Systems, 24(3), 1–11. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000438

Zhao, Y. Q., Zhou, C. H., & Tan, Y. Q. (2009). Effects of layer interface conditions on fatigue behavior of asphalt pavements with semi-rigid bases. Proceedings of the 9th International Conference of Chinese Transportation Professionals, ICCTP 2009: Critical Issues in Transportation System Planning, Development, and Management, 358, 2426–2435.

Zheng, Z., Lu, P., & Pan, D. (2019). Predicting Highway-Rail Grade Crossing Collision Risk by Neural Network Systems. Journal of Transportation Engineering Part A: Systems, 145(8), 1–8.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 48-64
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303048k

DESIGNING A FRAMEWORK FOR SUBCONTRACTOR'S SELECTION IN CONSTRUCTION PROJECTS USING AN MCDM MODEL

Ravande Kishore [1], Seyed Ali Mousavi Dehmourdi [1]*, M. Gopal Naik [1], Malek Hassanpour [2]

[1] Department of Civil Engineering, UCE, Osmania University, Telangana State
[2] Department of Environmental science, UCS, Osmania University, Telangana State

Received: 20 June 2020
Accepted: 10 August 2020
First online: 24 September 2020

Research paper

Abstract: *The difficulties discovered in selecting subcontractors via a simple method of bid price as the main factor along with an initial screening of subcontractor properties impressed us to look at a little beyond the existing trend and offer a coherent procedure for this purpose. Despite this, we know that the main factor in outsourcing a project is a bid price and this is in full agreement with the existing circumstances of subcontractor selection in Iran, but the objective of this research was integrating all criteria with the same importance for selecting a subcontractor. The questionnaire was used for collecting initial data of research to pass through the Analytic Hierarchy Process (AHP) and Multi-Criteria Decision-Making (MCDM) model of Simple Additive Weighting (SAW). The findings showed the priority in subcontractors' selection as Hejrat Manesh Izeh (1), Khesht Sazan Karoun (2), Yeganeh saze omid (3), Sakht karan Moongasht (4), Darya Sanat Khavarmianeh (5), Omran mehragane Yosef (6) respectively. The present study offered a coherent procedure to select the subcontractor regardless of the bid price importance and integrating all interfering criteria in the same importance.*

Keywords: *Subcontractor, Construction projects, MCDM, Model*

1. Introduction

The construction industry is a well-developing and thriving industry in the world. The industry encompasses a huge budget of nations to implement road and building projects. The maintenance, lack of rework, use of innovative techniques comprised main aspects of advances in the construction industry. The aspects ensure the durability of construction projects with regard to the fact that this industry surrounds complex endeavors with a huge outlay and costs. That is why this industry

* Corresponding author.
kravande58@gmail.com (R. Kishore), Salimousavi.d32@gmail.com (A. Mousavi Dehmourdi), mgnaikc@gmail.com (M. Gopal Naik), / (M. Hassanpour).

expanded and included excellent opportunities for business and commerce. The government construction budget was around two billion two hundred and sixty-one million dollars for Khuzestan province in 2019. The Ahwaz municipality construction budget allocated around 91,058,000 USD. It has been spent a huge budget for other provinces too. We are reporting the budget associated with Khuzestan province because of project location in Iran. Nowadays, Iran is under the pressure of heavy sanctions that resulted in a recession of construction projects, but it will move towards progress levels by providing budget. To construct the projects, lots of private and semi-private companies participate in Iran. The procedure of contractor and subcontractor selection has been based on the bid price, and technical and professional experiences of companies (Jafari and Hassanpour, 2014).

Outsourcing construction projects to contractors and subcontractors is a common rule in lots of nations. The successful implementation of construction projects depends on solutions defined by in-charge organizations. The responsibility of the contractor is very weighting in comparison to the subcontractor. Actually, the subcontractor plays the second role in the implementation of a project, as suppliers of materials, manpower, equipment, tools, or assigns lots of specialists in this regard (Kumaraswamy and Matthews, 2000). The use of MCDM models in lots of projects containing various scales and vague dimensions to make a clear decision has been widely expanded. The influencing parameters make the designer, constructor and engineers to select the best choice among a series of items. To solve and hold back this kind of difficulty, a large number of models that are called MCDM models have been introduced. The circumstances of application and use of models are explained by Kahraman (2008), Zavadskas, and Turskis (2011), as the famous scientists in this regard, in a variety of studies. The selection of the best subcontractor, quality control, risk assessment, crisis management, reasons for delays in the project schedule, identification of causes of delay, value engineering also underwent MCDM systems and sensitivity analysis in terms of comparison of different models to make a decision by lots of studies. By the present study, we used an MCDM model to select the subcontractor for the project.

The subcontractors hold a prominent role with regard to the first contractor or firsthand contractor in such a way to be its effect around 70-90% of the total value of the project (Hinze and Tracey, 1994). Its role is ensuring the project well-implementation in parallel with a contractor role. The firsthand contractor takes the highest responsibility in the project development stage as a supervisor who involves upper hand supervisors from ruling organizations. The subcontractor is introduced to the project when the contractor has got financial support difficulties or encountered a peak in project construction, etc. So, hiring the subcontractor performs an especial task and influences the project performance and its completion. The selection of subcontractor came through some complex pathways such as the relationship with the firsthand contractor, relationship with the main supervisor of project or employer, selection based on financial ability, equipment and facilities ability, and selection by bids and beneficiary purposes and lots of other options and definitions (Clough et al., 2015).

Nowadays, company managers forced to comply with existing rules and take enough responsibility in better performing duties. On the other hand, the competition between stockholders and employers caused the definition of strict rules to improve their efficiency in the constructive processes. Following a certain strategy is an important task to promote efficiency and performance (Lingard et al., 2017). Therefore, selecting the subcontractor is a good strategy to confer part of work to third parties with new breath in proceeding the task. However, the very important task is associated with circumstances of subcontractor selection in the defeat of successful proceeding the project. The subcontractor selection can experience lots of difficulties in terms of incomplete and biased, and lacking consideration to time, cost, and quality and safety standards from subcontractor and contractor sides.

Improper selection of subcontractors leads to delay, defeat, losing time, rework, and other kinds of project crises. Therefore, lots of cases and factors interfere with the right selection of subcontractors. The current research study attempting to select the subcontractor depends on the main criteria in a practical project that is being constructed in Iran now. The experts in completing the project were the consultants and executive managers, project engineers, and supervisors. The ranking and weighing systems were chosen to prioritize the options and alternatives and finally, the right decision was made for selecting the relevant subcontractor.

Many studies show the procedure to select subcontractors in construction projects, and some of them have defined conceptual frameworks, but in Iran, Khuzestan province, additional research is needed to be approached to choose subcontractors in the construction industry through the MCDM model. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, etc. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria. The purpose is to support decision-makers who are facing such problems and decision-maker preference facilitates project development. The specific objectives of current research are stated below.

- Investigating the general subcontractor selection methods from existing literature.
- Conducting the questionnaire-based survey with Iranian construction experts to identify the significance of essential criteria in subcontractor selection.
- Evaluating the subcontractor competence and performance, based on the questionnaire to obtain the capacity of each subcontractor.
- Applying the MCDM model to select the best subcontractors in the construction industry by keeping the existing situations.

Generally, the present research objectives encompassed (1) important criteria selection, (2) subcontractor selection, (3) weighing and ranking alternatives, (4) subcontractor competence evaluation.

In Iran, due to the lack of a defined framework to select a subcontractor according to the existing situation in terms of the subcontractor's financial capacity, ownership of equipment for the project, compliance with administrative instructions and the subcontractor's managerial capacity, this study considering the same importance of factors for tendering the construction projects has formulated important criteria in this regard. On the other hand, lots of companies participate in attracting the project, and in Iran, the project is assigned at the lowest bid price, regardless of other important factors involved in an apparent situation. Therefore, questionnaires were designed with the cooperation of experts involved in the tendering of the project to solve the existing problem.

First, the authors tried to do a relevant literature review for the research and collect appropriate studies, then the criteria were chosen regarding the location of project and workplace conditions. Then, questionnaires were designed and distributed among experts to determine the main criteria of subcontractor selection and prequalification assay, and the results were presented in Tables. In the subcontractor competence assay, a questionnaire was distributed among the subcontractors to know the inventory list of each company, which included various parameters, such as 18 factors related to the equipment and devices required for the construction of the project. The other items consisted of various factors, most of which were associated to managerial aspects such as company's professional work experience records in implementing previous projects, professional experience of prominent staff, project purpose achievements, planning and managing ability, experience in similar contracts, HSE guidelines observation, expert workforces along with the bid price offered by each company to obtain the project. The questionnaires were analyzed according to different criteria and the results were further analyzed in tables and excel sheets according to the methodology. In the end, the weight and ranking systems used led to the selection of the best option.

2. Literature review

To conduct present research, we first tried to come through the literature review to understand and identify the criteria and most difficulties recognized in selecting the subcontractors. Also, it was taken into consideration the reasons for the defeat and success of conducted construction projects and a glance view based on weighing and ranking models employed in prioritizing the criteria and alternatives. A study reported the emergence of satisfaction from the employer for the implemented project regardless of the presence of main performance criteria in contractor selection. It was recommended by clients in South Africa and the universal construction industry (Bowen et al., 1997). Russell et al. (1992) applied the effects of 20 decision criteria via Spearman Rank Correlation analysis to find the major influencing criteria on contractor selection. So, it was found a series of major criteria including financial stability, experience, and past performance. A study came through a strong literature review pointing out the inclusion of the contractor's pre-qualification method as one of the main criteria in the tendering process (Holt et al., 1995). The competence screening step has carried out via interview, questionnaire, and various strategic methods with taking account of the global benchmarks in this field, contractors and subcontractors experiences, professionally completed projects, etc. The most important criteria have been detected to be economical soundness, technical ability, management capability, and the health and safety performance of contractors (Hatush and Skitmore, 1997a, b). The study of Doloi (2009) aimed to understand the quality of criteria selected (43 cases) to evaluate the performance of the project via multiple linear regression models. Sacks and Harel (2006) deployed a predictive model for assessing the subcontractor resources via game theory. The successful move of the project joined the relationship between managers and having strong commitments in going ahead. By research, 29 experts participated to demystify the scores of criteria in selecting the suitable sub-contractor via a questionnaire survey supported by SPSS software analysis (Marzouk et al., 2013). The most important criteria have been realized to be the project price among criteria of quality, cooperation, and technical know-how in subcontractor selection by the multi-nominal model in Singapore (Hartmann, and Tan, 2009). The performance of the sub-contractor has been recognized to be an important point in conducting the objective of the project. The study revealed that 80-90% of Australian building projects outsourced to the subcontractor with regard to the affordability of contractors and consultants to move the project in terms of time, quality, and costs (Hinze and Tracy, 1994). The subcontractors play some prominent roles in project risks and take responsibilities against redeployment, hiring and firing of workers, and financial difficulties. However, reliable subcontractor selection will recede the difficulties experienced by the way. Sari and El-Sayegh (2007) suggested considering a collection of factors through the literature review for distinguishing the right criteria for a certain company among general factors, construction management factors, and general contracting factors. So, they will enable you to figure out the proper matrix of criteria for the construction management at-risk contractor. Akintan and Morledge (2013) assessed the relations between the main contractor and subcontractor based on qualitative and quantitative factors and connections between them via integrated project delivery and the last planner system. In the United Kingdom, the questionnaire was applied to assess a contractor view in terms of particular criteria of construction projects. The data were analyzed using SPSS software and taking into account the lowest-price wins principle (Wong and et al., 2000). In Singapore, industry-based contractors' selection was performed using questionnaires and criteria and alternative choices. Findings manifested to offer the most important criteria for the criterion of contractor professional experience (Singh and Tiong, 2006). In Australia, the questionnaire method was used to assay the relationship among 20 contractors in a selection program. The questionnaire included three main success reasons for the project such as time, quality, and outlay. Findings comprised a set of contributed criteria with identifying the most and least interfering criteria (Hatush and Skitmore, 1998). Kumaraswamy and Matthews (2000) used the questionnaire procedure to select the subcontractor regarding 20-step interviews. So, it showed the subcontractor's thrift by 10% of outlays in tender price and promoting the time and quality performances in the project. Maturana et al. (2007) took the questionnaire procedure to select subcontractors from among 29 cases. The performance was reported by the contractor's experience mostly.

It has been used as an algorithm for the selection of sub-contractor pertaining to fuzzy preference relation, from a mathematical point of view containing an example regarding the criteria of reputation, technical capabilities, financial situation, and organizational skills (Ibadov, 2015). AHP was taken into consideration to select the subcontractor via a questionnaire participated by 29 persons with allocating some criteria and alternatives extracted from the literature review in Putrajaya, Malaysia (Manoharan, 2005). Li et al. (2007) accepted the prequalification screening step as a standard procedure in sub-contractor selection. They passed through the step in a tunnel construction project based on a fuzzy approach to prioritize the criteria and alternatives in China. Juan et al. (2009) applied a hybrid approach combining fuzzy set theory and quality function deployment to set up a housing refurbishment contractor selection model with lots of criteria and alternatives. The developed model passed through the sensitivity analysis via another MCDM model such as Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) successfully. Araujo, et al. (2015) approached to objectives of his research for contractor selection by paying attention to a set of contractors, resources, and limitations by assigning MCDM models such as group decision and Integer Programming, Delphi, and PROMETHEEGDSS models. In the United Kingdom, utility theory was exploited to contractor selection via MCDM models along with bid price assessment (Hatush and Skitmore, 1998). In India, a questionnaire passed out among project managers to evaluate the contractor based on theoretical methods. In the following step, MCDM models of TOPSIS and Grey-SAW determined the best option considering bids and financial affordability (Puri and Tiwari, 2014). In Hong Kong, a study underpins the framework of a matrix of data for best contractor selection via AHP joined to MCDM models in a variety of scenarios along with a minimum bid (Fong and Choi, 2000). Ng and Luu (2008) proposed a case-based intellectual model for selecting subcontractors. The technical aspect of performing the contract was pointed out to be a point for the decision-making process and developing standards and frameworks of subcontractor selection.

Borujeni and Gitinavard (2017) studied the mining contractor selection problem via a hesitation phase compromise model. The weighing and ranking of alternatives were followed with a sensitivity analysis to promote the accuracy and precision of results. Chiang and et al. (2017) used the AHP to find important aspects in selecting contractors during the bidding phase via identifying the appropriate criteria and embarking the criteria in a hierarchical structure collecting opinions of experts for making a decision matrix. Cheaitou et al. (2019) have done a case study to select the efficient contractor in a public organization via MCDM models and fuzzy logic theory following with data envelopment analysis. So, in terms of the efficient contractors identified in the United Arab Emirates, Mirmousa, and Dehnavi (2016) used MCDM models for the supplier selection purpose in Yazd, Iran. By the way, 43 important criteria were chosen and then around 14 criteria were confirmed for further processing in the questionnaire designed. Further processing was completed by 11 experts and data passed through the decision making systems to rank and weight alternatives. By Morkunaite et al. (2019), contractor selection passed through the quantitative and qualitative criteria, weighing system of AHP and evaluation in the PROMETHEE model. Stević et al. (2020) used Measurement Alternatives and Ranking according to the Compromise Solution (MARCOS) model to select the sustainable supplier for the healthcare industry in Bosnia and Herzegovina. To classify and rank the matrix of 8×21 alternative × criteria, the MARCOS model was assigned along with a sensitivity analysis including rank reversal and findings of other MCDM model.

3. Methodology

3.1. Research design

The survey questionnaire procedure was used to collect the data and literature review and the authors' experiences were taken into account for the right selection of criteria and alternatives. The literature review was also used to select criteria. The present project is a building construction and is currently being developed in Khuzestan, Iran. The present project has included the area of a school to be built and is located in Ahvaz, Khuzestan province, Iran. The main contractor of the project was Shahin Niloofar Jangi Company and all consultants had been recruited based on the lowest bid price and competitive tender, and coincidentally. The supervision of the project was undertaken by the first contractor and government office of the School Innovation and Equipment Department in Khuzestan, Iran. The Khuzestan province is located in the southwest of Iran, as a neighbor with Iraq and the Persian Gulf, covering an area of 63, 238 km^2. The total built-up area of the building was 2800 m^2. The main structure of the building was structural steelwork and this paper tried to select a subcontractor through a MCDM model. The main contractor, Shahin Niloofar Jangi Company, had been invited to undertake the project with described conditions. The Figure 1 displays the steps undergone by conducted research.

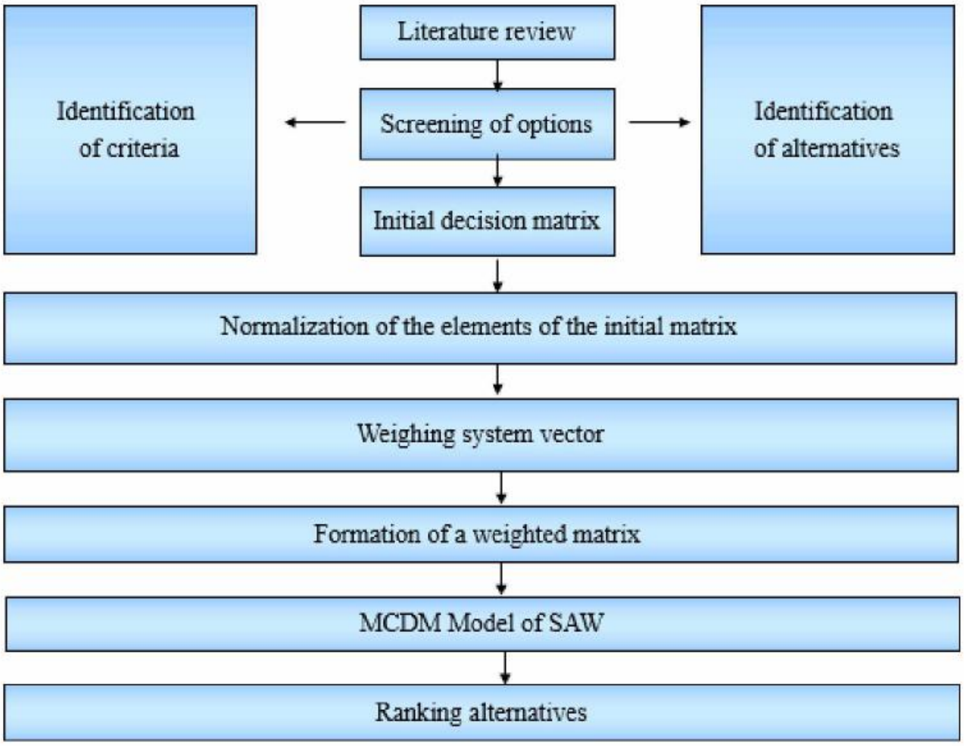

Figure 1. Flowchart of the conducted research

3.2. AHP method

AHP, introduced by Saaty in the 1980s, is a popular MCDM instrument. It consists of a defined mathematical structure built over consistent matrices and associated with Eigenvectors to derive the true weights of compared criteria. Although the AHP technique is more than three-decade-old, its flexibility and robustness keep it in use as a reliable method. The AHP method used in this study is the result of a multiplication of the criteria (*αij I*) with an inverse exponent of criteria numbers (*1/K*) according to Equation 1. Then, the values in columns (*Xij*) have been divided by the sum of them according to Equation 2.

$$Xij = \left(\prod_{I=1}^{k} aij\, I\right)^{1/K}, I = 1,2, \dots, K \; i,j = 1,2, \dots, n, i \neq j \quad (1)$$

One of the reasons for using the AHP method, which also states the advantages of this weighting method, is the fact that it has the ability to determine the weight of both quantitative and qualitative criteria. It has been introduced as one of the methods with a high degree of reliability because it has a strong theory and is formulated based on obvious principles (Stankovic et al., 2019).

3.3. SAW Model

It is a long time that the SAW model has been used to solve various uncertainties in global world challenges. The model of SAW is one of the simplest methods of MCDM techniques, which can be easily used in ranking the alternatives. To use this method, the decision matrix is normalized by the linear conversion method and then the weighted and normalized values are added together to determine the ranking values of alternatives (subcontractors). Its framework is composed of two simple equations. By Equations 2 and 3, *Xij, R* and *Wj* are the values, ranked, and weighted values respectively. The normalization of the decision matrix was done based on Equation (2) (Hassanpour and Pamucar, 2019). It is needed to explain that *Xij* is the values for the SAW model.

$$\text{Pij} = \frac{\text{Xij}}{\sum_{i=1}^{n} xij} \qquad i = \Gamma, m; \; j = \Gamma, n \quad (2)$$

$$\text{R} = \sum (Pij \,.\, Wj) \quad (3)$$

4. Result and discussion

Lots of criteria are interfered with in selecting the best-qualified subcontractors. The criteria were listed in two separate questionnaires and the opinions of Decision Makers (DM) who were holding enough experience and knowledge in this regard were used. The numerical values of 1, 2, 3, 4, 5, 6, and 7 for the criteria encompassed linguistic words as very low, low, slightly low, medium, slightly high, high, and very high in questionnaires respectively. The main criteria used in a separate questionnaire encompass the following according to Table 1.

The DM reached to priority and importance of main subcontractor selection factors as Tender price > Executive Human Resource = Good performance in previous projects > Equipment, tools and machinery ability > Management and planning ability = Experience in similar projects = HSE instructions. According to Table 1, we figured out that the main criterion in outsourcing a project is a bid price and this is in full agreement with the existing circumstances of subcontractor selection in Iran. However, the objective of this research was integrating all criteria with the same importance. It means the bid price is held back and lots of criteria are interfering in subcontractor selection. That is why this research attempted to offer a coherent procedure to be taken into consideration. The criteria taken into account for conducting this study comprised the below cases in full detail. In Table 2, the full names of criteria are as 400 amp diesel welding motor (C_1), CNC drill (C_2), Rectifier (C_3), H-instrument (C_4), 7-function punch scissors (C_5), Round drill (C_6), Drill Magnet (Magnet) (C_7), 8 ton tower crane (C_8), Powder under welding machine (C_9), Wind compressor 8 times (C_{10}), Fire saw (C_{11}), Diesel generator (C_{12}), 5, 10, 15 ton crane (C_{13}), Truck for cargo transportation (C_{14}), Air capsules (C_{15}), 10 ton jack (C_{16}), Handheld electrode heater (C_{17}), Grinding stone wall machine (C_{18}), other aspects (C_{19}). Also, the remaining symbols are Company (CO), Number of devices and facilities (N), Ownership (O), Score (S), Professional Experience (PE), Professional Experience of Prominent Staff (PEPS), Project purpose achievements (Ppa), Planning and managing ability (Pma), Experience in similar contracts (Esc), HSE guidelines consideration (HSEgc), Expert workforces (Ewf), Bid price (Bp).

In Table 2, lots of various criteria are actually composed of two parts (qualitative and quantitative aspects). The C_1-C_{18} that are the same among companies in three rows of N, O, and S representing the inventory list of each company, which has included various parameters, belong to the equipment and devices required for the construction of the project. The second part included the other items (C_{19}) consisted of various criteria, most of which were associated to the company's professional work experience records in implementing previous projects and the bid price offered by each company to obtain the project, such as PE, PEPS, Ppa, Pma, Esc, HSEgc, Ewf, and Bp. Table 2 was arranged to include all criteria together as the research design of the current study. The data were gone through the normalization step and then the values of the weights were assigned to determine the final weights. The AHP method was used as the weighing system of this study. Its procedure accounts for the values of tables to be multiplied with each other and then reaches to the exponential reverse of numbers. Finally, each number was divided into the sum of amounts released via the exponential reverse of numbers.

Table 3 denotes the values of weights obtained by the AHP and SAW models. According to Table 3, the highest weight was devoted to the criterion of N in both systems of AHP and SAW models because of variations in the number of devices, tools, and equipment applied. Reasonable results appeared by the current research with looking at the values of Bp that were as $ 8055.55, $ 10000, $ 9166.66, $ 6666.66, $ 8333.33, and $ 7500 for the companies of Hejrat Manesh Izeh (1), Khesht Sazan Karoun (2), Yeganeh saze omid (3), Sakht karan Moongasht (4), Darya Sanat Khavarmianeh (5), Omran mehragane Yosef (6) respectively.

Table 1. The main criteria of subcontractor selection by DM opinion

Main Criteria	Equipment, tools and machinery ability	Good performance in previous projects	Management and planning ability	Experience in similar projects	HSE instructions	Executive Human Resources	Tender price
DM	5	6	3	3	3	6	7

Table 2. The criteria for subcontractor selection

CO/criteria		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}
(1)	N	3	2	1	1	2	1	1	-	1	1	1	1	1	1	3	-	2	2	-
	O	1	1	0.5	0.5	1	0.5	0.5	-	1	0.5	1	1	0.5	0.5	1	-	1	1	-
	S	1	-	0.5	0.5	1	0.5	0.5	-	1	0.5	1	1	-	0.5	1	-	1	-	-
	PE																			5
	PEPS																			7
	Ppa																			6
	Pma																			1*
	Esc																			3*
	HSEgc																			1*
	Ewf																			4*
	Bp																			1
(2)	N	3	1	4	1	1	2	1	-	-	1	1	2	1	1	1	-	1	1	-
	O	1	1	1	0.5	1	1	0.5	-	-	0.5	1	0.5	0.5	0.5	1	-	1	0.5	-
	S	1	1	1	0.5	-	-	0.5	-	-	0.5	1	0.5	-	0.5	1	-	1	0.5	-
	PE																			5
	PEPS																			6
	Ppa																			6
	Pma																			1*
	Esc																			1*
	HSEgc																			1*

	Ewf																			4.5*
	Bp																			3
(3)	N	2	1	2	1	3	4	2	-	2	1	2	2	1	2	4	-	2	2	-
	O	1	1	0.5	0.5	1	1	0.5	-	1	0.5	1	0.5	0.5	0.5	1	-	0.5	1	-
	S	1	1	0.5	0.5	1	1	0.5	-	1	-	1	0.5	0.5	0.5	1	-	0.5	1	-
	PE																			6
	PEPS																			5
	Ppa																			5
	Pma																			1*
	Esc																			1*
	HSEgc																			1*
	Ewf																			5*
	Bp																			4
(4)	N	1	2	1	1	2	2	2	-	2	2	2	1	1	-	3	-	1	2	-
	O	1	0.5	1	0.5	0.5	0.5	1	-	1	0.5	1	1	0.5	-	1	-	0.5	0.5	-
	S	1	0.5	1	-	0.5	0.5	1	-	-	0.5	1	1	0.5	-	-	-	0.5	0.5	-
	PE																			6
	PEPS																			5
	Ppa																			5
	Pma																			1*
	Esc																			2.5*
	HSEgc																			-
	Ewf																			5.5*
	Bp																			2
(5)	N	1	2	1	3	1	2	2	-	-	2	2	1	1	-	1	-	-	2	-
	O	1	0.5	1	1	0.5	1	1	-	-	0.5	1	1	0.5	-	1	-	-	0.5	-
	S	1	0.	1	-	0.	0.5	1	-	-	0.5	-	-	0.5	-	1	-	-	0.5	-

			5			5														
	PE																			6
	PEPS																			4
	Ppa																			5
	Pma																			1*
	Esc																			2*
	HSEgc																			1*
	Ewf																			6*
	Bp																			5
	N	2	2	2	1	-	2	1	-	1	-	2	1	-	1	2	1	1	2	-
	O	1	1	1	0.5	-	1	0.5	-	0.5	-	1	0.5	-	0.5	1	0.5	0.5	1	-
	S	1	1	-	0.5	-	-	0.5	-	0.5	-	1	0.5	-	0.5	1	0.5	0.5	-	-
	PE																			6
(6)	PEPS																			5
	Ppa																			6
	Pma																			2*
	Esc																			1*
	HSEgc																			0.5*
	Ewf																			6*
	Bp																			6

Ownership=1, Rented=0.5, Full score=1, No score=0, Medium score=0.5
*Sum of scores depends on the number of managers and professional experience
Khesht Sazan Karoun (1), Darya Sanat Khavarmianeh (2), Hejrat Manesh Izeh (3), Yeganeh saze omid (4), Omran mehragane Yosef (5), Sakht karan Moongasht (6)

Table 3.: The values of weights in AHP method and ranks for alternatives

	CO/Criteria	AHP	SAW	Rank
(1)	N	0.48226106	3.954540667	2
	O	0.26102609	1.148514787	
	S	0.25671286	0.872823707	
	PE	0.17857143	0.031887755	
	PEPS	0.25	0.0625	
	Ppa	0.21428571	0.045918367	
	Pma	0.03571429	0.00127551	
	Esc	0.10714286	0.107142857	
	HSEgc	0.03571429	0.00127551	
	Ewf	0.14285714	0.020408163	
	Bp	0.03571429	0.00127551	6.247
(2)	N	0.47499271	3.609944573	5
	O	0.26553607	1.137379511	
	S	0.25947122	0.808685304	
	PE	0.18181818	0.033057851	
	PEPS	0.21818182	0.047603306	
	Ppa	0.21818182	0.047603306	
	Pma	0.03636364	0.001322314	
	Esc	0.03636364	0.001322314	
	HSEgc	0.03636364	0.001322314	
	Ewf	0.16363636	0.02677686	
	Bp	0.10909091	0.011900826	5.727
(3)	N	0.56798939	5.263368325	1
	O	0.21351003	0.754402092	
	S	0.21850059	0.699201876	
	PE	0.21428571	0.045918367	
	PEPS	0.17857143	0.031887755	
	Ppa	0.17857143	0.031887755	
	Pma	0.03571429	0.00127551	
	Esc	0.03571429	0.00127551	
	HSEgc	0.03571429	0.00127551	
	Ewf	0.17857143	0.031887755	
	Bp	0.14285714	0.020408163	6.882
(4)	N	0.53410426	4.495377498	3
	O	0.23698415	0.888690549	
	S	0.2289116	0.648582857	
	PE	0.22222222	0.049382716	
	PEPS	0.18518519	0.034293553	
	Ppa	0.18518519	0.034293553	
	Pma	0.03703704	0.001371742	
	Esc	0.09259259	0.008573388	
	HSEgc	0	0	
	Ewf	0.2037037	0.041495199	
	Bp	0.07407407	0.005486968	6.2
(5)	N	0.51243088	3.751726	6
	O	0.26194853	0.991662	
	S	0.22562059	0.539878	

	PE	0.2	0.04	
	PEPS	0.13333333	0.017777778	
	Ppa	0.16666667	0.027777778	
	Pma	0.03333333	0.001111111	
	Esc	0.06666667	0.004444444	
	HSEgc	0.03333333	0.001111111	
	Ewf	0.2	0.04	
	Bp	0.16666667	0.027777778	5.44
(6)	N	0.51153388	3.83650408	4
	O	0.25576694	0.95912602	
	S	0.23269918	0.83174796	
	PE	0.18461539	0.03408284	
	PEPS	0.15384615	0.023668639	
	Ppa	0.18461539	0.03408284	
	Pma	0.06153846	0.003786982	
	Esc	0.03076923	0.000946746	
	HSEgc	0.01538462	0.000236686	
	Ewf	0.18461539	0.03408284	
	Bp	0.18461539	0.03408284	5.8

5. Conclusion

The challenges posed in subcontractor selection based on the lowest bid price seem to be forgotten by considering and taking into account the same importance for all criteria. By the way, it conducts an easy way for in-charge staff to recede the difficulties, challenges, and argues in subcontractor selection. The SAW model used had a relevant connection for all partitions and released the ranks in a reasonable and discernible way. The findings and procedures of the current study can be taken into consideration across Iran and other nations. It can be concluded that the lowest bid price cannot be a strong decision in holding back the construction crises unless there are lots of interfering criteria in this regard. The sensitivity analysis ignored to verify the implemented method because of variation raised in contents of Table 3 and difficulties in research design based on existing conditions and circumstances in tendering. That is why future research orientation may include lots of criteria and factors despite we took important matters in Iranian projects. The bid price also converted to crisp numbers to rise the precision and accuracy applied in the objective followed. We hopefully declare the civil engineers will extend the procedure and questionnaire designed in the workplace to choose the right subcontractors in future plans.

6. Acknowledgment

This research was conducted as part of the corresponding author's Ph.D. Any opinions, findings, and conclusions expressed in this publication are those of the author and necessarily reflect the current views and policies. The authors would like to thank the experts who gave the responses.

References

Akintan, O. A., & Morledge, R. (2013). Improving the collaboration between main contractors and subcontractors within traditional construction procurement. Journal of Construction Engineering, 20(13)1-11.

Araújo, M. C. B., Alencar, L. H., & Mota, C. M. (2015). Contractor selection in construction industry: A multicriteria model. IEEE International Conference on Industrial Engineering and Engineering Management. Singapore, Singapore, 519-523.

Borujeni, M. P., & Gitinavard, H. (2017). Evaluating the sustainable mining contractor selection problems: An imprecise last aggregation preference selection index method. Journal of Sustainable Mining, 16(4), 207-218.

Bowen, P., Akintoye, A., Pearl, R., & Edwards, P. J. (2007). Ethical behavior in the South African construction industry. Construction Management and Economics, 25(6), 631-648.

Cheaitou, A., Larbi, R., & Al Housani, B. (2019). Decision making framework for tender evaluation and contractor selection in public organizations with risk considerations. Socio-Economic Planning Sciences, 68, 100620, 1-12.

Chiang, F. Y., Vincent, F. Y., & Luarn, P. (2017). Construction contractor selection in Taiwan using AHP. *International Journal of Engineering and Technology*, *9*(3), 211-215.

Clough, R. H., Sears, G. A., Sears, S. K., Segner, R. O., & Rounds, J. L. (2015). Construction contracting: A practical guide to company management. John Wiley & Sons. USA.

Doloi, H. (2009). Analysis of pre-qualification criteria in contractor selection and their impacts on project success. Construction Management and Economics, 27(12), 1245-1263.

Fong, P. S. W., & Choi, S. K. Y. (2000). Final contractor selection using the analytical hierarchy process. Construction management and economics, 18(5), 547-557.

Hartmann, A., Ling, F. Y. Y., & Tan, J. S. (2009). Relative importance of subcontractor selection criteria: evidence from Singapore. Journal of construction engineering and management, 135(9), 826-832.

Hassanpour M., Pamucar D. (2019). Evaluation of Iranian household appliance industries using MCDM models. Operational Research in Engineering Sciences: Theory and Applications, 2(3), 1-25

Hatush, Z., & Skitmore, M. (1997a). Criteria for contractor selection. Construction Management & Economics, 15(1), 19-38.

Hatush, Z., & Skitmore, M. (1997b). Evaluating contractor prequalification data: selection criteria and project success factors. Construction Management and Economics, 15(2), 129-147.

Hatush, Z., & Skitmore, M. (1998). Contractor selection using multi-criteria utility theory: an additive model. Building and environment, 33(2-3), 105-115.

Hinze, J., & Tracey, A. (1994). The contractor-subcontractor relationship: the subcontractor's view. Journal of construction engineering and management, 120(2), 274-287.

Holt, G. D., Olomolaiye, P.O., Harris, F. C. (1995). A review of contractor selection practice in the UK construction industry. Building and environment, 30(4).533-561.

Ibadov, N. (2015). Contractor selection for construction project, with the use of fuzzy preference relation. Procedia Engineering, 111(1), 317-323.

Jafari, A. J., & Hassanpour, M. (2014). Performance assessment of three companies (road construction) using business excellence models. The International Journal of Business & Management, 2(10), 6-15.

Juan, Y. K., Perng, Y. H., Castro-Lacouture, D., & Lu, K. S. (2009). Housing refurbishment contractor's selection based on a hybrid fuzzy-QFD approach. Automation in Construction, 18(2), 139-144.

Kahraman, C. (2008). Fuzzy multi-criteria decision making: theory and applications with recent developments (Vol. 16). Springer Science & Business Media. New York, NY, USA.

Kumaraswamy, M. M., & Matthews, J. D. (2000). Improved subcontractor selection employing partnering principles. Journal of management in engineering, 16(3), 47-57.

Li, Y., Nie, X., & Chen, S. (2007). Fuzzy approach to prequalifying construction contractors. Journal of construction engineering and management, 133(1), 40-49.

Lingard, H., Hallowell, M., Salas, R., Pirzadeh, P. (2017). Leading or lagging? Temporal analysis of safety indicators on a large infrastructure construction project. Safety Science, 91, 206–220.

Manoharan, R. (2005). Subcontractor Selection Method Using Analytic Hierarchy Process. April, 2005 (Doctoral dissertation, MSc Thesis. Universitit Teknologi Malaysia: Malaysia).

Marzouk, M. M., El Kherbawy, A. A., & Khalifa, M. (2013). Factors influencing sub-contractor's selection in construction projects. HBRC Journal, 9(2), 150-158.

Maturana, S., Alarcón, L. F., Gazmuri, P., & Vrsalovic, M. (2007). On-site subcontractor evaluation method based on lean principles and partnering practices. Journal of Management in Engineering, 23(2), 67-74.

Mirmousa, S., & Dehnavi, H. D. (2016). Development of criteria of selecting the supplier by using the fuzzy DEMATEL method. Procedia-Social and Behavioral Sciences, 230, 281-289.

Morkunaite, Z., Podvezko, V., Zavadskas, E. K., & Bausys, R. (2019). Contractor selection for renovation of cultural heritage buildings by PROMETHEE method. *Archives of Civil and Mechanical Engineering*, *19*, 1056-1071.

Ng, S. T. T., & Luu, C. D. T. (2008). Modeling subcontractor registration decisions through case-based reasoning approach. Automation in construction, 17(7), 873-881.

Puri, D., & Tiwari, S. (2014). Evaluating the criteria for contractors' selection and bid evaluation. International journal of engineering science invention, 3(7), 44-48.

Russell, J. S., Hancher, D. E., & Skibniewski, M. J. (1992). Contractor prequalification data for construction owners. Construction Management and Economics, 10(2), 117-135.

Sacks, R., & Harel, M. (2006). An economic game theory model of subcontractor resource allocation behaviour. Construction Management and Economics, 24(8), 869-881.

Sari, A., & El-Sayegh, S. M. (2007). Factors affecting the selection of the appropriate construction management at risk contractor. In Latin American and Caribbean proceeding of the international Conference for Engineering and Technology in Tampico, México 29(1)1-8.

Singh, D., & Tiong, R. L. (2006). Contractor selection criteria: investigation of opinions of Singapore construction practitioners. Journal of construction engineering and management, 132(9), 998-1008.

Stankovic, M., Gladovic, P., Popovic, V. (2019). Determining the importance of the criteria of traffic accessibility using fuzzy AHP and rough AHP method. Decision Making: Applications in Management and Engineering, 2(1), 86-104.

Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). Computers & Industrial Engineering, 140, 106231.

Wong, C. H., Holt, G. D., & Cooper, P. A. (2000). Lowest price or value? Investigation of UK construction clients' tender selection process. Construction management and economics, 18(7), 767-774.

Zavadskas, E.K., Turskis, Z. 2011. Multiple criteria decision making (MCDM) methods in economics: an overview. Technol. Econ. Dev. Eco. 17 (2), 397–427.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 65-83
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303065w

NOVEL POKA-YOKE APPROACHING TOWARD INDUSTRY-4.0: A LITERATURE REVIEW

Sugiri Widjajanto[1], Humiras Hardi Purba [1], Sansuri Choesnul Jaqin [1]*

[1] Industrial Engineering, Universitas Mercu Buana Jakarta, Indonesia

Received: 05 August 2020
Accepted: 19 October 2020
First online: 12 November 2020

Review Paper

Abstract: *Understanding quality in manufacturing starts with learning why errors happen and this could be improved by analysis with root causes related to human errors. Human reliability influenced by equipment design or working environment will come to concept of poka-yoke (mistake proofing), and various means to reduce mistakes that have been greatly improved recently with latest sophisticated technology. This article will discuss poka-yoke technology related to the Industry 4.0 (I4.0) or Smart Manufacturing concept. The method is to review research articles published within 2015-2020 with a keyword poka-yoke or mistake-proof or fault-proof and verify further whether their poka-yoke tools have implemented the I4.0 concept. The results obtained 50 selected articles, with 13 of them that already applied information technology, cloud computing, and augmented reality, which are considered as I4.0 tools. However, its application is not always satisfying concerning its suitability function, requirement of industries, culture, local regulation, and internal business concern, especially in terms of efficiency and cost.*

Keywords: *Poka-yoke, mistake-proof, fault-proof, industry 4.0.*

1. Introduction

There is a concept in quality management that prevents the human fault from occurring in production, which was introduced by Shigeo Shingo and named as poka-yoke (Malega, 2018). It deals with mistake-proof or error-proof as per original wording *yokeru* (avoid) and *poka* (mistakes) (Kurhade, 2015). The mistake can occur at any job at any type, e.g., misoperation, not performed as per protocol, using wrong tools, missing parts, having defects during assembling, using incorrect components, or inaccurate measurement (Kurhade, 2015).

Currently, we are facing Industry 4.0 or in short form as I4.0, and conventional industries will evolve to a smart and autonomous style (Ahmed et al., 2019), and it will introduce and develop new tools that reduce human error at an early step of

* Corresponding author.
swidjajanto@gmail.com (S. Widjajanto), humiras.hardi@mercubuana.ac.id (H.H. Purba), sansurijaqin@gmail.com (S.C. Jaqin)

product and process development (Lazarevic et al., 2019). It can be a communication strategy (Tezel & Aziz, 2017), or automation with a human touch (Romero et al., 2019) or software application to avoid mistyping (Hudori et al., 2017) or a smart decision tool (Ahmed et al., 2019) or a computerized testing tool (Bici et al., 2017) or using advanced technology like augmented reality to point out mistakes (Dario Antonelli & Astanin, 2015). Then, it comes to the question, how can poka-yoke and I4.0 supplement each other? And which I4.0 tools can support a poka-yoke method?

The precondition for this literature study is looking at various lean approaches including mistake-proofing methods. Indeed, there are many ideas of mistake-proofing methods with proper implementation according to their circumstances. However, there are insufficient published articles with this specific mistake-proof topic.

2. Research Methods

This literature review is the best method to study and analyze from basic theory, tools, experience, and lessons learned from either academic or practical exercise. According to Figure 1, this paper study starts with the initial collection as step number one of the total five steps. Collecting from various publishers, i.e. Science Direct, Research Gate, ProQuest Search, MDPI, Springer Open and Google Scholar within the year of 2015 until 2020. The keyword is "poka-yoke" or "mistake-proof" or "error-proof" or "fault-proof" for the industrial sector with the number of collected articles shown in Table 1.

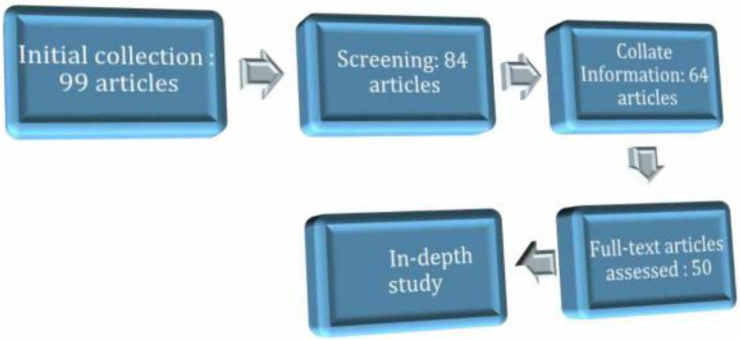

Figure 1 Literature Study Framework

Table 1. Number of Articles at every stage

Stage	Article Qty
1	99
2	84
3	64
4	50
5	50

- Stage 1. The initial collection, managed to collect 99 articles relevant to poka-yoke.

- Stage 2. Screening; omitted numbers of papers due to irrelevant research objects and kept 84 of them.
- Stage 3. Collate information, also removing the number of papers when digging information inside, only selected 64 related to industrial and manufacturing.
- Stage 4. Full-text article assessed, gained more knowledge and chosen 50 standing out.
- Stage 5. In-depth study for those remaining 50 articles.

Digesting more the article contents, it has been listed out all articles based on the industrial type or place of research, poka-yoke type, and country of the researcher. Segregation based on poka-yoke type is mechanical, electronic, mechanical-electronic (mix), IT or system software, and the last is organizational, which is a focus on the development of protocol or procedure for the human-error problem. The summary of results based on the year of published papers is presented in Figure 2.

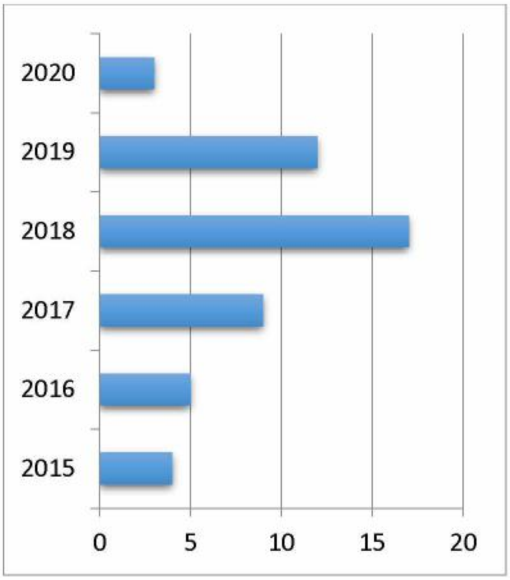

Figure 2 Collected articles & papers based on the publishing year

Analyzing the content from the final collected articles, there was a focus on a few aspects:

- Industrial type,
- Selected mistake-proof type (see Figure 3),
- Implementation,
- Enablers and inhibitors.

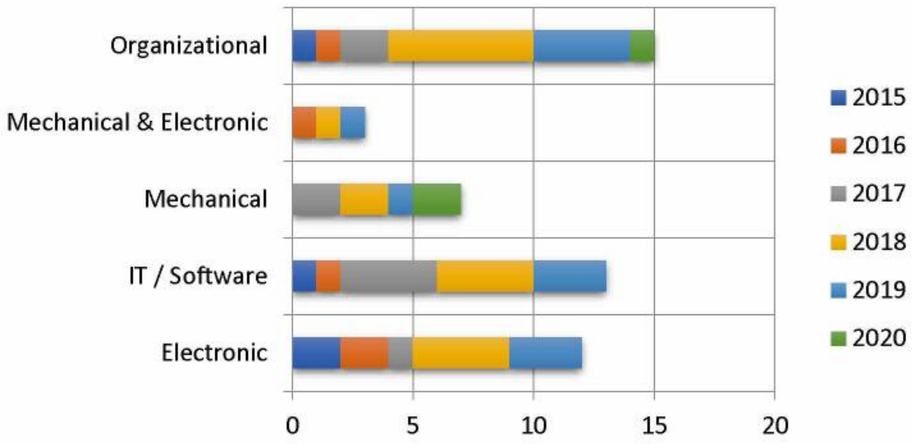

Figure 3 Poka-yoke type

Based on theory, the poka-yoke implementation started in the automobile industry (in the 1960s as part of Toyota Production System (TPS) in Japan), and furthermore it was adopted by textile, construction, electronics, woods, services, and other industries in various countries.

3. Results and Discussion

All articles and papers are elaborated in Table 2, including the country of author, research object and respective result. Surprisingly, the article published by the Japanese is none at this literature study and this concern can be reserved for future research.

Table 2 Mapping Poka-Yoke Implementation from 50 articles

No	Paper Identity	Country of Author	Research object	Result
1	(Dahivale & Lokhande, 2020)	India	Rejection from reverse logistics and scrap	After implementation of poka-yoke, rejection and scrap rates are significantly reduced to 'zero'.
2	(Solaimani & Sedighi, 2020)	Netherland	Lean implement-ation including Poka Yoke in Construction	Carry out and sustain the lean in construction and poka-yoke is part of them, particularly for safety.
3	(Selvam & Loganathan, 2019)	India	Design & fabric-ation of hydraulic conduit connector	Improvement on quick releasing coupling. Part of assembly is made noticeable. Eventually, it raises a confidence level of the operator's.
4	(Muharam & Latif, 2019)	Indonesia	Vibration signal for machine monitoring	Poka yoke device can observe machine condition, such as bearing abnormal alarm. Furthermore, this system is also being used to see machinery and equipment condition.
5	(Romero et al., 2019)	Italy	Jidoka/Automation with human touch	Advised for step-by-step fully-automated operation deployment to let workers gain knowledge and change working culture towards semi-automated or fully automated operation, through development of stages and adopting Jidoka Systems, instead of immediate applying a fully automated solution.
6	(Rösiö et al., 2019)	Sweden	Assessment manu-facturing system and Poka Yoke as part of diagnosable criteria	Develop assessment model to measure ability for modification and change variation of product and volume.
7	(Putri & Handayani, 2019)	Indonesia	Craft bag product quality (for cement powder)	Improvement with 3 poka yoke methods, i.e. warning, control & shutdown.
8	(Hoellthaler et al., 2019)	Germany	Digitalization to support Poka-Yoke for a lean production system	Digital manner for tools and methods is indeed achievable, eventually reduces waste of time, cost and quality.
9	(Attia et al., 2019)	Egypt	Poka yoke in clothes printing machines	A mechanical poka yoke prototype is manufactured for diminishing problems.
10	(D. Antonelli & Stadnicka, 2019)	Italy	Identify potential mistakes either by human or robot.	Define proper mistake proofing (poka yoke) methods in an HRC (Human-Robot Collaboration) assembly work cell. The best solution is to standardize the part and uniform the dimension.
11	(Saputra et al., 2019)	Indonesia	Molding machine of plastic industry	Improvement is achieved gaining a value of 1.65 of SPC through poka-yoke implementation.
12	(Rubio-romero & Pardo, 2019)	Spain	Perform an analysis of lean, fault-proof and preventive activity in construction	"Personal-Protective-Equipment" or PPE is considered poka-yoke, and also warning sign with RFID and reflective railings.
13	(Ahmed et al., 2019)	Australia	SVPD in design, process and inspection	Disseminate a smart system based on experimental expertise to support product development design, product planning that is able to enhance manufacturing process.

14	(Qeshmy et al., 2019)	Sweden	Aim to identify human error fact-ors in an assembly line using Augmented Reality for Smart Factory.	Augmented-Reality is not suitable if the aim is identification of human failure. The AR is not fully developed for the moment.
15	(Bajjou & Chafi, 2018)	Morocco	Survey in Moroccan con-struction industry	61 % of the respondents are familiar with lean construction practices, and 68% are not familiar with Poka-yoke.
16	(Satolo et al., 2018)	Brazil	To rank the tools of the lean	Poka yoke is rank 11 among lean tools like VSM, six-sigma, 5S, kaizen, etc.
17	(S. Kumar et al., 2018)	India	SME with continuous improvement	Achieving by Lean-Kaizen approaching. However, found weakness in motivation of employees to eliminate wastes.
18	(Gavriluţă et al., 2018)	Romania	Laboratory system for modern manu-facturing	Develop a laboratory situation and environment for a sophisticated industrial method, including a simulating flow of process and lean.
19	(Soni & Yadav, 2018)	India	Review on produc-tivity improvement by poka yoke implementation	Application of poka yoke on a liner cutting machine to prevent possibility of liner mouth misalignment and increase the productivity.
20	(Vinayagasundaram, R. Velmurugan, 2018)	India	Pick-to-light at compressor manufacturing	Implement poka yoke approaching for a zero-defect in an assembly line; pickers or operators are prompted by lights (hence the name pick-to-light).
21	(Dawood et al., 2018)	Saudi Arabia	Lean tools in a soft drink company, Poka-yoke for variable missing operations, under fill, over fill, break ages.	Identify non-value adding activities, thereby enhancing productivity. Step 1: Detect the abnormality-(Andon), Step-2: Stop the equipment or line by Poka-yoke, Step-3: Fix and correct the immediate condition by Poka-yoke, Step 4: Verify causes and install a counter measure Poka-yoke.
22	(Lilja, 2018)	Sweden	Tetrapak packaging machine	Using three sub-functions (Physical, signaling and control) in the solution as all these functions seek to improve the environment around the assembler.
23	(Malega, 2018)	Slovak	Business process and system in a general review	Poka yoke represents an excellent method for eliminating human errors in production process.
24	(Prayogi et al., 2018)	Indonesia	Smart-key assembly in car manufacturing	Design two poka-yoke devices along with sensors that are integrated to the whole assembly system.
25	(Sundaramali et al., 2018)	India	Avoiding unneces-sary assembly of defective compo-nents and marking them	The whole inspection from the beginning has involved Poka Yoke.
26	(Pötters et al., 2018)	Germany	Shop floor process simulation for several methods including poka-yoke	Identification of how to get optimal quality involves optimization experts in the company. This initial identification approach is carried out before the actual test is conducted.
27	(Ardi et al., 2018)	Indonesia	Process of mounting actuator bracket	The design with Poka yoke overcomes the occurrence of bolt damage when installing the bracket.

28	(Kurdve et al., 2018)	Sweden	Prototype for building wood modules with poka-yoke	The eco-strategy can be used, but need more consideration to optimize the product life, optimize product function, and minimize environmental waste in the specification and concept phase. Chosen material can be finalized during prototyping.
29	(Kurdve, 2018)	Sweden	Assembly-line work instruction in digital manner with fault-proof safety & quality	Poka-yoke, standardized work instruction and using ready-assembly materials became solutions at Husmuttern (wood-ware factory) although there is digital support available, but it does not fit with workers' skills at wood-ware company.
30	(Schaede et al., 2018)	Germany	Decision tree of CNC program with product parameters	CNC is programmed for automatic with a limited parameter. Decision tree is used to determine the best procedure. Example implementation was presented, proving beneficial of automated CNC program.
31	(M. Kumar et al., 2018)	India	Adding real time production data as poka-yoke system	PLCs are equipped with servers for real-time fabrication data to ensure 100% inspection is carried out and sent to management. This is a poka-yoke method, so that operators cannot take a short-cut in production.
32	(Erdogan et al., 2017)	USA	Measure kaizen effectiveness in the wood industry	Provide the latest views on the use of Kaizen and other improvement opportunities while staying focused on quality, safety, fault-proof and waste.
33	(Lemahieu et al., 2017)	USA	Lean in education	Highlighted lean in educational environment and delivering more efficient education and training.
34	(Tezel & Aziz, 2017)	UK	Visual-management (VM) system in England construction project	Identify beneficial of Visual-management system for a transportation construction project. Potential of poka-yoke system for quality inspection and worker safety.
35	(B. Kumar & Kumar, 2017)	India	Poka yoke on needle roller bearing	Poka yoke implementation has decreased a missing needle and obtained maximum efficient bearing.
36	(Che-Ani MN. et al., 2017)	Malaysia	Quality in process production	Quality has improved and ensured economic benefit by poka-yoke.
37	(Ardi & Abdurrahman, 2017)	Indonesia	Oxygen sensor machine functiona-lity	Increase efficiency check of oxygen sensor machine by poka yoke system. Rating errors reduced by 0.14% and MOR hit 90% target.
38	(Hudori et al., 2017)	Indonesia	Pallet package information at shipping dept	Poka yoke implementation for pallet package information.
39	(Rojo Abollado et al., 2017)	UK	Optimize business process and change the information systems to support evolving of the business.	Overview of benefits that the implementation of digital workflow is doable in an aerospace company, along with detailed challenges of both digital workflows and human factor risks.
40	(Bici et al., 2017)	Italy	Computer-aided-tolerancing-and-inspection	Automatic measurement through specific algorithms is useful in guaranteeing measurement results involving many samples.
41	(Isnain & Karningsih, 2016)	Indonesia	Car body parts manufacturing	Implement Poka Yoke sensors at a press machine and finish wrapping.
42	(Alghozali et al., 2016)	Malaysia	Vending machine product quality	Quality improvement in vending machine services by adopting the poka-yoke approach, adding date-based alarm warnings.

43	(Thareja, 2016)	India	Real life or common use exemplars	By citing various tools for correction, error proofing (poka yoke) of the processes is done.
44	(Fauzan et al., 2016)	Indonesia	Printing processing with minimizing waste defect	Improvement suggestions were made as well as a poka yoke system as an effort to minimize waste defect.
45	(D. Antonelli & Stadnicka, 2016)	Italy	Mistake-proof solution by Fuzzy logic for: 1. Welding spot 2. Kitting process 3. Roller bearing seals	Propose a package to get the most suitable solution by using fuzzy-logic on KPI criteria.
46	(Tak & Wagh, 2015)	India	Poka-yoke on punching machine	Problems can be managed by poka-yoke.
47	(Singh & Singh, 2015)	India	Continuous improvement of North India manufacturing	Significantly increased OEE reached 3.01%.
48	(Shrigadi et al. 2015)	India	Using a sensor on a particular place, then it can prevent mixing of different casting on a process line.	If there is an incorrect casting, the sensor gives an alarm and the conveyor stops, so the operator changes the wrong one.
49	(Dario Antonelli & Astanin, 2015)	Italy	Augmented-Reality (AR) to improve welding quality	Using AR devices displayed welding point data.
50	(Lazarevic et al., 2019)	Serbia	Literature review of Poka Yoke, 211 manuscripts with 50 examples	Poka-yoke's new approach is to recognize existing gaps and describe using experience in the field.

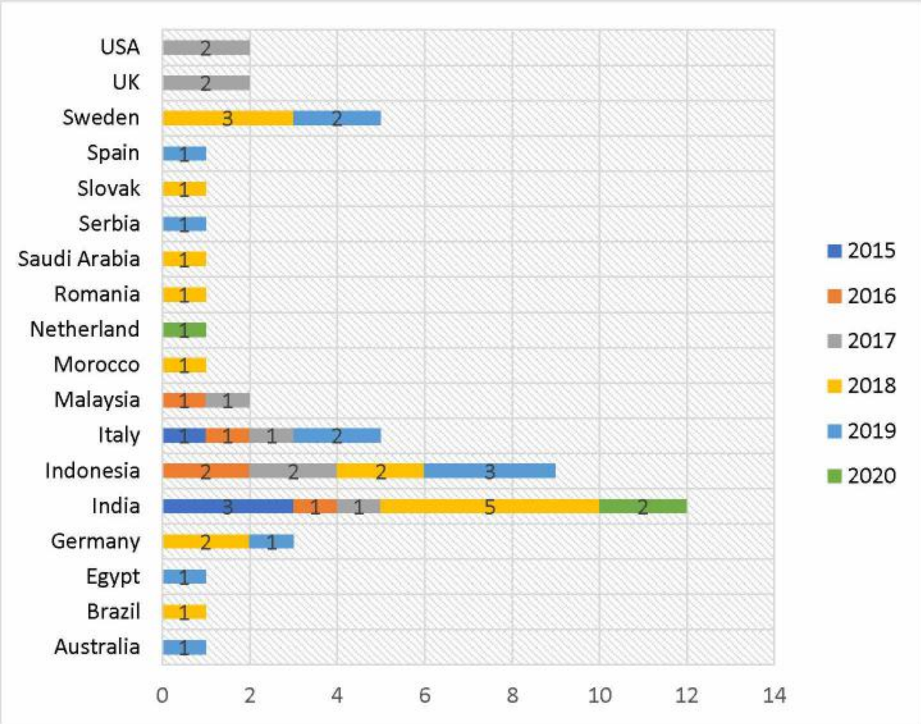

Figure 4 Country of author

3.1. Brief Results Based on Country

Around a quarter of the collected articles are published by authors from India as seen in Figure 4. There are also authors from many European nations as well as Asia followed by the US, Australia, and Africa. This representation of authors' countries shows that a poka-yoke idea is spread all over the nations, see Table 2 that maps all articles and Figure 4.

3.2. Review on Poka-yoke Type

Various articles & researchers on mapping all articles of Table 2 are divided based-on five poka-yoke types as shown in Table 3.

Table 3. Poka-yoke type in respective articles

Poka-yoke type	Article Author	Sum
Electronic	(Muharam & Latif, 2019), (Putri & Handayani, 2019), (Saputra et al., 2019), (Vinayagasundaram, R. Velmurugan, 2018), (Dawood et al., 2018), (Prayogi et al., 2018), (Ardi et al., 2018; Ardi & Abdurrahman, 2017), (Isnain & Karningsih, 2016), (Alghozali et al., 2016), (Tak & Wagh, 2015), (Shrigadi et al., 2015).	12
Mechanical	(Dahivale & Lokhande, 2020), (Selvam & Loganathan, 2019), (Attia et al., 2019), (Soni & Yadav, 2018), (Sundaramali et al., 2018), (B. Kumar & Kumar, 2017),	7

	(Che-Ani MN. et al., 2017)	
Mix Mech-Elect	(Rubio-Romero & Pardo, 2019), (Lilja, 2018), (Fauzan et al., 2016)	3
IT / Software	(Hoellthaler et al., 2019), (Ahmed et al., 2019), (Qeshmy et al., 2019), (Pötters et al., 2018), (Kurdve et al., 2018), (Schaede et al., 2018), (M. Kumar et al., 2018), (Tezel & Aziz, 2017), (Hudori et al., 2017), (Rojo Abollado et al., 2017), (Bici et al., 2017), (D. Antonelli & Stadnicka, 2016), (Dario Antonelli & Astanin, 2015)	13
Organizational	(Solaimani & Sedighi, 2020), (Romero et al., 2019), (Rösiö et al., 2019), (D. Antonelli & Stadnicka, 2019), (Bajjou & Chafi, 2018), (Satolo et al., 2018), (S. Kumar et al., 2018), (Gavriluţă et al., 2018), (Malega, 2018), (Kurdve, 2018), (Erdogan et al., 2017), (Lemahieu et al., 2017), (Thareja, 2016), (Singh & Singh, 2015), (Lazarevic et al., 2019)	15

Organizational, as a category, includes methods, protocols, procedures, or an IT / Software concept which is a recent advanced tool, i.e. a device connected to the server database, remote control access, control system, and another computerized approaching. The Electronics type, for instance, includes sensors, lights, electronic signs. Mechanical includes stoppers, railing fences, bolts/nuts, etc. Mix Electronic and Mechanical is sensors that are connected to mechanical actions.

There are many different tools for respective purposes. However, the poka-yoke techniques have various names and they can be overlapped with each other. Particular tools may have different implementation proposed by various researchers or different industries. Many of these tools are used in conjunction with each other like visual control (andon) (Dawood et al., 2018) and automation with a human touch (jidoka) (Romero et al., 2019) as a poka-yoke tool.

Results in Table 3 show that 15 articles are categorized as organizational because they did not specify actual implementation of the tool. Furthermore, they are part of lean improvement strategy instead of poka-yoke alone. Others are elaborated more in the next section based on the industry type and local or particular region condition.

3.3. Review on Industrial Type

The empirical study of poka-yoke approaching is grouped into several categories. This includes common industries as the specified or not specific industries mentioned in the article. There is also Service and Education under one group, and so on, as shown in Figure 5. Most of the research took place in the automotive industry, about 20% of the collected articles, then the machinery industry 16%. SME is only 2% while there are plenty of articles nowadays about small and medium enterprise industries, but very few about poka-yoke.

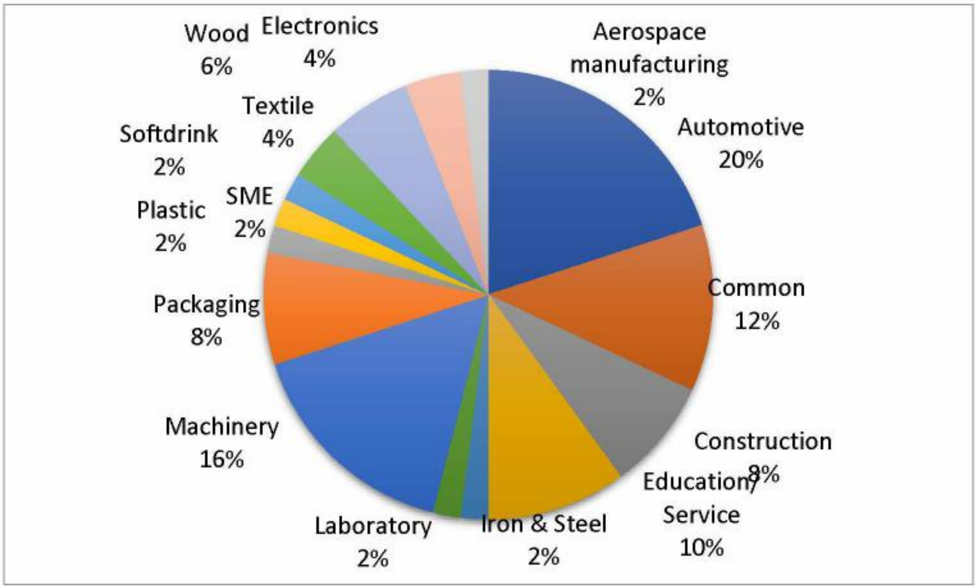

Figure 5 Industry type

Table 4. Poka-Yoke type versus Researcher's Country

Country	Electronic	IT / Software	Mechanical	Mech & Elect.	Organiza tional	Total
Australia		1				1
Brazil					1	1
Egypt			1			1
Germany		3				3
India	3	1	5		3	12
Indonesia	7	1		1		9
Italy		3			2	5
Malaysia	1		1			2
Morocco					1	1
Netherland					1	1
Romania					1	1
KSA	1					1
Serbia					1	1
Slovak					1	1
Spain				1		1
Sweden		2		1	2	5
UK		2				2
USA					2	2
Grand Total	12	13	7	3	15	50

As per history that a poka-yoke tool was started in the automotive industry, it is not surprising that poka-yoke articles are mostly released from automotive industries with 20% out of 50 articles, see Figure 5. It comes with various poka-yoke types, such as electronic sensors (Prayogi et al., 2018), a photo-electric detector (Ardi & Abdurrahman, 2017), a proximity sensor & push button (Ardi et al., 2018), a sensor on a pressing machine (Isnain & Karningsih, 2016), a metal clip interlock (Tak & Wagh, 2015), and a sensor for casting (Shrigadi et al., 2015). Also, mechanical poka-yoke like different part dimensions & color code (Che-Ani MN. et al., 2017), IT poka-yoke with computer visualization (Qeshmy et al., 2019), and organizational poka-yoke with developing model (Rösiö et al., 2019) and introducing volume flexibility, product flexibility and process flexibility (Singh & Singh, 2015).

Poka-yoke approaching in service & education articles are mostly started from conceptual until implementation, i.e. developing lean laboratory (Gavriluţă et al., 2018), systematic poka yoke implementation (Lazarevic et al., 2019), lean for education (Lemahieu et al., 2017), shop floor simulation (Pötters et al., 2018), and warning sign of vending service (Alghozali et al., 2016). Besides the automotive industry as originator, this poka-yoke is also suitable to be applied in the education and service area.

Looking at the construction sector, poka-yoke is implemented to cope with safety issues as PPE (Personal Protective Equipment) (Solaimani & Sedighi, 2020) including a warning sign, reflective railing & RFID tag (Rubio-Romero & Pardo, 2019) and utilize information technologies (IT) in inspection and safety (Tezel & Aziz, 2017). However, there is irony from survey results in the construction sector where most of the respondents are not familiar with a poka-yoke method, about 68% out of 330 valid responses, even though the personal protective equipment (PPE) is a poka-yoke tool in safety (Bajjou & Chafi, 2018).

3.4. Review on Research Place and Country

In general, the relationship between mistake-proofing implementation and organization culture is bond to one another (Satolo et al., 2018). Different countries have different cultures, different labor capabilities, local industry policy, education, etc. That is the reason the mistake-proof tools vary significantly among the nations since they are developed based on the appropriate and specific approaching of respective local requirements, see Fig. 3 and Table 5.

There is a factory in India that has poka-yoke approaching of engraved marking on scrap & disposal just to prevent someone sell the rejected ones to the black market (Sundaramali et al., 2018). For sure, this will not be happening in a developed country like the UK or Australia. On the other hand, there is a poka-yoke idea in a European factory to recognize a welding spot by using augmented reality (Dario Antonelli & Astanin, 2015), which is for another country. This idea is costly and too much in terms of saving cost of optimization.

Regardless of industry type or country, the poka-yoke tool is generally part of lean manufacturing to optimize and eliminate waste. The lean will make organizations more efficient and effective, especially related to quality, reliability, flexibility, innovation and cost and ultimately achieving organizational goals (Satolo et al., 2018).

Facing the challenging circumstance during the Covid-19 outbreak, and raising concern about medical equipment industries, it can be an exciting future research concerning lean manufacturing as well as poka-yoke approaching.

3.5. Novel Poka-yoke with I4.0 Approaching

Poka-yoke helps operators to avoid mistakes. Regardless of what kind of technology is being used, the goal is to detect and eliminate abnormal conditions that lead to the prevention of product defects. This can be a sort of sequence forced on the execution process and which stops when there is an error. Also, the same is done for I4.0 implementation.

Sophisticated technology at the moment, like auto-identification system that can ensure correct identification and digitalized product-ID, allows to retrieve components and identify incorrect ones (Mayr et al., 2018). It can be artificial intelligence (Mayr et al., 2018) that can automatically be adjusted to ensure optimal product quality. There are also augmented reality head-mounted displays to improve quality inspection (D. Antonelli & Stadnicka, 2016; Dario Antonelli & Astanin, 2015; Qeshmy et al., 2019), and RFID-readers can be used for the safety barrier of contractor workers (Rubio-Romero & Pardo, 2019).

As a result of reviewing relevant literature, a simple matrix is shown in Table 5 below figuring out I4.0 methods that can be utilized or support the novel poka-yoke approaching.

Table 5. Possible I4.0 tools versus Poka-Yoke (Mayr et al., 2018)

Industry 4.0 Tools	Poka yoke
Human-computer interaction	√
Virtual representation (e.g. VR, AR)	√
Auto Identification	√
Digital object memory	√
Cloud	√
Real-time	√
Big data	√
Artificial Intelligent	√

Accordingly, several articles particularly relevant with the idea of I4.0 tools are collected and summarized in Table 6 below. Mostly, those are categorized under the IT/Software poka-yoke type (see Table 3). There are usages of information technology for pallet information spreadsheet that can avoid mistyping during data entry (Hudori et al., 2017), Computer Aided Tolerancing & Inspection (CAT&I) to improve inspection (Bici et al., 2017), implementation of digital workflow in aerospace manufacturing that removes many human errors (Rojo Abollado et al., 2017) and digitalization in making a prototype of building wood modules (Kurdve et al., 2018).

Less satisfactory results occur when the I4.0 technology itself is not sufficiently mature or not suitable with the chosen industry, for instance, the augmented reality for welding spot inspection (Dario Antonelli & Astanin, 2015) and for managing errors caused by the human on the assembly line of automotive industry (Qeshmy et al., 2019). It can enhance the quality of manufacture; however, it needs further study for the overall process and cost constraint.

Cloud computing is introduced for an electronic industry with real-time production data working as a poka-yoke, so there is no chance to bypass the system (M. Kumar et al., 2018).

Table 6 Novel Poka-Yoke with I4.0 Approaching

Researcher	Brief Description
(Hoellthaler et al., 2019), Germany	Digitalization of various methods and tools (including Poka-Yoke) will look forward as Industry 4.0 concepts.
(Ahmed et al., 2019), Australia	SVPD (Smart Virtual Product Development) enhances quality and time as I4.0 concepts, Poka-yoke is one of the enablers.
(Qeshmy et al., 2019), Sweden	Design Augmented Reality and Artificial Intelligent to present any error occur and avoid wrong choices.
(Pötters et al., 2018), Germany	Develop a model with shop floor simulation. This includes 5S, Poka Yoke, etc.
(Kurdve et al., 2018), Sweden	Develop a system prototype for eco-friendly building modules including fault-proofing (poka-yoke).
(Schaede et al., 2018), Germany	New integrated CNC (Computer Numeric Control) presented a promising human-error-free solution.
(M. Kumar et al., 2018), India	Cloud computerization for manufacture, particularly SME in India. Poka-yoke is used for 100% inspection.
(Tezel & Aziz, 2017), UK	The IT usage replaces conventional systems in the construction sector including a poka-yoke system for inspection and worker safety.
(Hudori et al., 2017), Indonesia	Poka-yoke method is implemented in software application: 1) Avoid errors or mistyping during data entry, 2) Warning, 3) The same template as earlier design that the operator has been familiar with to reduce misunderstanding, 4) Time saving, no manual entry.
(Rojo Abollado et al., 2017), UK	Digital workflow systems eliminate human errors, and save time. This system can overcome the actions that are late or negate other tasks.
(Bici et al., 2017), Italy	CAT&I (Computer Aided Tolerancing & Inspection) very useful in following: • Avoiding errors of measurement points. • Shape deviation analysis relevant, e.g. plastic shrinkage.
(D. Antonelli & Stadnicka, 2016), Italy	Propose a Poka-Yoke system to assist industrial problem solving by applying fuzzy logic. The mistake is detected during a production process of 1. Welding spot 2. Kitting process 3. Roller bearing seals.
(Dario Antonelli & Astanin, 2015), Italy	Sophisticated tool (Augmented-reality) is applied to improve quality by error-free.

Introducing I4.0 technologies for novel poka-yoke tools depends on several factors, i.e. usability, selective data, end-user acceptance, ethical, regional requirements, and cost. The novel poka-yoke tools should be well-considered as part of improvements.

The presented novel poka-yoke in Table 6 is not a single tool for cost reduction. This should be part of lean manufacturing, which is a more complex solution. If I4.0 facility is implemented as “nice-to-have” solutions, it can be ended with unsatisfactory results.

Based on reviewed articles, most of them try to develop a tool in conjunction with others to enhance results. Strategically, every concept can be aligned with lean. And actually there are a lot of ways for improvement like Condition-based monitoring that are integrated with a Maintenance database system, remote visual management, cloud computing, etc. (Mayr et al., 2018)

Based on organizational practices, lean tools that can be adopted successfully in a common industry are: standardization, control, training / learning, team-based organization, employee empowerment, adaptability, reward system, belief, commitment, communication, work methods, etc. (Lazarevic et al., 2019).

4. Conclusion

Implementation of I4.0 concept as a novel poka-yoke tool is an encouraged part of lean strategy. As for I4.0 perspective, everything is digital; business models, production systems, machines, operators, products and services. However, this must consider many factors, i.e. respective regional condition, social aspect, regulation and internal organization requirement with regard to business process and cost-effectiveness and the most important is its functionality that appropriates with a respective industry. Otherwise, it will undoubtedly end in dissatisfaction. There is a rule of thumb that the industry needs to measure their efforts of poka-yoke implementation as performance measurement. Organizations need to conduct the right measures and then make encouragements if there is a wrong direction of chosen approaching. However, that information is hard to get, and only specific articles provide measurement values. For future research, production effectivity metrics need to be developed to justify the performance value before poka-yoke approaching against post-implementation.

Acknowledgement: The paper is a part of quality engineering study project in Mercu Buana University Jakarta, Indonesia.

References

Ahmed, M. B., Sanin, C., & Szczerbicki, E. (2019). Smart virtual product development (SVPD) to enhance product manufacturing in industry 4.0. *Procedia Computer Science*, *159*(2018), 2232–2239. https://doi.org/10.1016/j.procs.2019.09.398

Alghozali, F. I., Jamaludin, R., & Bahaudin, A. Y. (2016). Enhancing Quality of Service: A Conceptual Poka-Yoke Approach. *Journal of Technology and Operations Management*, *11*(2), 47–56.

Antonelli, D., & Stadnicka, D. (2016). Classification and efficiency estimation of mistake proofing solutions by Fuzzy Inference. *IFAC-PapersOnLine*, *49*(12), 1134–1139. https://doi.org/10.1016/j.ifacol.2016.07.651

Antonelli, D., & Stadnicka, D. (2019). Predicting and preventing mistakes in human-robot collaborative assembly. *IFAC-PapersOnLine*, *52*(13), 743–748. https://doi.org/10.1016/j.ifacol.2019.11.204

Antonelli, Dario, & Astanin, S. (2015). Enhancing the quality of manual spot welding through augmented reality assisted guidance. *Procedia CIRP*, *33*, 556–561. https://doi.org/10.1016/j.procir.2015.06.076

Ardi, S., & Abdurrahman, H. (2017). Design of pokayoke systems to increase the efficiency of function check oxygen sensor machine using programmable logic controller in manufacturing industry. *Proceedings - 2017 4th International Conference on Information Technology, Computer, and Electrical Engineering, ICITACEE 2017*, *2018-Janua*, 192–196. https://doi.org/10.1109/ICITACEE.2017.8257701

Ardi, S., Nurdin, M. A. R., & Ponco, A. (2018). Design of pokayoke system on the process of mounting actuator bracket based on programmable logic controller in automotive manufacturing industry. *MATEC Web of Conferences*, *197*, 4–7. https://doi.org/10.1051/matecconf/201819714014

Attia, E., Khader, K., & Nada, O. (2019). Mistake Proofing Cam Mechanism Through Six-sigma Process: Case Study on Clothes Printing Machines. *International Journal of Engineering*, *32*(3), 438–444.

Bajjou, M. S., & Chafi, A. (2018). Lean construction implementation in the Moroccan construction industry. *Journal of Engineering, Design and Technology*, *16*(4), 533–556. https://doi.org/10.1108/JEDT-02-2018-0031

Bici, M., Broggiato, G. B., Campana, F., & Dughiero, A. (2017). Computer Aided Inspection Procedures to Support Smart Manufacturing of Injection Moulded Components. *Procedia Manufacturing*, *11*(June), 1184–1192. https://doi.org/10.1016/j.promfg.2017.07.243

Che-Ani MN., AS., S., IA, A., & S., K. (2017). Solving Production Processes Disparity Issue through Implementation of Poka-Yoke Concept. *International Journal of Materials, Mechanics and Manufacturing*, *5*(4), 278–281. https://doi.org/10.18178/ijmmm.2017.5.4.333

Dahivale, R. P., & Lokhande, H. (2020). Operational process improvement by eliminating rejections and avoiding scrap by implementing “poka-Yoke.” *Our Heritage UGC Care Listed Journal*, *68*(49), 46–52.

Dawood, S. A., Elsayed, E. A., Rahaman, A., & Karthikeyan, R. (2018). Role of Lean Manufacturing Tools in Soft Drink Company. *SSRG International Journal of Mechanical Engineering*, *5*(1), 1–7.

Erdogan, S., Quesada-Pineda, H., & Bond, B. (2017). An empirical tool to measure the effectiveness of Kaizen events: A case study in the wood products industries. *Forest Products Journal*, *67*(3–4), 164–178. https://doi.org/10.13073/FPJ-D-16-00044

Fauzan, M. R., Poeri, P., Iqbal, M., & Defect, W. (2016). Usulan Perbaikan Proses Pencetakan Motif Pada Kain Grey Untuk Meminimasi Waste Defect Di Pt. Kharisma Printex Dengan Pendekatan Lean Manufacturing Improvement Proposal of Motifs Printing Processing At Pt Kharisma Printex for Minimizing Waste Defect Using. *E-Proceeding of Engineering*, *3*(2), 2974–2981.

Gavriluţă, A., Niţu, E. L., Gavriluţă, A., Anghel, D. C., Stănescu, N. D., Radu, M. C., CreȚu, G., BiriȘ, C. M., & Păunoiu, V. (2018). the Development of a Laboratory System To Experiment Methods To Improve the Production Flows. *Proceedings in Manufacturing Systems*, *13*(3), 127–132. https://search.proquest.com/docview/2137835746?accountid=26642%0Ahttp://link.periodicos.capes.gov.br/sfxlcl41?url_ver=Z39.88-

2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Aengineeringjournals&atitle=THE+DEVELOPMENT+OF+A+LABORA

Hoellthaler, G., Braunreuther, S., & Reinhart, G. (2019). Requirements for a methodology for the assessment and selection of technologies of digitalization for lean production systems. *Procedia CIRP*, *79*, 198–203. https://doi.org/10.1016/j.procir.2019.02.046

Hudori, M., Simanjuntak, J. M., & Belakang, L. (2017). Poka Yoke untuk Pembuatan Palet Package Information di Bagian Shipping. *Industrial Engineering*, *6*(1), 16–21.

Isnain, S. K., & Karningsih, P. D. (2016). Perancangan Perbaikan Proses Produksi Komponen Bodi Mobil Daihatsu dengan Lean Manufacturing di PT. "XYZ." *Jurnal Studi Manajemen Dan Bisnis*, *3*(2), 144–156.

Kumar, B., & Kumar, P. (2017). Implementation of Poka Yoke in Needle Bearing Assembly Process. *International Journal of Engineering Science Invention*, *6*(11), 1–10.

Kumar, M., Vaishya, R., & Parag. (2018). Real-time Monitoring System to Lean Manufacturing. *Procedia Manufacturing*, *20*, 135–140. https://doi.org/10.1016/j.promfg.2018.02.019

Kumar, S., Dhingra, A., & Singh, B. (2018). Lean-Kaizen implementation: A roadmap for identifying continuous improvement opportunities in Indian small and medium sized enterprise. *Journal of Engineering, Design and Technology*, *16*(1), 143–160. https://doi.org/10.1108/JEDT-08-2017-0083

Kurdve, M. (2018). Digital assembly instruction system design with green lean perspective-Case study from building module industry. *Procedia CIRP*, *72*, 762–767. https://doi.org/10.1016/j.procir.2018.03.118

Kurdve, M., Hildenbrand, J., & Jönsson, C. (2018). Design for green lean building module production - Case study. *Procedia Manufacturing*, *25*, 594–601. https://doi.org/10.1016/j.promfg.2018.06.096

Kurhade, A. J. (2015). Review on "Poka-Yoke: Technique to Prevent Defects." *International Journal Of Engineering Science & Research Technology*, *4*(11), 652–659.

Lazarevic, M., Mandic, J., Sremcev, N., Vukelic, D., & Debevec, M. (2019). A systematic literature review of poka-yoke and novel approach to theoretical aspects. *Strojniski Vestnik/Journal of Mechanical Engineering*, *65*(7–8), 454–467. https://doi.org/10.5545/sv-jme.2019.6056

Lemahieu, P. G., Nordstrum, L. E., & Greco, P. (2017). Lean for education. *Quality Assurance in Education*, *25*(1), 74–90. https://doi.org/10.1108/QAE-12-2016-0081

Lilja, E. (2018). *Poka-yoke design of rubber rail for holding and transversal sealing of packages*. 1–57.

Malega, P. (2018). Poka – Yoke – solution to human errors in the production process. *International Journal of Business Management and Technology*, *2*(5), 207–213.

Mayr, A., Weigelt, M., Kühl, A., Grimm, S., Erll, A., Potzel, M., & Franke, J. (2018). Lean 4.0-A conceptual conjunction of lean management and Industry 4.0. *Procedia CIRP*, *72*, 622–628. https://doi.org/10.1016/j.procir.2018.03.292

Muharam, M., & Latif, M. (2019). Design of poka-yoke system based on fuzzy neural network for rotary- machinery monitoring Design of poka-yoke system based on fuzzy neural network for rotary-machinery monitoring. *Materials Science and Engineering*, 1–9. https://doi.org/10.1088/1757-899X/602/1/012003

Pötters, P., Schmitt, R., & Leyendecker, B. (2018). Total Quality Management & Business Excellence Effectivity of quality methods used on the shop floor of a serial production – how important is Poka Yoke? *Total Quality Management*, *29*(10), 1200–1212. https://doi.org/10.1080/14783363.2018.1488559

Prayogi, E., Setiadi, D. K., Pancasila, U., & Teknik, F. (2018). Perancangan Sistem Pokayoke Untuk Part Smart Key Pada Proses Perakitan Mobil di PT. XYZ. *Seminar Rekayasa Teknik*, 575–583.

Putri, D. R., & Handayani, W. (2019). Zero Defect Pada Produksi Kantong Kraft Melalui Metode Poka Yoke Di Pt. Industri Kemasan Semen Gresik. *Jurnal MEBIS (Manajemen Dan Bisnis)*, *4*(1), 44–58. https://doi.org/10.33005/mebis.v4i1.52

Qeshmy, D. E., Makdisi, J., Da_Silva, E. H. D. R., & Angelis, J. (2019). Managing Human Errors: Augmented Reality Systems as a tool in the quality journey. *Procedia CIRP*, *28*, 24–30. https://doi.org/10.1016/j.promfg.2018.12.005

Rojo Abollado, J., Shehab, E., & Bamforth, P. (2017). Challenges and Benefits of Digital Workflow Implementation in Aerospace Manufacturing Engineering. *Procedia CIRP*, *60*, 80–85. https://doi.org/10.1016/j.procir.2017.02.044

Romero, D., Gaiardelli, P., Powell, D., Wuest, T., & Thürer, M. (2019). Rethinking jidoka systems under automation & learning perspectives in the digital lean manufacturing world. *IFAC-PapersOnLine*, *52*(13), 899–903. https://doi.org/10.1016/j.ifacol.2019.11.309

Rösiö, C., Aslam, T., Srikanth, K. B., & Shetty, S. (2019). Towards an assessment criterion of reconfigurable manufacturing systems within the automotive industry. *Procedia Manufacturing*, *28*, 76–82. https://doi.org/10.1016/j.promfg.2018.12.013

Rubio-Romero, J. C., & Pardo, C. (2019). Poka-Yokes as Occupational Preventive Measures in Construction Safety. A Review. *Nature*, 556–562.

Saputra, T. M., Hernadewita, H., Yudha, A., & Saputra, P. (2019). Quality Improvement of Molding Machine through Statistical Process Control in Plastic Industry. *Journal of Applied Research on Industrial Engineering*, *6*(2), 87–96. https://doi.org/10.22105/jarie.2019.163584.1068

Satolo, E. G., Leite, C., Goes, G. A., & Salgado, D. D. A. (2018). Ranking lean tools for world class reach through grey relational analysis. *Grey Systems: Theory and Application*, *8*(4), 399–423. https://doi.org/10.1108/GS-06-2018-0031

Schaede, C., Seifermann, S., & Metternich, J. (2018). Automated generation of CNC programs for manufacturing of individualized products. *Procedia CIRP*, *72*, 1251–1257. https://doi.org/10.1016/j.procir.2018.03.064

Selvam, R., & Loganathan, G. B. (2019). Product detail and analysis of hydraulic quick releasing coupling. *Materials Today: Proceedings*, *22*, 751–755. https://doi.org/10.1016/j.matpr.2019.10.081

Shrigadi, S. S., Pol, S. P., & Joshi, A. K. (2015). Poka-Yoke: Mistake Proofing To Achieve Zero Defects. *International Journal of Innovation in Engineering, Research and Technology (IJIERT)*, 1–6.

Singh, J., & Singh, H. (2015). Performance Enhancement of a Manufacturing Unit of Northern India Using Continuous Improvement Strategies — A Case Study. *Productivity*, *56*(1), 88–96.

Solaimani, S., & Sedighi, M. (2020). Toward a holistic view on lean sustainable construction: A literature review. *Journal of Cleaner Production*, *248*, 119213. https://doi.org/10.1016/j.jclepro.2019.119213

Soni, P., & Yadav, T. (2018). Review Paper on "Productivity Improvement by using Poka-Yoke." *IRJET*, *5*(12), 761–763.

Sundaramali, G., Abinav Shankar, S., & Manoj Kummar, M. (2018). Non-conformity recovery and safe disposal by Poka Yoke and hallmarking in a piston unit. *International Journal of Productivity and Quality Management*, *24*(4), 460–474. https://doi.org/10.1504/IJPQM.2018.093445

Tak, P. D., & Wagh, S. S. (2015). Poka Yoke Implementation on Punching Machine: a Case Study. *International Journal of Research in Engineering and Technology*, *04*(02), 98–106. https://doi.org/10.15623/ijret.2015.0402014

Tezel, A., & Aziz, Z. (2017). Benefits of visual management in construction: cases from the transportation sector in England. *Construction Innovation*, *17*(2), 125–157. https://doi.org/10.1108/CI-05-2016-0029

Thareja, P. (2016). Poka Yoke: Poking into Mistakes for Total Quality! *OmniScience: A Multi-Disciplinary Journal*, *6*(2), 1–8.

Vinayagasundaram, R. Velmurugan, C. (2018). IMPLEMENTATION OF ZERO DEFECT THROUGH POKA YOKE APPROACHES. *International Journal of Pure and Applied Mathematics*, *119*(17), 2319–2332.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 84-100
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303085k

MODELS FOR RANKING RAILWAY CROSSINGS FOR SAFETY IMPROVEMENT

Sandra Kasalica [1]*, Marko Obradović [2], Aleksandar Blagojević [1], Dušan Jeremić [1], Milivoje Vuković [3]

[1] Academy of Technical and Art Applied Studies Belgrade,
department High Railway School, Belgrade, Serbia
[2] Faculty of Mathematics, University of Belgrade, Belgrade, Serbia
[3] Infrastructure of Serbian Railways, Belgrade, Serbia

Received: 20 August 2020
Accepted: 11 November 2020
First online: 15 November 2020

Original scientific paper

Abstract: *Analysis of high-risk locations, accident frequency and severity for railway crossing is necessary in order to improve the safety and consequently diminish the number of accidents and their severity. In order to extract the necessary parameters that quantify the risk associated with railway crossings in Serbia, we have carefully analyzed available statistical models commonly used in this kind of studies. A zero-inflated Poisson model and a multinomial logistic model were used for the assessment of accident frequency and accident severity respectively. In order to quantitatively evaluate the risk, a well known measure – total risk was modified and a new measure for risk – empirical risk was introduced. The road sign warning device* ($p = 2.76 \cdot 10^{-9}$)*, exposure to traffic* ($p = 4.3 \cdot 10^{-7}$)*, and maximum train speed at a given crossing* ($p = 1.36 \cdot 10^{-5}$) *were significantly associated with probability of accident frequency and significantly influenced the expected total number of fatalities or injuries caused by traffic accidents.*

Keywords: *railway crossings, high-risk locations, accidents, regression models*

1. Introduction

The identification of the high-risk railway crossings in Serbia is of great importance because, to our knowledge, no such study has been performed in the past. For example, from 2007 to 2011, 312 accidents occurred at 2,138 railway crossings in Serbia. These accidents resulted in 59 fatalities and 130 injuries (Statistics on accidents at Serbian railways 2011). Currently, more than 74% of the 2,138 railway crossings in Serbia are of passive control type (St. Andrew's cross and Stop sign). From 2004 to 2012, only 22 railway crossings were equipped with an

sandra.kasalica@gmail.com (S. Kasalica)*, relzzup@gmail.com (M. Obradović), aleksandar.blagojevic23@gmail.com (A.Blagojević), jeremicd@gmail.com (D. Jeremić), milivoje.vukovic1962@gmail.com (M.Vuković),

active control type (flashing lights with half gates). Along with a control type, other railway crossing factors (e.g., train frequency, train speed, daily road traffic, sight triangle, crossing width and angle) might increase the likelihood of accident occurring at railway crossings. Therefore, investigations of the risk factors that may be associated with accidents at railway crossings are vital in order to identify the crossings for future safety improvement.

Statistical regression models are formulated to express the expected accident count of an entity as a function of its traits. Because of non-negative and count data nature of accident frequency for a time period, the Poisson or negative binomial (NB) models and their variants are developed to model crash or accident frequency, or both, at spatial locations on highways (Miaou, 1994; Persaud et al., 1999; Lord et al., 2005). The NB was verified by (Austin & Carson, 2002). Saccomanno et al. (2004) used Poisson and NB distribution in their risk based statistical models which were also used for identifying the high-risk railway crossings. Extensions of these two models are a zero-inflated Poisson (ZIP) regression model and a zero-inflated negative binomial (ZINB) regression model which have also been utilized for modeling accident data on railway crossings (Miranda-Moreno & Fu, 2006). Three alternative models - the NB model, the heterogeneous negative binomial (HNB) model, and the Poisson lognormal model and two ranking criteria - marginal and posterior mean of accident frequency are considered in a study by Miranda-Moreno et al. (2005) for identification of the high-risk railway crossings. Similarly, Miranda-Moreno et al. (2009) proposed a Bayesian multinomial model to estimate the severity levels of each individual involved in an accident. The generalized logit model was used to explore the key factors that may be responsible for different degrees of accident severity at railway crossings (Huet et al., 2010). A ZIP model was used to describe the relationship between the extra zero count fatality or injury data and explanatory variables on railway crossings in Taiwan (Hu et al., 2011). Rovšek et al. (2014) identified the key risk factors of traffic accident injury severity on Slovenian roads using a non-parametric classification tree. Recently, Washington et al. (2014) applied a quintile regression model for identifying black spots. Moreover, they proposed a more complex formula for modeling a number of crashes based on equivalent property damage crashes.

This paper is the first attempt to analyze accident data using count data and multinomial regression in Serbia and countries in our region. Due to the fact that we have gathered the unique set of the data, we believe that the analyses will serve not only to identify unsafe railway crossings but also additionally verify the methodology used.

Four types of regression models are considered for accident frequency and empirical risk: Poisson, NB, ZIP and ZINB. The analysis of accident severity was performed using a multinomial logit model. The high-risk locations were determined using total risk analysis (Saccomanno et al., 2003). Finding out that variables of accident frequency and accident severity are slightly correlated, we also introduced a new risk measure - empirical risk. The final high-risk location was created using both of these methods.

2. Data source and description

2.1. Inventory data set

The data supporting this research came from two sources; (1) the Serbian railway crossing inventory database (2007-2011) (SRCID) and (2) Accident database of Serbian railway crossings (2007-2011) (ADSRC). The second one is the first database of this kind in Serbia, and we created it for the purpose of this very research.

SRCID contains the characteristics of each railway crossing and its traffic conditions. On the territory of the Republic of Serbia, the railway network has the total length of about 4,000 km, out of which 276 km are multiple tracks and 934 km are electrified. There are 2,138 railway crossings in total. All these crossings have various warning devices.

Certain numbers of crossings were found to be poorly specified. Namely, some attributes associated with railway and highway features and traffic exposure with regard to the number of daily trains and average annual daily traffic (AADT) were missing. In the present study, we have excluded the crossings with incomplete data. In order to avoid possible selection bias, we have carefully analyzed distributions of the excluded crossings and found no significant statistical grouping (see Appendix). The final set was compiled by merging SRCID and ADSRC databases and it consisted of 745 railway crossings.

There were 17 independent variables considered in this study for modeling purpose and they were derived from the SRCID (Table 1).

They can be classified as follows:

- railway characteristics: railway category, maximal train speed at a given crossing and number of tracks.
- traffic volume: Exposure (EXPO) at a given crossing is defined as the geometric mean of number of trains per day and average annual daily traffic volume (AADT).
- crossing characteristics: crossing surface type, crossing width, sight triangle and crossing angle.
- road characteristics: road category mainline, road category regional, road category rural and local, road category farm and non-categorized and road category street.
- warning devices: road signs, flashing lights, full gates and half gates.

Table 1. Independent variables and their characteristics

Variable	Short name	Description	Coding / Unit
x_1	KATPRM	Railway category	Mainlines =1; Others =0
x_2	EXPO[b]	Sqrt [AADT · daily trains]	vehicles/day
x_3	MBRZ[b]	Maximal train speed at a given crossing	km/h
x_4	BRKOLB	Number of tracks	Single track = 1; Multiple tracks = 0
x_5	VRKOLA	Crossing surface type	asphalt, concrete panels and rubber panels = 1; cobblestone, wood planks and gravel = 0
x_6	KPM	Road category mainline	Indicator

x_7	KPR	Road category regional	Indicator
x_8	KPSL	Road category rural and local	Indicator
x_9	KPPNP	Road category farm and non-categorized	Indicator
x_{10}	KPU	Road category street	Indicator
x_{11}	SIRPPB	Crossing width	6m or less = 1; more than 6m = 0
x_{12}	TRPRP	Sight triangle	exist = 1; does not exist = 0
x_{13}	UGUKR	Crossing angle	From 60° to 90° = 1; less than 60° = 0
x_{14}	VOSIG	Warning devices road signs	Indicator
x_{15}	VOSV	Warning devices flashing lights	Indicator
x_{16}	VOBR	Warning devices full gates	Indicator
x_{17}	VROSP	Warning devices half gates	Indicator

Note: All variables are categorical except EXPO and MBRZ which are numerical;
a The mainline includes reference and intermediate lines and others are supplementary lines.

b In order to get more convenient coefficients for the models, the observed values for maximum train speed at a given crossing and daily traffic volume were divided by ten.

2.2. Accident occurrence data

The available historical accident data-set for modeling accidents at railway crossings were collected from 2007-2011 (5 years of accident information). The data-set provides the information about the time, location and conditions of accident for 2,138 railway crossings, but we observed 745 crossings.

The Accident database of Serbian railway crossings (2007-2011), contains four types of information:

- basic accident data: including the accident reference number, the date and the time of accident, location and cause of accident.
- involved road vehicle driver, vehicle and train data: including information on road vehicle driver action at time of collision (e.g., ignored warning devices, drove through gates, failed to stop), gender and age, visibility, vehicle type and train type. It should be noted that our data lacked the information about the train operator.
- accident type: a road vehicle was hit by a train or a train was hit by a road vehicle.
- data on severity of consequences: including information on the number of fatalities, serious injuries and a property damage-level for each accident.

In this paper, we considered three dependent variables: accident frequency, accident severity and empirical risk. The accident frequency is the number of accidents that took place at a given time period. It is a countable variable that, in our observations, takes values from 0 to 5. The frequency of these values is given in

Table 2. It represents the number of accidents that took place at observed 745 crossings in the period from 2007 through 2011. In this period of time, at 514 (69%) crossings there were no accidents, and at the remaining 231 (31%) crossings there were 312 accidents in total.

Accident severity is defined as an average impact per accident. The average impact is a weighted average of deaths and injuries in each accident. In this paper, the accident severity is characterized as equivalent fatality. For example, Saccomanno et al. (2004) equalized one fatality to 44 injuries to yield a crossing collision consequence score (CS) for the purpose of further crash severity modeling. In Taiwan, one injury from a highway accident has been equalized to 0.37 fatalities, or conversely, a fatality has been treated as 2.72 injuries (Hu et al., 2010). Similarly, we equalized three injuries as an equivalent of one death. The factor 3 was chosen out of practical considerations and matches the regulations for personal compensation stated in the Regulation on personal compensation (Official Gazette of the Republic of Serbia, no. 34/2010). Therefore, the formula for accident severity becomes:

$$\text{Accident severity} = (3 \times \text{fatalities injuries})\ /\text{accident frequency} \tag{1}$$

This dependent variable is further categorized into three levels: 0 (0 accident severities), 1 (less than 3 accident severities), and 2 (3 or more accident severities). In other words, accident severity is 0 if there were no injuries or fatalities, it takes value 1 if there were less than 3 injuries (or 1 fatality) per accident, and it takes value 2 if there were 3 or more injuries (or 1 fatality) per accident. The frequency of these values is given in Table 2.

The empirical risk is defined as a weighted sum of number of fatalities and the number of injuries. Once again, three injuries were considered an equivalent of one fatality. Consequently, empirical risk is defined as follows:

$$\text{Empirical risk} = (3\ \times\ \text{fatalities}) +\ \text{injuries} \tag{2}$$

The observed empirical risk frequency is shown in Table 2. In our sample, the empirical risk takes values from 0 to 14.

Table 2. Observed accident frequency, accident severity frequency and empirical risk frequency of Y=y

Accident frequency level	Observed frequency	Accident severity level	Observed frequency	Empirical risk level	Observed frequency
$y = 0$	514	$y = 0$	633	$y = 0$	633
$y = 1$	180	$y = 1$	72	$y = 1$	45
$y = 2$	35	$y = 2$	40	$y = 2$	18
$y = 3$	6			$y = 3$	31
$y = 4$	6			$y = 4$	3
$y \geq 5$	4			$y \geq 5$	15

3. Developed models regarding crossing accidents

3.1. Accident frequency model

The review of the prior research for the accident frequency modeling helped us find the most suitable model. Four types of regression models are considered: Poisson, NB, ZIP and ZINB. In our analysis, we included 17 independent variables shown in Table 1. The outcome variable was accident frequency at railway crossings in the period from 2007 to 2011, (Table 2).

For the comparison of two non-nested models, the Vuong test was used (Washington et al., 2003; Miranda-Moreno & Fu, 2006). Results of three Vuong's tests are presented in Table 3.

Table 3. The comparison of models with Vuong's statistic

First model	Second model	Value of $\lvert V \rvert$	p value	Better model
Poisson	NB	$\lvert V \rvert = 3.60$	$p = 1.70 \cdot 10^{-6}$	NB
NB	ZIP	$\lvert V \rvert = 5.84$	$p = 2.56 \cdot 10^{-9}$	ZIP
ZIP	ZINB	$\lvert V \rvert = 2.15$	$p = 0.016$	ZIP

The ZIP model was chosen for modeling accident frequencies (p = 0.016). The particular ZIP model considered in this study has the following form (Lambert, 1992):

$$P(Y_i = y_i) = p_i + (1 - p_i)e^{-\lambda_i} \quad \text{if} \quad y_i = 0$$

$$P(Y_i = y_i) = (1 - p_i)\frac{e^{-y_i}\lambda^{y_i}}{y!} \quad \text{if}\, y_i = 1, 2, 3, \ldots \tag{3}$$

where p_i is the probability of being in the zero state and y is the number of events per period.

The coefficients for the final ZIP model are presented in Table 4. The model was obtained using the function zero-infl from the R-package (Zeileis et al., 2008). Eight independent variables out of 17 were found to be of significance for the model.

The variables regarding the warning device have been shown to be significant. The ZIP model chose two out of four dummy variables, namely road signs (VOSIG) $p = 2.76 \cdot 10^{-9}$ and full gates (VOBR) $p = 1.23 \cdot 10^{-5}$. The half gates variable (VROSP) here acts as a reference variable and the flashing light signal (VOSV) was excluded from the model probably because of lack of enough crossings with this type of device. This means that the probability number of accidents at crossings with road signs, which is the most common type of site protection, is higher than on reference (half gates) crossings. The full gates device has a negative coefficient, which shows us that they are superior to half gates regarding accident prevention. The prevalence of passive control devices may be attributed to a large number of sites with low traffic and train volumes for which the cost of upgrading to automated devices is not justifiable from a cost-benefit analysis in terms of the projected accident reductions at these sites (Ehrlich, 1989). One would suspect that the presence of gates would predictably result in fewer accidents, and the model estimation process did in fact result in a positive effect for the presence of half gate. The gates provide a physical blockade that serves as a deterrent to crossing, but is also cost prohibitive for implementation at all sites. Also, according to Wigglesworth & Uber (1991), upgrading crossings with flashing light to boom barrier status reduce fatal accidents at crossings. However, many accidents are caused by vehicles running through a crossing to beat a train, occasionally around gates that are deployed (Caird et al., 2002; Cooper & Ragland, 2012). And indeed, automated control devices are not faultless. For example, automated signal control devices are susceptible to false alarms and excessive warning times, which may lead driver to rely on their own hazard judgment and ignore the signal, as well resorting to risky behavior by circumventing the lowered gates (Leibowitz, 1985; Meeker & Barr, 1989).

Table 4. ZIP accident prediction model result

Description	Independent variable	Estimated coefficients	Standard error	z–statistic	$P_r(>\|z\|)$
	Model count				
Intercept	Constant	-1.668	0.287	-5.823	5.78e-09 ***
Road signs	VOSIG	0.984	0.166	5.945	2.76e-09 ***
Full gates	VOBR	-1.394	0.319	-4.373	1.23e-05 ***
Crossing width	SIRPPB	-0.530	0.155	-3.416	0.001 ***
Sqrt[AADT · daily trains]	EXPO	0.020	0.005	4.320	1.56e-05 ***
Maximal train speed	MBRZ	0.122	0.028	4.350	1.36e-05 ***
Number of tracks	BRKOLB	-0.370	0.180	-2.053	0.040 *
Crossing surface type	VRKOLA	-0.228	0.137	-1.662	0.096 .
Farm and non-categorized road	KPPNP	0.188	0.147	1.285	0.199
Log (theta)		-1.322	0.167	-7.896	2.87e-15 ***
	Model zero				
Intercept	Constant	-1.160	1.626	-0.713	0.476
Road signs	VOSIG	2.012	1.293	1.556	0.120
Full gates	VOBR	-0.580	2.786	-0.208	0.835
Crossing width	SIRPPB	-22.424	1203.8	-0.019	0.985
Sqrt[AADT · daily trains]	EXPO	-0.058	0.060	-0.969	0.333
Maximal train speed	MBRZ	0.078	0.142	0.546	0.585
Number of tracks	BRKOLB	0.462	1.069	0.432	0.665
Crossing surface type	VRKOLA	-3.860	1.233	-3.132	0.002 **
Farm and non-categorized road	KPPNP	3.771	1.135	3.321	0.001 ***
Log-likelihood: -509.4 on 18 Df AIC: 1054.79					

Level of significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Two different traffic characteristics proved to be significant in affecting the railway crossing accident frequency. The exposure (EXPO) coefficient is positive ($p = 4.3 \cdot 10^{-7}$). The numbers of trains and road vehicles are often first variables that are considered in developing a model for accident prediction (Austin & Carson, 2002; Saccomanno et al., 2004; Miranda-Moreno et al., 2005). The higher the traffic volume, the more vehicles are exposed to risky situations with incoming trains, which enlarges the accident probability. According to Austin & Carson (2002), higher numbers of trains and the AADT were found to increase a railway crossing accident frequency.

The maximum train speed at a given crossing (MBRZ) is also associated with a higher predicted accident frequency ($p = 1.36 \cdot 10^{-5}$). This is consistent with Austin & Carson (2002), the higher the defined maximum train speed, the higher the predicted accident frequency. As the train speed increases, the stopping distances of trains extend, and the time available for driver to spot the obstacle and stop the train decreases. On the other hand, difficulties that the drivers of vehicles have, concerning speed and distance of incoming train, are known (Leibowitz, 1985; Meeker et al., 1997; Meeker & Barr 1989; Kasalica et al., 2012), and as the train speed increases, the time the driver has got to react in order to change the wrong decision to cross decreases.

The crossing width, as well as the number of tracks, has been shown to have some significance. This finding is most likely related to the earlier; higher train and traffic volumes require a greater number of tracks and traffic lanes to operate. Road surface also have some significance, but this factor seems inconsequential compared to other railway, road or crossing characteristics likely to affect railway crossing safety.

It should be noted that some crossing characteristics (crossing angle or sight triangle), as well as road category do not have observable influence on the number of accidents.

From this model, we can conclude that the best way in which safety can be improved and the number of accidents can be reduced is upgrading the warning device system. The other variables are either out of our control (maximum train speed and exposure) or do not have significant influence on the number of accidents (road category, road geometry, road surface, etc.).

3.2. Accident severity model

The analysis of accident severity is performed using a multinomial logit model. Multinomial logit models have gained popularity for this type of data mainly because they can account for the dependent variable's ordinal nature.

Let $\pi_j(\mathbf{x}) = P(Y = j; \mathbf{x})$ be the probability of $Y = j, j = 0, 1, 2$. The multinomial logit model is given as follows (Hu et al., 2010):

$$\text{logit}[\pi_j(\mathbf{x})] = \log\frac{\pi_j(\mathbf{x})}{\pi_0(\mathbf{x})} = \alpha_j + \mathbf{x}\,\beta_j, j = 1,2. \tag{4}$$

Here α_j is the intercept parameter, and $\beta_j = (\beta_{j\alpha_j 1}, \beta_{j2}, \dots, \beta_{j17})^T$ is 17- dimensional vector of regression parameters for j – the value of dependent variable. From Eq.(4), taking $\alpha_0 = 0$ and $\beta_0 = 0$, we obtain:

$$\pi_j(\mathbf{x}) = \frac{\exp(\alpha_j + \mathbf{x}\boldsymbol{\beta}_j)}{\sum_{k=0}^{2}\exp(\alpha_k + \mathbf{x}\boldsymbol{\beta}_j)}, \quad j = 0, 1, 2 \tag{5}$$

The analyses have been done using the R-function multinom (Venables & Ripley, 2002). Here, we also used the Akaike information criterion (AIC) stepwise procedure. The parameters were estimated using the maximum likelihood estimate (MLE) method. The results were presented using the function mlogic.display (Chongsuvivatwong, 2012). The coefficients for the final model accident severity are presented in Table 5.

Table 5. Multinomial logit model result for accident severity

Independent variable	Severity level (y = 1)		Confidence interval	Severity level (y = 2)		Confidence interval
	Coefficients/SE		RRR (95% CI)	Coefficients/SE		RRR (95% CI)
Intercept	-5.76	0.694***	-	-5.55	0.826***	-
VOSIG(x_{14})	1.33	0.385***	3.78(1.78,8.04)	0.65	0.428	1.92(0.83,4.44)
VOBR(x_{16})	-1.28	0.667	0.28(0.08,1.03)	-1.93	1.051	0.15(0.02,1.14)
SIRPPB(x_{11})	1.26	0.297***	3.53(1.97,6.31)	1.20	0.378**	3.33(1.58,6.98)
MBRZ(x_3)	0.22	0.068**	1.24(1.09,1.42)	0.12	0.083	1.12(0.95,1.32)
EXPO(x_2)	0.08	0.015***	1.08(1.05,1.11)	0.05	0.017**	1.05(1.02,1.09)
BRKOLB (x_4)	-0.87	0.427*	0.42(0.18,0.97)	-0.36	0.463	0.70(0.28,1.73)
KATPRM(x_1)	-0.39	0.311	0.67(0.37,1.24)	0.74	0.430	2.09(0.90,4.87)
Residual Deviance: 668.53						
AIC = 700.53						

Level of significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

These estimated results of the effects of independent variables from this model by the use of the relative risk ratio (RRR) are described in the following section.

The relative risk ratio is the ratio of probabilities of a chosen state and the reference state. In Table 5, their RRR values and 95% confidence intervals (CI) are given. The ratios given are for Y = 1 (e.g., accident severity of 1) and Y = 2 (e.g., accident severity of 2), while Y = 0 (e.g., accident severity of 0). The variables regarding the warning device have been shown to be significant. The multinomial logit model chose two out of four dummy variables, namely road signs (VOSIG) and full gates (VOBR). The half gates variable (VROSP) here acts as a reference variable.

The value for RRR of road signs (VOSIG) for accident severity of $Y = 1$ is $RRR = 3.78, 95\%$ CI $(1.78, 8.04)$, which means that upgrading road signs to reference half gates will result in a lower probability of accident severity of $Y = 1$. The value for RRR of road signs (VOSIG) for accident severity of $Y = 2$ is $RRR = 1.92, 95\%$ CI $(0.83, 4.44)$, which means that upgrading road signs to reference half gates will also result in lower probability of accident severity of $Y = 1$. However, since the RRR is smaller in the second case, we can see that the upgrading from road signs to half gates will better prevent less severe accidents than more severe ones. From the RRR values for full gates (VOBR), we can see that upgrading from half gates to full gates will result in lowering probabilities for both accident severities of $Y = 1$ and $Y = 2$. However, this is much less significant change than the one when upgrading from road signs to half gates. This finding confirms the design-related issues of this investigation. This is in an agreement with Austin & Carson (2002): "... rather than focus on design-related improvements, one may want to consider improvements in the use of warning devices at railway crossings". However, railway crossings in Serbia are not adequately equipped with modern devices which are standardized, used and are part of the National Railway Level Crossing Safety Strategy in the developed countries. In such circumstances, the safety at railway crossings in Serbia depends mostly on human and physical factors according to Reports of safety and functionality of Serbian Railways (2002-2012). According to Cairney (2003), "the form of traffic control implemented at a railway crossing greatly affects the decision that has to be made by the driver of the road vehicle on the safety of the crossings".

Regarding crossing width variable, the RRR values indicate that wider crossings have higher probabilities for accident severities for both states, $RRR =$

$3.53, 95\%$ CI $(1.97, 6.31)$ for Y = 1 and RRR = $3.33, 95\%$ CI $(1.58, 6.98)$ for Y = 2. It can be noted that this variable has about the same influence on less severe and more severe accidents.

The maximum train speed variable also has a significant influence on accident severity. The RRR value indicates that the ratio of probabilities for Y = 1 and Y = 0 will increase 1.24 times when the maximum train speed is increased by 10 km/h. The ratio of probabilities for Y = 2 and Y = 0 is increased 1.12 times when the maximum train speed is increased by 10 km/h. This means that increasing the speed of trains has not a direct impact on mortality.

The exposure to traffic also has a significant influence. For one unit increase of EXPO, the ratio of probabilities is increased RRR = 1.08 times (Y = 1) and RRR = 1.05 times (Y = 2). The exposure to traffic has been shown to be an important factor for accident prediction (Ogden, 2002; Austin & Carson, 2007; Hu et al., 2010). A higher number of trains and road vehicles, which is often found in urban areas, are shown in this paper to have an impact on high accident severity. It could be said that crossings with a higher exposure to traffic can provide higher probability of accidents and irregular behavior (Fitzpatrick et al., 1997). Also, according to Hu et al. (2010), one common characteristic found in the railway crossings with more severe accidents is that these railway crossings are usually located in urban areas where traffic exposure is relatively high, and compared to rural areas more traffic accidents are observed in these traffic busy areas.

Regarding number of tracks, the RRR indicates that the probabilities for accident severities are higher when there are multiple tracks as opposed to a single one. As for the last variable from the model, the railway category, it can be seen that the main railways have lower probabilities for accident severity of Y = 1, and higher probabilities for accident severity of Y = 2.

It can be noted that crossing parameters, such as road and railway geometry (crossing angle and sight triangle), as well as the road type, as it was the case with the ZIP model of accident frequencies, were not accepted by this model.

4. High-risk location analysis

One of the primary tasks in the development of the program for safety improvement in some parts of traffic infrastructure (e.g., road crossings or railway crossings), is to identify the locations that have a high accident risk. This process is also known as black spot identification (Saccomanno et al., 2003; Saccomanno & Lai, 2005). Identifying high-risk locations is the initial step of the process of improving safety (Persaud, 2001). This would then lead to further engineering treatment such as crossing closure or grade separation, improving the crossing geometry or upgrading warning devices to make the crossing safer.

One of the approaches to high-risk identification is based on regression models. This method uses some ranking criteria in order to sort the list of locations and identify the ones with the highest risk. Miranda-Moreno et al. (2009) proposed a Bayesian multinomial model in order to estimate the accident severity for each person involved in an accident. The total risk is defined as the product of accident frequency and its severity (Saccomanno et al., 2004; Miranda-Moreno et al., 2009).

The deaths and injuries are our main concern, so the total risk is the goal we want to achieve. Two criteria are considered for estimating the total risk. The first criterion is the mean total risk for a crossing obtained as the product of mean accident frequency and mean accident severity, given as follows:

$$\mathrm{mTR_i} = \mathrm{mFreq_i} * \mathrm{mSev_i} \tag{6}$$

where: $\mathrm{mTR_i}$ is mean total risk for crossing *i*; $\mathrm{mFreq_i}$ is mean accident frequency for crossing *i* obtained from the accident frequency model (Table 4) and $\mathrm{mSev_i}$ is mean accident severity for crossing *i* obtained from the accident severity model (Table 5). The second criterion presented here is based on the empirical risk model. The estimate for total risk for a crossing *i* would be the mean empirical risk (mERi). The reason for introducing this additional criterion is that in our data the variables accident frequency and accident severity are slightly correlated ($R = 0.36$).

Similar to what was done for modeling accident frequency; we tried different count data regression models for empirical risk modeling. Four types of models are considered: Poisson, NB, ZIP and ZINB. Those models were obtained using the stepwise AIC. Obtained models were then compared using Vuong's test (Table 6).

Table 6. The comparison of models with Vuong's statistic

First model	Second model	Value of |V|	p value	Better model
Poisson	NB	$\|V\| = 4.60$	$p = 1.70 \cdot 10^{-6}$	NB
NB	ZINB	$\|V\| = 4.30$	$p = 8.34 \cdot 10^{-6}$	ZINB
ZIP	ZINB	$\|V\| = 1.98$	$p = 0.029$	ZINB

The comparison with Vuong's test showed significant difference ($p = 0.029$) between zero inflated Poisson (ZIP) and zero inflated negative binomial (ZINB), which means that overdispersion is not only caused by excess of zeros, but there is another source of overdispersion. Suppose y is a discrete random variable consisting of the counts on n subjects, $y_1, y_2, \ldots, y_n$. Observations that go into structural zeros ($y_i = 0$) have a degenerate distribution at zero with a probability of occurring is p. While the observations included in the NB counts ($y_i = 0, 1,2 \ldots$) 2, follow a negative binomial distribution with probability of occurring is $(1 - p)$. Therefore, Y is ZINB distributed, which is defined by:

$$Y = \begin{cases} \mathit{structural\ zeros}, & \text{with probability } p \\ \mathit{counting\ process}, & \text{with probability } 1 - p \end{cases} \tag{7}$$

Based on the probability function of the zero-modified distribution, then probability mass function (pmf) for ZINB distribution is (Garay et al., 2015):

$$P_r(Y = y) = \begin{cases} p + (1-p)\left(\frac{\emptyset}{\mu + \emptyset}\right)^{\emptyset}, & y = 0 \\ (1-p)\frac{\Gamma(y + \emptyset)}{\Gamma(y+1)\Gamma(\emptyset)}\left(\frac{\emptyset}{\mu + \emptyset}\right)^{\emptyset}\left(\frac{\mu}{\mu + \emptyset}\right)^{y}, & y = 1,2,\ldots \end{cases} \tag{8}$$

where $(\emptyset)^{-1}$, μ and $\Gamma(.)$ represent a dispersion parameter, mean, and gamma function, respectively.

The estimated parameters of the ZINB model for empirical risk are given in Table 7.

Table 7. ZINB accident prediction model result for empirical risk

Description	Independent variable	Estimated coefficients	Standard error	z - statistic	$P_r(>\|z\|)$
	Model count				
Intercept	Constant	-1.926	0.667	-2.886	0.004 **
Road signs	VOSIG	0.618	0.314	1.969	0.049 *
Full gates	VOBR	-2.121	0.520	-4.080	4.50e-05 ***
Crossing width	SIRPPB	-0.535	0.324	-1.650	0.099 .
Maximal train speed	MBRZ	0.240	0.066	3.666	2.46e-04***
Sqrt[AADT · daily trains]	EXPO	0.011	0.012	0.928	0.354
Crossing surface type	VRKOLA	-0.665	0.275	-2.416	0.016 *
Log (theta)		-1.322	0.167	-7.896	2.87e-15 ***
	Model zero				
Intercept	Constant	9.613	3.863	2.489	0.013 *
Road signs	VOSIG	-5.095	2.013	-2.531	0.011 *
Full gates	VOBR	-5.181	3.118	-1.662	0.011 *
Crossing width	SIRPPB	-7.600	1.789	-4.248	2.15e-05 ***
Maximal train speed	MBRZ	0.829	0.489	1.695	0.090 .
Sqrt[AADT · daily trains]	EXPO	-0.999	0.321	-3.115	0.002 **
Crossing surface type	VRKOLA	2.868	1.531	-1.873	0.061 .
Theta = 0.2666					
Log-likelihood: -509.4 on 18 Df					

The variable that has the highest impact on empirical risk is maximum train speed ($p = 0.000246$). Other variables of importance are road signs ($p = 0.048910$), exposure to traffic ($p = 0.353520$), crossing width ($p = 0.098971$) and road surface type ($p = 0.06110$). Therefore, the probability of the railway crossing being at risk of a fatality varied with these risk factors.

Two lists of railway crossings are compared using two methods, namely percentage deviation and the Spearman correlation coefficient. These two criteria were used in order to create a list of high-risk locations for crossings on the Serbian railway network. Based on each criterion, two lists were made. A simple way to compare the two lists is the percentage deviation. For this purpose, a certain number of top locations from both lists were selected. The percentage deviation is defined in the following way (Miranda-Moreno & Fu, 2006):

$$\% \text{ deviation} = 100 \times (1 - b/m) \quad (9)$$

where b is the number of common locations on the two lists, and m is the number of selected top locations. The percentage deviation is calculated for various thresholds (No. of crossings). The value of deviation is between 40% and 60%. It can be noted that this deviation is greater when there are shorter lists of top locations, and gradually goes down when the length of lists is increased.

The Spearman correlation coefficient is a non-parametric technique to measure the linear correlation between two variables (Miranda-Moreno et al., 2005). Here, the Spearman coefficient is calculated to measure the correlation between these two risk models. In other words, it measures the degree of matching between the two lists. It is calculated in the following way (Miranda-Moreno et al., 2005):

$$r = 1 - \frac{6 \cdot \sum_{i=1}^{n} d_i^2}{m \cdot (m^2 - 1)} \quad (10)$$

where: r is the Spearman coefficient, d_i is the difference in ranks between the two models for the same crossing i and, m is the number of selected top locations. The correlation is R = 0.50.

In Table 8, there is a list of 20 crossings that were identified as high-risk locations that were common for both estimation criteria. For each crossing it is shown how many top locations appear in both lists, as well as the value of mean total risk and mean empirical risk. In this list, we can notice that 60% of crossings are with road signs, and 40% are with half gates. The high-risk location list in Table 8 shows that most crossings, 90%, are located on main railways in urban areas. One of the possible explanations is that urban areas experience greater volume of traffic, which can cause a higher accident rate. On the other hand, the mean maximum train speed at these 20 crossings is 100 km/h, which is significantly higher than the mean maximum speed for the whole sample (70 km/h). This confirms that the maximum train speed has a more pronounced effect on the number of injuries and deaths.

Table 8. List of high-risk locations based on two criteria

First 20 high-risk locations	Crossing No.	Km position	Competent railway station	Warning devices	Mean total risk	Mean empirical risk
10	87	20+993	Batajnica	PB	4.116	2.879
10	28	7+070	Rakovica	DS	2.220	2.495
10	94	34+694	Stara Pazova	PB	1.123	2.502
20	22	253+700	Belotince	DS	1.053	2.108
20	121	74+241	Pirot	DS	1.032	1.990
20	276	252+523	Niš	DS	0.945	2.057
20	298	82+030	Sr. Mitrovica	PB	0.668	4.238
30	27	335+818	Suva Morava	DS	0.901	1.670
30	90	116+080	Šid	PB	0.831	1.573
30	164	57+306	Odžaci	DS	0.651	1.857
30	521	76+983	Ruma	DS	0.637	2.670
30	92	74+019	Voganj	PB	0.581	2.180
30	300	99+549	Sr. Mitrovica	PB	0.581	2.180
30	36	94+920	Velika Plana	DS	0.558	2.110
40	244	119+207	Vrbas	DS	0.854	1.354
40	72	31+037	Kr. Trnovče	DS	0.733	1.310
40	257	78+247	Palanka	PB	0.615	1.294
40	96	97+785	Sr. Mitrovica	DS	0.562	1.298
40	24	79+362	Palanka	PB	0.518	1.254
40	79	26+019	Loz. Saraoci	DS	0.691	1.294

Note: PB = half gates; DS = road signs; a value for a period of five years

It should be noted that many of the predicted high-risk locations were not upgraded during the analysis period, suggesting that possible high-risk crossings as predicted by the model were not considered for safety intervention.

To assess the railway crossing for safety intervention, the Serbian Railways method is based on engineering judgment supplemented by simple statistical analysis of the historical accident data. We examined the original data (first 20 locations according to the highest accident frequency and accident severity). Then, we compared the lists of predicted and historical high- risk locations. Four crossings have been found common in both lists for accident frequency, and two crossings for accident severity. In this paper, it is asserted that high-risk locations cannot be established solely on the basis of historical accident experience. This is supported by (Saccomanno et al., 2004), a longer view of accident risk is needed to reflect the expected risk over a given period of time. Such estimates can be obtained only with accurate and reliable accident frequency and severity prediction models.

5. Conclusion

Ideally, the final outcome of this work would be reducing the number or the severity of accidents at railway crossings in Serbia. In order to achieve this goal, it was important to develop a model that can be applicable to the limited data set at our disposal and to estimate the influence of various parameters contained within the data. We have considered three risk models and two criteria for the identification of high-risk locations.

Data points used in this study, i.e. accident reports and railway crossings' characteristics were extracted from two official data-bases containing actual events and site descriptions. Prior to the modeling, we had analyzed available data in order to ensure that the data sample used was truly representative.

The first considered risk model was the Accident Frequency Model. In this model, we have found that the ZIP regression model produces the best fit for the data used. The second risk model we considered was also well-known in literature – the Accident Severity Model and the Multinomial Logit regression analysis. Both mentioned models provide useful information about the risks involved. However, our needs regarding the risk assessment required some additional quantitative parameters. A novel third model – Empirical Risk Model was introduced in order to satisfy these requirements.

Two criteria for the identification and risk-ranking of the railway crossings in Serbia were presented. One criterion was calculated as a product of mean accident frequency and mean accident severity. The other criterion was obtained using the Empirical Risk Model and we suggest the name mean empirical risk for the name of this quantity.

Because crash frequency and severity jointly determine the casualty risk level at a railway crossing, one can alternatively predict the casualty risk level by using a bivariate count data model. To incorporate the accident severity and some of the key factors such as vehicle occupancy into a total risk model (Miranda-Moreno et al., 2009), the use of posterior distributions through the Bayesian approach (Miranda-Moreno & Fu, 2006; Persaud et al., 1999) has been widely recommended for identification of high-risk locations. Furthermore, an in-depth investigation on vehicle drivers' behavior at individual railway crossings, which is currently being conducted by the authors, might answer the contradictory model estimation results found in this research. These are topics that are worthy of future research.

Appendix

Analysis of the site selection criteria

The sample of 745 railway crossings out of total 2,138 is located throughout the whole network of Serbian Railways. The railway line of major international importance through Serbia (according to European agreement on main international railway lines - AGC) is reference line E70 (Croatia)–Šid–Beograd–Niš–Dimitrovgrad–(Bulgaria). On this reference line, 215 out of total of 329 railway crossings were considered. For other main lines, the numbers of included railway crossings are the following: on reference line E85 (Hungary)–Subotica–Beograd–Preševo–(Macedonia) 39 out of 68; on intermediate line E79 Beograd–Vrbnica–(Montenegro) 11 out of 30; on E66 intermediate line Beograd–Pančevo–Vršac–(Romania) 25 out of 75; on supplementary line Lapovo–Kraljevo–Kosovo Polje 42 out of 78. On other supplementary railway lines, 413 out of remaining 1,558 railway crossings were considered. Therefore, railway crossings of national and local importance, which are located both in urban and rural areas, were included. The sample of 745 railway crossings is composed of 231 (31%) railway crossings on which accidents occurred in a period 2007–2011 according to the Accident database of Serbian railway crossings (2007-2011), and also of 514 (69%) on which accidents did not occur, for which we had adequate data according to the Serbian railway crossing inventory database (2007-2011). With all the data that was at our disposal, we believe that the truncation of railway crossings with incomplete parameters was fairly random, although we cannot exclude some higher order correlations. We believe that our sample is suitable for the purpose of identifying the high-risk crossings in Serbia.

References

Austin, R. D., & Carson, J. L. (2002). An alternative accident prediction model for highway-rail interfaces. Accident Analysis and Prevention, 34(1), 31- 42.

Caird, J. K., Creaser, J. I., Edwards, C. J., & Dewar, R. E. (2002). A human factors analysis of highway-railway grade crossing accidents in Canada. Report TP 13938E, Canada Transport Development Centre, Transport Canada.

Cairney, P. (2003). Prospects of improving the conspicuity of trains at passive railway crossings. Report CR 217, Australian Transport Safety Bureau, Canberra.

Cameron, A. C., & Trivedi, P. K. (1998). Regression analysis of count data. Cambridge University Press, Cambridge, UK.

Chongsuvivatwong, V. (2012). epicalc: Epidemiological calculator. R package version 2.14.1.6. http://CRAN.R-project.org/package=epicalc.

Cooper, D., & Ragland, D. (2012). Applying safety treatments to rail-highway at grade crossings. Safe TREC. University of California, Berkeley.

Ehrlich, D. (1989). Driver behavior and decision making. Paper presented at the National Conference on Rail-Highway Safety, San Diego.

European agreement on main international railway lines (AGC). ECE/TRANS/SC.2/2006/4. Economic and Social Council. United Nations.

Fitzpatrick, K. M., Carlson, P. J., Bean, J. A., & Bartoskewitz, R. E. (1997). Traffic violation at gated highway-railroad grade crossings. Report TX-98/2987-1, Texas transportation institute, Texas department of transportation.

Garay, A. M., Lachos, V. H., Bolfarine, H. (2015), Bayesian estimation and case influence diagnostics for the zero-inflated negative binomial regression model. Journal of Applied Statistics, 42(6), 1148-1165.

Hu, Shou-Ren., Li, Chin-Shang., & Lee, Chi-Kang. (2010). Investigation of key factors for accident severity at railroad grade crossings by using a logit model. Safety Science, 48(2), 186-194.

Hu, Shou-Ren., Li, Chin-Shang., & Lee, Chi-Kang. (2011). Assessing Casualty Risk of Railroad-Grade Crossing Crashes Using Zero-Inflated Poisson Models. Journal of Transportation Engineering, 137(8), 527–536.

Kasalica, S., Vukadinović, R., & Lučanin, V. (2012). Study of drivers behaviour at a passive railway crossing. Promet - Traffic and Transportation, 24 (3), 193-201.

Lambert, D. (1992). Zero-inflated Poisson regression with an application to defects in manufacturing. Technometrics, 34 (1), 1-14.

Leibowitz, H. W. (1985). Grade crossing accidents and human factors engineering. American Scientists, 95, 558-562.

Lord, D., Washington, S. P., & Ivan, J. N. (2005). Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory. Accident Analysis and Prevention, 37(1), 35–46.

Meeker, F. L., & Barr, R. A. (1989). An observational study of driver behaviour at a protected railroad grade crossing as trains approach. Accident Analysis and Prevention, 21(3), 255-262.

Meeker, F. L., Fox, D., & Weber, C. (1997). A comparison of driver behavior at railroad grade crossings with two different protection systems. Accident Analysis and Prevention, 29(1), 11-16.

Miaou, S. P. (1994). The relationship between truck accidents and geometric design of road section: Poisson versus negative binomial regressions. Accident Analysis and Prevention, 26(4), 471-482.

Miranda-Moreno, L. F., & Fu, L. (2006). A comparative study of alternative model structures and criteria for ranking locations for safety improvements. Networks and Spatial Economics, 6: 97-110.

Miranda-Moreno, L. F., Fu, L., Saccomanno, F. F., & Labbe, A. (2005). Alternative risk models for ranking locations for safety improvement. Transportation Research Record, 1908, 1-8.

Miranda-Moreno, L. F., Fu, L., Ukkusuri, S., & Lord, D. (2009). How to incorporate accident severity and vehicle occupancy into the hotspot identification process? Paper No. 09-2824 presented at 88th Annual Meeting of the Transportation Research Board, Washington, DC.

Official Gazette of the Republic of Serbia no. 34/2010; in Serbian. Regulation on personal compensation.

Ogden, B. D. (2007). Railroad-highway grade crossing handbook: Revised second edition. FHWA-SA-07-010, Federal Highway Administration, U.S. DOT, Washington, DC.

Persaud, N.B. (2001). Statistical method in highway safety analysis: a synthesis of highway practice. NCHRP synthesis 295, Transportation Research Board, Washington, DC.

Persaud, N.B., Lyon, C., & Nguyen, T. (1999). Empirical Bayes procedure for ranking sites for safety investigation by potential for safety improvement. Transportation Research Record, 1665. 7-12.

R Development Core Team. (2012). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www. R-project.org/.

Rovšek, V., Batista, M., & Bogunović, B. (2014). Identifying the key risk factors of traffic accident injury severity on Slovenian roads using a non-parametric classification tree. Transport, 1-10.

Saccomanno, F. F., & Lai, X. (2005). A model for evaluating countermeasures at highway-railway grade crossings. Transportation Research Record, 1918. 18-25.

Saccomanno, F. F., Fu, L., & Miranda-Moreno, L. F. (2004). Risk-based model for identifying highway-rail grade crossings blackspots. Transportation Research Record, 1862. 127-135.

Saccomanno, F. F., Fu, L., Ren, C., & Miranda-Moreno, L. F. (2003). Identifying highway-rail grade crossing black spots. Report T8200-011518/001/MTB, Department of civil engineering University of Waterloo, Ontario, Canada.

Serbian Rail Administration. Accident database of Serbian railway crossings (2007-2011), Serbian Railways; in Serbian.

Serbian Rail Administration. Statistics on accidents on Serbian railways 2011; in Serbian.

Serbian Rail Administration. The Serbian railway crossing inventory database (2007-2011), Serbian Railways; in Serbian.

Serbian Rail Expert Service. Reports of Safety and Functionality of Serbian Railways. Annual reports 2002-2012; in Serbian.

Venables, W. N., & Ripley, B. D. (2002). Modern applied statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0.

Washington, S. P., Haque, M. M., Oh, J., & Lee, D. (2014) Applying quantile regression for modeling equivalent property damage only crashes to identify accident blackspots. Accident Analysis and Prevention, 66(1), 136-146.

Washington, S. P., Karlaftis, M. G., & Mannering, F. L. (2003). Statistical and econometric methods for transportation data analysis. Chapman and Hall/CRC, Washington, DC.

Wigglesworth, E. C., & Uber, C. B. (1991). An evaluation of the railway level crossing boom barrier program in Victoria Australia. Journal of Safety Research, 22(3), 133-140.

Zeileis, A., Kleiber, C., & Jackman, S. (2008). Regression models for count data in R. Journal of Statistical Software, 27(8), 1-25.

Operational Research in Engineering Sciences: Theory and Applications
Vol. 3, Issue 3, 2020, pp. 101-122
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta20303101k

EVALUATION OF THE EFFECT OF COVID-19 ON COUNTRIES' SUSTAINABLE DEVELOPMENT LEVEL: A COMPARATIVE MCDM FRAMEWORK

Sema Kayapinar Kaya

Department of Industrial Engineering, Munzur University, Tunceli, Turkey

Received: 02 November 2020
Accepted: 01 December 2020
First online: 06 December 2020

Original scientific paper

Abstract: *The extent of the outbreak of coronavirus disease (COVID-19) had a major impact on health, social life, economic and environmental activities in almost every country over the world. It has disrupted the sustainable development of countries and brought many uncertainties for their future capabilities. In this study, the effects of the COVID-19 on OECD countries' sustainable development were investigated, and the sustainable development performance of the countries was evaluated by the MultiAttributive Ideal-Real Comparative Analysis (MAIRCA) method. Data for the second quarter of 2020 and the same quarter of the previous year is considered. Then, the results obtained by the MAIRCA method were compared with two different multi-criteria decision-making (MCDM) methods called MABAC (Multi-Attributive Border Approximation Area Comparison) and WASPAS (Weighted Aggregated Sum Product Assessment). The effectiveness and validity of the results obtained from these methods were tested with Spearman's correlation coefficient. Finally, to examine the effect of COVID-19 on the indicators of sustainable development, a non-parametric Wilcoxon signed-rank test was applied. As a result, it was concluded that COVID-19 negatively affected the sustainable development of countries. However, sustainable development performances of developed countries have been observed to be better than developing countries.*

Keywords: *Pandemic, COVID-19, Sustainability, MAIRCA, Multi-Criteria Decision Making*

1. Introduction

In December 2019, Chinese Center for Disease Control and Prevention and Wuhan city health authorities reported an unknown pneumonia outbreak in Wuhan City, Hubei Province, China. On January 7, 2020, the center detected a new type of coronavirus that has never been seen in humans from the lower respiratory tract samples of patients (Wang et al., 2020; Li et al., 2020). Samples from the first patients

kysem24@gmail.com; semakayapinar@munzur.edu.tr

were tested with many known pathogens. The new type of coronavirus showed similarity to respiratory diseases such as Severe Acute Respiratory Syndrome (SARS-CoV) and Middle East Respiratory Syndrome (MERS) (Lai et al., 2020). Symptoms of the new type of coronavirus include fever, cough, shortness of breath, and dyspnea. However, these symptoms differ from person to person. While most infected people develop mild to moderate symptoms, some patients experience severe pneumonia, pulmonary edema, and multiple organ failure, leading to death.

This infectious virus has been officially named as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) by the World Health Organization (WHO). WHO used the term COVID-19 to describe the disease caused by the virus (WHO, 2020). This disease, the first case of which appeared in China in the last days of 2019, later began to occur in countries such as Japan, South Korea, and Thailand (Chen et al., 2020). The disease spread rapidly around the world in January 2020, and cases of virus began to be reported in several countries in Europe, North America, and Asia-Pacific (CDC, 2020; Hui et al., 2020; Bedford et al., 2020). On March 11, 2020, WHO declared COVID-19 as a global pandemic (WHO, 2020). At the time of writing this paper, the COVID-19 epidemic affected 213 countries and regions worldwide, infected more than 11 million 600 thousand people and the number of people who died globally has exceeded 530 thousand (COVID-19 Virus Pandemic, 2020). After WHO announced that the epicenter of the COVID-19 outbreak was Europe in the spring of 2020, the loss of life caused by COVID-19 increased in many countries, especially in Italy, France, Spain, and the United Kingdom. Again, at the time of writing this paper, it was announced by WHO that the new epicenter of COVID-19 was the continent of America and Asia. It was also reported that the pandemic risk continues largely; the USA, with more than 7 million cases, and India, with 6 million cases, have been the two countries in the world with the most COVID-19 cases. The number of deaths in both countries is increasing day by day and 200 thousand people in the USA and 96 thousand people in India died due to COVID-19 (Coronavirus Update, 2020). Although the COVID-19 pandemic was initially seen as a global health crisis, the situation has changed as the extent of the pandemic increased, and COVID-19 has become a deep political, economic, social, and environmental crisis in every country it touched. Due to the pandemic, in almost 90% of the world a wide range of social isolation and curfews have been implemented, many businesses have been closed, and domestic and international transportation services have been disrupted. Social restrictions and home isolation negatively affected many sectors especially production, health, transportation, tourism, real estate, education, energy, banking, etc. (Deloitte | Annual Turkish M&A Review, 2019). Even in the largest economies of the world, an economic contraction is foreseen that exceeds the estimates. According to International Monetary Fund (IMF) report titled "great isolation" dated April 14, 2020, the world is expected to experience the biggest global economic crisis since the "great depression" in 1929. In the report published by IMF, the growth expectation of the global economy has been revised as 3% shrinkage instead of 3.3% growth for 2020, and it is expected that global trade will decrease by 11% and oil prices by 42%. Due to the pandemic, a great decrease has occurred in the production and service sector and this made developing countries face high inflation and increasing unemployment. The gross domestic product, one of the most important economic indicators, fell by 1.8% in the OECD region in the first quarter of 2020 (World Economic Outlook, 2020).

However, it is not exactly known how dramatic the effects of the COVID-19 outbreak on the global economy will be. In The World Economic Forum report, it was stated that in addition to the economic problems, many countries would face many multidimensional problems in tourism, the housing market, demand for commercial products, transportation, unemployment, education, energy consumption, and impact on social life (World Economic Outlook, 2020). Tourism and service transportation is one of the sectors heavily hit by COVID-19. Transportation and transport activities have almost come to a halt during the quarantine process.

The World Travel and Tourism Council stated that 50 million jobs operating in the global tourism and travel industry are at risk (*News Article | World Travel & Tourism Council (WTTC)*, 2020). With the decrease in production in the pandemic period, the amount of energy needs to be decreased, as a result of which a decrease in energy production and investment was experienced. The positive aspect of the pandemic is that despite the decline in energy investments, renewable energy has resisted and continued to grow against the pandemic (IEA, 2020). Even though the disruption of the education process of children was prevented by initiating the distance / online education processes in the quarantine process, the discount / free meal application given in schools in many countries, which is especially important for disadvantaged people, was disrupted, and some of the students suspended their education as they could not connect to the internet, and this situation brought about socio-economic inequalities. As can be seen, the pandemic is a multidimensional global crisis that affects the economic, social, and environmental factors of the countries and disrupts its sustainable development. The United Nations (UN) stated that all the work done during and after this crisis should focus on building more resilient, equal, inclusive, and sustainable economies in the face of the challenges we face. Also, it was emphasized that the countries' recovery and sustainable development goals should be taken into consideration more than ever before to cope with the shocks that may be encountered in the pandemic in the future (UNDP, 2020).

Only a few studies have addressed the threat of the coronavirus pandemic to the sustainable development levels of countries. This paper attempts to investigate how the COVID-19 pandemic has changed the level of sustainable development for developed and less developed countries. Additionally, MCDM has become widely used in different sustainable development context over the past few years (Perez-Gladish et al., 2020). For this purpose, this study is to evaluate and compare the *level* of *sustainable development* of the OECD countries by using the MAIRCA model. MAIRCA is an effective MCDM method that takes into account the concept of the positive and negative ideal solution. The results obtained with the MAIRCA method were compared with new multi-criteria decision-making methods such as MABAC and WASPAS. The efficacy and validity of the results obtained in the three methods were tested with Spearman's correlation coefficient. Finally, the Wilcoxon signed-rank test was performed to examine the impact of COVID-19 on the indicators of sustainable development.

The rest of the paper is organized as follows: In Section 2, literature review on MAIRCA has presented. The steps of the MAIRCA method is explained in Section 3. Evaluation of the effect of COVID-19 on countries' sustainable development level based on the MAIRCA method is given in the fourth section. The results obtained to test the effectiveness and validity of MAIRCA method are illustrated in Section 5. Next section, the results of the Non-Parametric Wilcoxon signed-rank test are presented. Results and some limitations are discussed in detail in Section 7..

2. Literature review

MAIRCA is a popular method within the group of MCDM methods which is developed by Professor Dragan Pamucar in the Logistics Research Centre at the University of Defence in Belgrade (Pamucar et al., 2014). MAIRCA is easy to use in computation procedure and its calculation steps are similar to the ideal and non-ideal solution approach in the technique for order of preference by similarity to ideal solution (TOPSIS) method. (Gul and Ak, 2020).

The MAIRCA model is a considerable new decision-making method that can be very successfully combined with different MCDM methods. Related literature has been evaluated over the years. Gigović et al. (2016) aimed to determine the appropriate location for the ammunition depots by using the Geographic Information System (GIS) and MAIRCA methods together. To do this, the priority weights criteria of depots were determined by DEMATEL-ANP, and then the ranking of alternative regions was performed by MAIRCA. In the study by (Pamučar et al., 2017a), using a hybrid approach, the tenderers of the public procurement tender were evaluated by means of rough number based on DEMATEL, ANP, and MAIRCA methods. In another study, Pamucar et al. (2018) used the Full Consistency Method (FUCOM) and MAIRCA integrated methods in the location selection of level crossings to reduce the number of traffic accidents. Pamučar et al. (2019) defined six alternatives in determining the landing departure point of the vehicles in combat operations and they ranked their priorities with MAIRCA using interval-valued fuzzy-rough numbers. In their research, Badi and Ballem (2018) evaluated the supplier selection process by applying the integration of the rough numbers with the Best-Worst Method (BWM) and MAIRCA methods. As a result, it is determined that the cost, quality, and company profile are the three most important criteria. Chatterjee et al. (2018) evaluated the suppliers' performances considering the green supply chain criteria with the help of rough DEMATEL, Analytic Network Process (ANP) and MAIRCA methods. Pamucar et al. (2018) performed the location selection for a multi-model logistics facility that took into account sustainability criteria with the help of DEMATEL-MAIRCA methods. Based on the two main criteria that affect the ergonomic risk level, Ekinci and Can (2018) developed the CRITIC-MAIRCA method to achieve a combined risk level by taking into consideration the evaluation results made for the sub-criteria of these main criteria. Boral et al. (2020) listed the types of errors seen in the production facility of a small and medium-sized (SME) company operating in the automobile industry using the fuzzy MAIRCA method. Ulutaş (2019) used the Step-Wise Weight Assessment Ratio Analysis (SWARA) and MAIRCA integrated method in the selection of the catering company. Aycin (2020) used The criteria importance through intercriteria correlation (CRITIC) and MAIRCA methods in the selection of personnel to work in the IT department of a company operating in the logistics industry. Arsić et al. (2019) made a menu evaluation for a restaurant with BWM and rough MAIRCA methods. In the study by (Chatterjee et al., 2020), the MAIRCA method was used to evaluate the alternatives in lightweight environmentally friendly materials in the automotive industry. Pirbasti et al. (2020) selected the waste disposal facility location of eight hospitals using a hybrid approach with fuzzy SWARA and GIS-MAIRCA. In the study by

Pamučar and Savin (2020), BWM and MAIRCA methods were utilized together for the selection of military land vehicles, taking into account the 11 criteria defined. Gul and Ak (2020) used BWM and MAIRCA methods under fuzzy conditions to analyze potential risks in the marble factory. The relative importance of the three risk factors in the traditional Fine-Kinney method was calculated with fuzzy BWM, and the identified risks were ranked by fuzzy - MAIRCA.

3. MAIRCA method

MAIRCA, which has been added to MCDM literature by Gigovic et al., 2016, is a method based on defining the gaps between ideal and empirical ratings. By the addition of the gaps for each criterion, the total gap for decision alternatives is obtained. At the end of the application process, the alternative that is the closest to the ideal ratings according to most of the criteria, or in other words, the alternative with the lowest total gap value is determined as the best alternative (Gigović et al., 2016; Pamučar et al., 2017). The MAIRCA method has an implementation process consisting of eight steps (Pamucar et al., 2018).

Step 1: Creating the Initial Decision Matrix (X): The criteria(C_j) values obtained from each alternative (A_i) are shown in Equation (1).

$$X = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ & \end{matrix} \\ X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (0)$$

Step 2: Determining the Priorities of Alternatives: The absence of a priority in the alternative selection process of the decision-maker is an assumption of the method, m as the total number of alternatives, i. The priority of the alternative Pr_{Ai} is calculated as shown in Equation (2).

$$Pr_{Ai} = \frac{1}{m}; \qquad \sum_{i=1}^{m} Pr_{Ai} = 1 \qquad i = 1, 2, \dots, m \quad (2)$$

The decision-maker is equidistant to any alternative. Therefore, all priorities are equal, as shown in Equation (3).

$$Pr_{A1} = Pr_{A2} = \cdots = Pr_{Am} \quad (3)$$

Stage 3: Construction of the Theoretical Rating Matrix (T_p): The elements of the matrix (t_{pij}) are calculated by multiplying the priorities of alternatives (Pr_{Ai}) and the criterion weights (w_j), as shown in Equation (4).

$$\boldsymbol{T_p} = \begin{bmatrix} \mathrm{Pr_{A1}}.\mathrm{w_1} & \mathrm{Pr_{A1}}.\mathrm{w_2} & \dots & \mathrm{Pr_{A1}}.\mathrm{w_n} \\ \mathrm{Pr_{A2}}.\mathrm{w_1} & \mathrm{Pr_{A2}}.\mathrm{w_2} & \dots & \mathrm{P_{rA2}}.\mathrm{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{Pr_{Am}}.\mathrm{w_1} & \mathrm{Pr_{Am}}.\mathrm{w_2} & \dots & \mathrm{Pr_{Am}}.\mathrm{w_n} \end{bmatrix} \tag{4}$$

Stage 4: Defining the Real Rating Matrix (T_r): In order to obtain T_r matrix, theoretical grading matrix T_p and initial decision matrix X are used. Matrix elements should be calculated by using Equation (5) for maximization criteria and Equation (6) for minimization criteria.

$$\mathrm{t_{rij}} = \mathrm{t_{pij}} \ . \ \left(\frac{\mathrm{x_{ij}} - \mathrm{x_{ij}^-}}{\mathrm{x_{ij}^+} - \mathrm{x_{ij}^-}}\right) \tag{5}$$

$$\mathrm{t_{rij}} = \mathrm{t_{pij}} \ . \ \left(\frac{\mathrm{x_{ij}} - \mathrm{x_{ij}^+}}{\mathrm{x_{ij}^-} - \mathrm{x_{ij}^+}}\right) \tag{6}$$

x_{ij}^+ is the highest value of the criterion from the alternative $(x_{ij}^+ = \max(x_1, x_2, \dots, x_m))$, x_{ij}^- is the lowest value of the criterion from the alternative $(x_{ij}^- = \min(x_1, x_2, \dots, x_m))$.

The actual rating matrix to be obtained as a result of calculations is shown in Eq. (7).

$$T_r = \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{bmatrix} \mathrm{t_{r11}} & \mathrm{t_{r12}} & \dots & \mathrm{t_{r1n}} \\ \mathrm{t_{r21}} & \mathrm{t_{r22}} & \dots & \mathrm{t_{r2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{t_{rm1}} & \mathrm{t_{rm2}} & \dots & \mathrm{t_{rmn}} \end{bmatrix} \tag{7}$$

Stage 5: Computation of Total Gap Matrix (G)

With the help of Gap Matrix (G), Equation (8), the difference between the theoretical rating matrix (T_p) and the actual grading matrix (T_r) is obtained as shown in Eq. (9).

$$g_{ij} = t_{pij} - t_{rij} \qquad g_{ij} \in [0, \infty) \tag{8}$$

$$G = T_p - T_r = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix} \tag{9}$$

Stage 6: Determining the Total Gap with Alternatives

If theoretical rating (t_{pij}) and real rating (t_{rij}) of an alternative (A_i) for a criterion (C_j) are equal and different from zero, the gap will be zero $(g_{ij} = 0)$. In this case, this alternative (A_i) would be the ideal alternative (A_i^+) for this criterion (C_j). If the theoretical rating (t_{pij}) of an alternative (A_i) for a criterion (C_j) equals zero $(t_{pij} = t_{rij} = g_{ij} = 0)$, then the gap for the alternative (A_i) for the criterion (C_j) is $(g_{ij} = 0)$. In this case, this alternative (A_i) will be the worst alternative (A_i^-) for this criterion (C_j).

Stage 7: Calculation of the Value (Q_i) of the Final Criteria Functions of Alternatives

The value of the criteria functions is calculated to take advantage of Equation (10) for each alternative.

$$Q_i = \sum_{j=1}^{n} g_{ij} \quad , \quad i = 1, 2, \dots, m \tag{10}$$

Q_i values are ranked from small to a large value, and alternatives are obtained.

4. Evaluate the effects of the COVID-19 pandemic on sustainable development performance of OECD countries

The Organization for Economic Co-operation and Development, or OECD in short, is an international platform that works jointly to solve the economic, social, and management problems of member countries. This establishment was founded in Paris in 1961 and was originally established with 20 countries. Later, the number of OECD member countries increased to 37 with the participation in developmentally and socioeconomically different countries (Our global reach - OECD, 2020). The main purpose of OECD is to support countries in ensuring sustainable economic growth, increasing employment, raising living standards, ensuring economic stability and contributing to the growth of world trade. Member states of the organization constitute 63 percent of GDP, three-quarters of world trade, 95 percent of world official development aid and more than half of world energy consumption in today's world (What is OECD, 2020).

In the study, Colombia, Luxemburg, Israel and New Zealand were excluded from this study due to the unavailability of some data for this method. The impact of COVID-19 on the sustainable development performances of a total of 33 OECD countries were analyzed using MAIRCA considering the data of the second quarter (Q2) of 2020 and the data of the same quarter of the previous year (2019). To test the validity and effectiveness of this method, the ranking results of MAIRCA were compared with the results obtained from novel MCDM models such as MABAC and WASPAS. Additionally, the Wilcoxon signed-rank test is conducted to determine whether the sustainable development indicators of OECD countries differ between the Q2/2019 and Q2/2020. The general framework of this study is summarized in Figure 1.

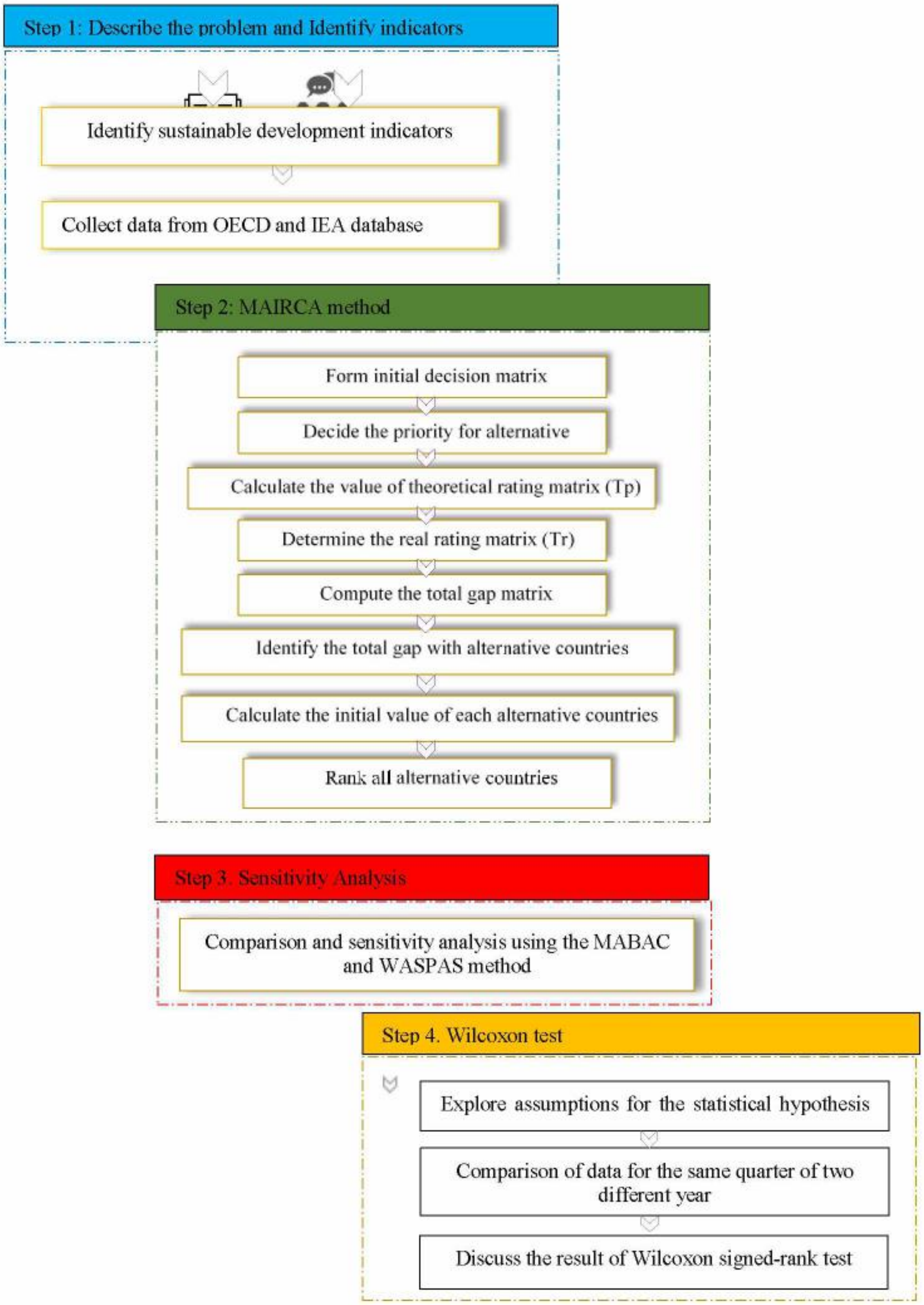

Figure 1. General framework of study

Sustainable development indicators of OECD countries have been determined in line with the sustainable development goals of OECD, the European Union, and the United Nations and literature review. In addition, all the indicators used in this study were designed to take into account all dimensions, namely the economy, environment, and social, which constitute the sustainable development model. Eight different sustainable development indicators comprising Total Electricity Production, Renewable Energy Production, Merchandise Trade, Customer Price Index (CPI), Analytical House Price Indicators (rent price), Gross Domestic Product (GDP), Producer Price Index (PPI), unemployment rate, aged 15 and over were selected in this study. The indicators were analyzed for their ability to measure the economic, environmental and social dimensions of sustainable development. Data on economic and social indicators (I3, I4, I5, I6, I7, I8) were obtained from the OECD databases, and environmental indicators (I1 and I2) were obtained from reports published by the International Energy Agency (IEA). Definitions, indices, and periods considered in the study regarding indicators of sustainable development are shown in Table 1.

Table 1. Indicators of sustainable development

Not.	Indicator	Unit	Quarter / Year	References
I1	Total Electricity Production	GWh	Q2/2019 - Q2/2020	(Ding et al., 2016); (Sustainable Development Goals, 2020)
I2	Renewable Energy production	GWh	Q2/2019 - Q2/2020	(Mateusz et al., 2018); (Kothari et al., 2010); (Sustainable Development Goals, 2020); (Sathaye et al., 2011)
I3	Merchandise Trade	US Dollar, Billions	Q2/2019 - Q2/2020	(Ding et al., 2016); (Sustainable Development Goals, 2020)
I4	Customer price index	Index, 2015=100	Q2/2019 - Q2/2020	(Gaspar et al., 2017); (Sustainable Development Goals, 2020)
I5	Analytical House Rent Price indicators	Index	Q2/2019 - Q2/2020	(Zavadskas et al., 2017); (Sustainable Development Goals, 2020)
I6	Gross Domestic Product	Annual growth rate (%)	Q2/2019 - Q2/2020	(Bali Swain and Yang-Wallentin, 2020); (Balcerzak and Pietrzak, 2016); (Ding et al., 2016): (Gaspar et al., 2017); (Sustainable Development Goals, 2020)
I7	Producer price index	Index, 2015=100	Q2/2019 - Q2/2020	(Sustainable Development Goals, 2020)
I8	The unemployment rate, aged 15 and over	%	Q2/2019 - Q2/2020	(Bali Swain and Yang-Wallentin, 2020); (Balcerzak and Pietrzak, 2016); (Ding et al., 2016); (Mateusz et al., 2018); (Gaspar et al., 2017)

Total Electricity Production (I1): Electricity generated different type of energy resources such as fossil fuels, nuclear power plants, hydropower plants (excluding pumped storage), geothermal systems, solar panels, biofuels, wind, etc.

Renewable Energy production (I2): Renewable Energy is the energy received from the energy flow that exists in the natural processes that continue continuously. They are hydro energy, wind, solar, geothermal, and other renewable energy sources.

Merchandise Trade (I3): Goods that add or subtract from the stock of material resources of a country by entering (imports) or leaving (exports) its economic territory.

Customer price index (I4): Defined as the change in the prices of a basket of goods and services that are typically purchased by specific groups of households.

Analytical House Rent Price indicators (I5): House price indices (rent prices), are index numbers that measure the rent prices of residential properties over time.

Gross Domestic Product (I6): The standard measure of the value-added created through the production of goods and services in a country during a certain period.

Producer price index (I7): The rate of change in the prices of products sold as they leave the producer.

The unemployment rate, aged 15 and over (I8): The number of unemployed people as a percentage of the labor force, where the latter consists of the unemployed plus those in paid or self-employment.

Table 2. Initial decision matrix

	Indicators							
Countries	I1	I2	I3	I4	I5	I6	I7	I8
Australia	21041	4304	69.61	106.6	102.5	1223934.95	111.1	5.231
Austria	6357	5842	44.75	106.7	114.4	469791.799	105.1	4.500
Belgium	6891	1376	112.24	107.9	103.9	553085.807	113.5	5.467
Canada	47322	31979	114.90	107.7	104.6	1723905.35	106.4	5.567
Chile	6804	2560	17.06	111.1	117.8	445180.531	108.8	6.980
Czech Republic	6613	925	50.17	108.1	109.7	406561.381	103.0	1.967
Denmark	2292	1955	27.84	103.1	104.9	308065.246	105.9	4.933
Estonia	489	137	4.11	109.9	130.7	45784.7699	109.7	4.867
Finland	5202	2999	18.65	103.4	108.2	254103.301	104.7	6.800
France	44439	9888	145.44	104.4	100.6	2908013.64	103.3	8.500
Germany	45887	20169	371.46	105.5	105.4	4150471.67	105.4	3.067
Greece	3117	1227	9.66	101.9	92.1	306790.238	104.7	17.333
Hungary	2258	358	30.36	109.4	123.4	307584.948	115.0	3.433
Iceland	1660	1660	1.28	109.4	120.0	18920.8022	99.0	3.367
Ireland	2293	625	42.61	102.1	115.9	413134.441	100.6	5.200
Italy	22141	10296	133.67	103.0	101.0	2335523.24	103.5	10.000
Japan	73035	36284	181.29	101.7	99.3	5356221.8	101.0	2.367
Korea	43570	3031	136.20	104.9	104.0	2150833.19	102.7	4.000
Latvia	402	244	3.94	109.4	107.0	55221.0561	110.5	6.367
Lithuania	282	206	8.41	110.4	126.0	96063.1159	107.2	6.100
Mexico	27884	5347	117.21	117.9	110.0	2388177.33	126.3	3.549
Netherlands	9374	1796	176.64	106.0	108.2	930705.86	109.4	3.333
Norway	9770	9502	26.31	110.6	107.6	331933.394	114.0	3.433
Poland	12052	1848	66.00	105.7	112.8	1204174.54	109.7	3.333
Portugal	4037	2176	16.89	104.2	107.5	339634.903	104.8	6.600
Slovak Republic	2264	695	22.21	106.0	101.3	181242.251	103.7	5.767
Slovenia	1419	588	11.31	105.4	118.4	75067.7421	103.1	4.367
Spain	20784	8803	84.80	104.6	103.0	1790431.14	105.3	14.200
Sweden	12703	7655	40.11	106.8	104.1	519697.892	112.1	6.533
Switzerland	5744	3551	61.12	102.0	102.1	569152.648	100.4	4.455
Turkey	23989	14407	44.52	158.2	141.4	2330974.19	186.2	13.867
United Kingdom	23914	8185	108.49	107.8	103.8	2948323.99	111.5	3.767
United States	332986	74378	408.63	108.0	115.3	19900185.1	106.94	3.633
AIM	MAX	MAX	MAX	MIN	MIN	MIN	MIN	MIN

In this study, one of the expert is an engineer with expertise in Regional development at the Ankara Development Agency in Turkey, and the others are two academics working in the economics and business department of the university. In line with the opinion received from three experts, as a result of interview with experts, the sustainable indicator should equal the importance weight. In the application of the MAIRCA method, data of 33 OECD countries are obtained from the OECD and IEA databases. The initial decision matrix for the second quarter of 2020 and the aim of each indicator are presented in Table 2.

Due to the nature of the method, the decision-maker should not have a priority in the choice of an alternative. Since there are 33 alternative countries (n), the priority (Pr_{Ai}) of each alternative is calculated as shown in Equation 2.

$$Pr_{Ai} = \frac{1}{n} = \frac{1}{33} = 0.030 \tag{11}$$

$$Pr_{A1} = Pr_{A2} = Pr_{A3} = Pr_{A4} = \dots\dots\dots\dots = Pr_{A33} = 0.030 \tag{12}$$

The theoretical rating matrix was calculated by Eq. (3) and Eq. (4), respectively. Matrix elements are obtained by multiplying the chosen alternative preferences (Pr_{Ai}) and the coefficients (w_i) of the weights of the indicators. Experts assumed that the indicator weights were of equal coefficient. The theoretical rating matrix (T_p) is shown in Table A1 (Appendix). After this matrix was calculated, the real evaluation matrix (T_r) was created, as given in Table A2 (Appendix). The actual evaluation matrix element is found by multiplying the theoretical rating matrix element with the normalized start matrix element. The normalized initial matrix was calculated using the Eq. (6) and Eq. (7). The total gap matrix (G) was obtained by subtracting the real rating matrix (t_{rij}) from the theoretical rating matrix (t_{pij}), as shown in Eq. (8) and Eq. (9).

It is preferred that the gap value be close to zero. The gap matrix is shown in Table A3 in Annex. In the last step of the method, by using the total gap matrix in Table A3 (Appendix), the criterion function values of decision alternatives were calculated by using Equation (10). The function values (Q_i) of the criteria obtained for the second quarter of 2019 with the MAIRCA method and the ranking of the OECD countries are shown in Table 3.

Similar steps were followed using data from the second quarter of 2020, when COVID-19 started to spread worldwide, and the ranking of the sustainability performances of OECD countries obtained by MAIRCA method for the second quarter of 2019 and 2020 is shown in Figure 1.

According to the results given in Table 3, the country with the best sustainability performance among OECD countries is the United States. This country is followed by Japan, Germany, Canada, Korea, and the Netherlands, respectively.

Table 3. The ranking of OECD countries using the MAIRCA method (Q2/2020)

Countries	Qi	Rank	Countries	Qi	Rank
United States	0.0090	1	Slovak Republic	0.0136	18
Germany	0.0091	2	Austria	0.0137	19
Japan	0.0095	3	Portugal	0.0138	20
Korea	0.0114	4	Finland	0.0138	21
Netherlands	0.0117	5	Sweden	0.0139	22
France	0.0119	6	Slovenia	0.0139	23
Switzerland	0.0121	7	Latvia	0.0146	24
United Kingdom	0.0123	8	Iceland	0.0146	25
Italy	0.0123	9	Mexico	0.0147	26
Belgium	0.0127	10	Spain	0.0148	27
Canada	0.0129	11	Hungary	0.0148	28
Czech Republic	0.0130	12	Greece	0.0150	29
Australia	0.0131	13	Estonia	0.0153	30
Denmark	0.0133	14	Lithuania	0.0157	31
Ireland	0.0133	15	Chile	0.0166	32
Norway	0.0135	16	Turkey	0.0249	33
Poland	0.0135	17			

The sustainability performance rankings of the countries in the second quarter of 2020, in which the COVID-19 pandemic spread worldwide, were compared in the same period of the previous year, as shown in Figure 2. According to the results obtained with MAIRCA in the second quarter of 2020, the USA belongs to the best sustainable development level among alternative countries. This country is followed by Germany, Japan, Korea and the Netherlands, respectively. Countries with the worst sustainable development performance of the same period, the lowest ranking countries in terms of sustainability performance, are Turkey (33^{rd}), Chile (32^{nd}), Lithuania (31^{st}), Estonia (30^{th}), and Greece (29^{th}). To examine how the COVID-19 pandemic has affected the sustainable development goals of OECD countries, data from the same period of the previous year were used and the MAIRCA method was resolved again. The comparison of the sustainable performance levels for both quarters is shown in Figure 2. Accordingly, the country with the highest sustainable development performance in April-May-June 2019 was America, followed by Japan, Germany, Canada and Korea, respectively. In the ranking results, Canada ranked 4^{th} in 2019, ranked 11^{th} during the pandemic period. The pandemic has been shown to seriously affect Canada's level of sustainable development. It can be seen that for Hungary, Turkey, Greece, Lithuania, Australia, Denmark, Norway, Poland, Sweden, in terms of development sustainability, rankings are stable.

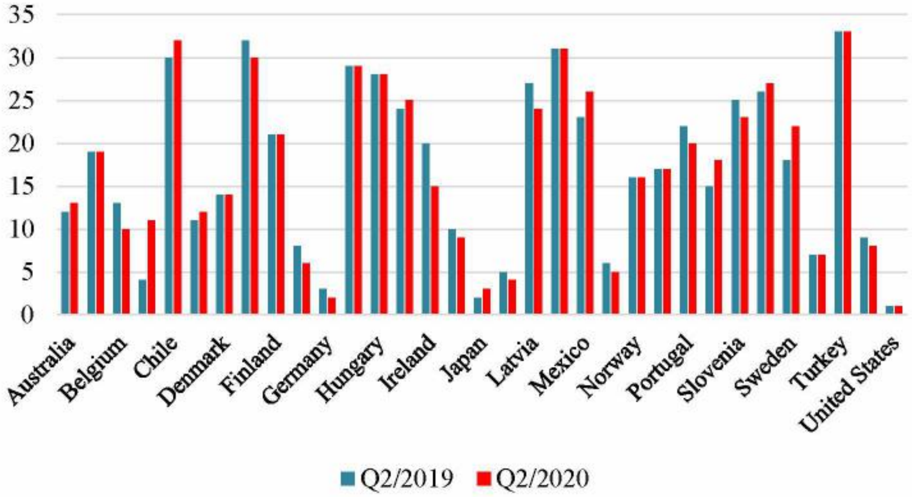

Figure. 2. Comparison of sustainability performance rankings (Q2/2019-Q2/2020)

5. Sensitivity Analysis

The reliability of the results obtained from the MAIRCA model should be tested to ensure the validity of the selected alternatives. For this purpose, the reliability and validity of the model were analyzed by using the MABAC method and WASPAS method. Results obtained with MAIRCA, MABAC and WASPAS methods are quite similar to each other. A comparison of results obtained using three MCDM methods are illustrated in Figure 3 and Figure 4, respectively. As can be seen from Figure 3, in all three methods, the United States has the best sustainable development performance. In the second quarter of 2019, Japan, Germany, Canada and Korea have the same rank in all three methods.

The Spearman correlation coefficient was used to determine the relationships between these methods. The Spearman correlation coefficient is used to measure the similarity between two group rankings. This method with a higher Spearman's rank relationship coefficient is accepted to be more significant than one with a lower Spearman's rank connection coefficient since it has better concurrences with other MCDM methods (Gang Kou, Yanqun Lu, Yi Peng, & Yong Shi, 2012). Spearman correlation coefficients for both years are shown in Table 4. According to the validity results, the correlation coefficient is above 87.2% and it has a high correlation. This confirms that the MAIRCA method is in agreement with other MCDM methods and its results are reliable.

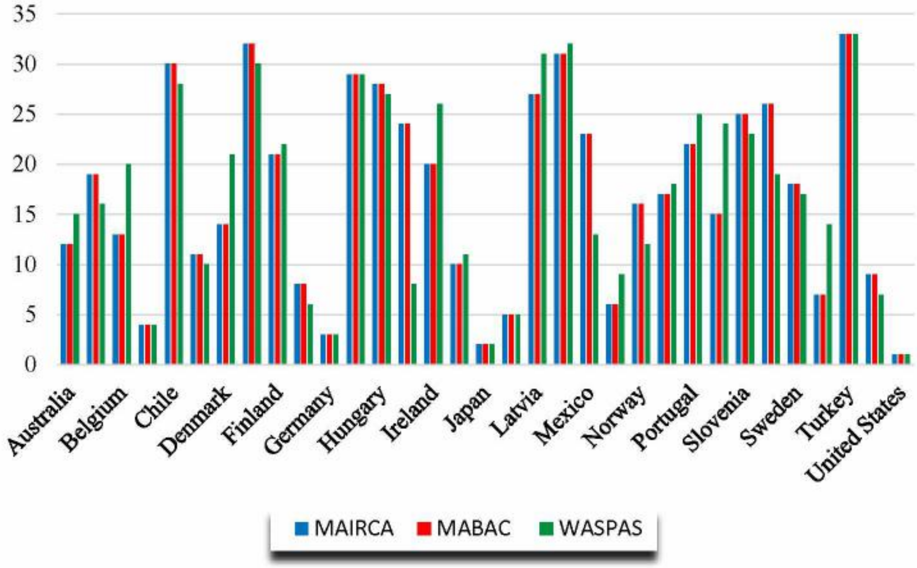

Figure 3. The ranking of OECD countries (Q2/2019)

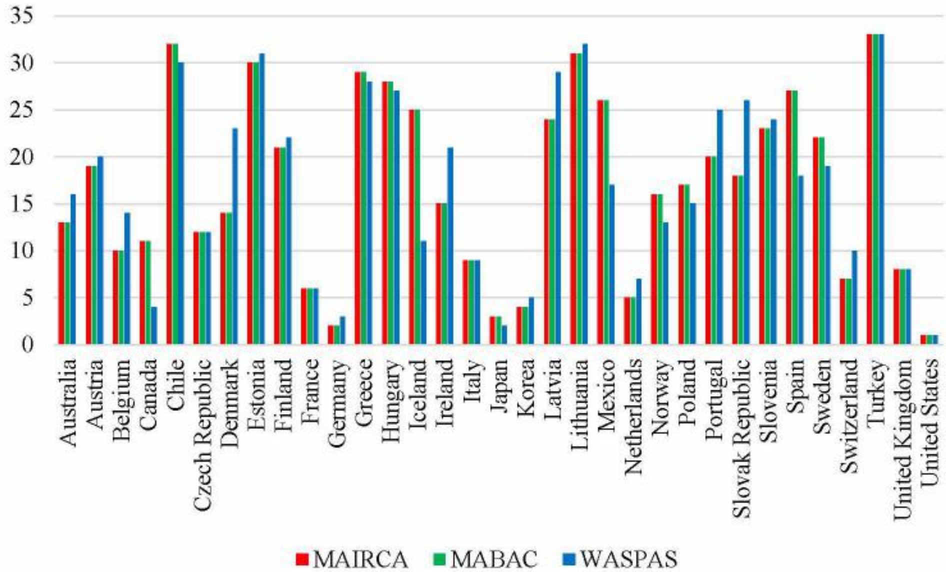

Figure 4. The ranking of OECD countries (Q2/2020)

Table 4. Correlation values of methods

Spearman's coefficient	MABAC	WASPAS	Average value
MAIRCA (Q2/2019)	1.000	0.872	0.936
MAIRCA (Q2/2020)	0.644	0.881	0.762

6. Wilcoxon Signed-Rank Test

The Non-Parametric Wilcoxon signed-rank test was applied to determine whether there is a significant difference between the second quarter of 2020 and the same quarter of the previous year in terms of the indicators of the sustainable development of OECD countries. It can be clearly seen in Table 5, *p* values of all indicators are less than 0.05 value. According to Wilcoxon test hypothesis, if *p*-value is less than zero, the null hypothesis is rejected and it is concluded that there is a significant difference between the period (April-June 2019) and (April-June 2020). Accordingly, Table 5 shows that as the *p* values of "Total Electricity Production (I1), Renewable Energy Production (I2), Merchandise Trade (I3), Customer Price Index (I4), Analytical house rent price indicators (I5), GDP (I6)", Producer Price Index (I7), Unemployment rate, aged 15 and over (I8) are less than 0.05, results demonstrated that there are differences between before and during the COVID-19 pandemic. Test results are clearly expressed in Table 5 and 6, respectively.

Table 5. Wilcoxon signed-rank test results

	I1(2020)-I1(2019)	I2(2020) - I2(2019)	I3(2020) - I3(2019)	I4(2020)-I4(2019)	I5(2020)-I5(2019)	I6(2020-I6(2019)	I7(2020)-I7(2019)	I8(2020)-I8(2019)
Z	-3.815[b]	-2.10[b]	-5.012[b]	-2.124[c]	-3.293[c]	-5.012[b]	-3.475[c]	-3.726[c]
p	0.000	0.036	0.000	0.034	0.001	0.000	0.001	0.000

a. Wilcoxon Signed-Rank Test, b. Based on positive ranks, c. Based on negative ranks

As seen in Table 6, the total electricity production of 26 OECD countries decreased in the second quarter of 2020. It is observed that the COVID-19 pandemic has negatively affected the energy production of OECD countries. However, this situation has changed in the amount of renewable energy generation. In the second quarter of 2020, which was heavily affected by the pandemic, the amount of renewable energy production of 22 countries increased compared to the second quarter of the previous year. It is interesting to note that COVID-19 pandemic has a positive effect on renewable energy goals. The global COVID-19 novel coronavirus pandemic has severe negative impacts on the global economy. GDP is an important indicator to bring coherence to the sustainable development goals. When the result on house rent prices were analyzed, the consumer price index of 27 countries increased compared to the second quarter of 2019. According to Table 6, Merchandise trade and GDP of all OECD countries plunged in the second quarter of 2020 as compared to the same period last year. The COVID-19 has prevented countries from achieving their sustainable development goals.

The producer price index means the average change over time in selling prices received by domestic producers of goods and services. The producer price index of 29 countries decreased compared to the same quarter of the previous year. The other important sustainable development indicator is the unemployment rate; the test result indicates that the unemployment rate of 26 countries has increased compared to the same period of the previous year. Coronavirus has hit unemployment in OECD countries. The results found that all sustainable development indicators, except renewable energy production, have been severely affected by the COVID-19 pandemic.

Table 6. Cash Ratio Ranks

		Number	*Mean Rank*	*Sum of Ranks*
I1 (2019) – I1(2020)	Negative Ranks	26	19.00	494.0
Total Electricity production	Positive Ranks	7	9.57	67.0
I2 (2019) – I1(2020)	Negative Ranks	11	14.82	163.0
Renewable energy	Positive Ranks	22	18.09	398.0
I3 (2019) – I1(2020)	Negative Ranks	33	17.00	561.0
Merchandise trade	Positive Ranks	0	0.00	0
I4 (2019) – I1(2020)	Negative Ranks	12	12.54	150.5
CPI	Positive Ranks	20	18.88	377.5
I5 (2019) – I1(2020)	Negative Ranks	4	20.00	80.0
Rent price	Positive Ranks	27	15.41	416.0
I6 (2019) – I1(2020)	Negative Ranks	33	17.00	561.0
GDP	Positive Ranks	0	0.00	0.0
I7 (2019) – I1(2020)	Negative Ranks	29	17.59	475.0
Producer price index	Positive Ranks	6	14.33	86.0
I8 (2019) – I1(2020)	Negative Ranks	7	10.29	72.0
Unemployment rate				
	Positive Ranks	26	18.81	489.0

7. Results and Limitations

World economies have faced serious health problems and socio-economic crises due to the COVID-19 pandemic. The COVID-19 pandemic continues to threaten life, to suppress the world economy, and to have a profound impact on social and environmental issues. National and international community organizations emphasized that countries should pay more attention to sustainable development goals in the post-COVID-19 recovery phase in order to reduce the destructive effect of the COVID-19 crisis.

In this study, the effect of the COVID-19 pandemic on the sustainable development of OECD countries was investigated with a novel MCDM method. For this purpose, the MAIRCA method was used to rank the sustainability performance of OECD countries and test its validity and reliability with MABAC and WASPAS methods. Moreover, statistical analysis was implemented and obtained results were discussed in view of sustainable development.

The analysis leads to the following conclusions: United States, Germany, Japan, France, and South Korea are with the best development performance while countries with the worst performance are Turkey, Chile, Lithuania, and Estonia for the same quarter of 2019 and 2020. Developed countries are in the top position in the ranking of sustainable development performance compared to developing countries, and this situation did not change with the appearance of the COVID-19 pandemic; the rankings score was the same. In order to test the validity and effectiveness of the MAIRCA method, the ranking results of MAIRCA were compared with the results obtained from novel MCDM models such as MABAC and WASPAS. It has been observed that all MCDM methods used give effective results to determine the ranking of countries under a sustainable development level. Furthermore, a Non-parametric Wilcoxon Signed-Rank test was used to determine whether the direction of changes of each sustainable development indicator was different between the pre-COVID-19 and COVID-19.

Accordingly, results demonstrated that there were significant differences between before and during the COVID-19 pandemic. Importantly, our results provide evidence that, except for renewable energy production, all sustainable indicators have adversely been affected by the COVID-19 pandemic. However, this study has revealed that COVID 19 has had an innovator effect by changing the direction of energy production resources. The pandemic has tripped the scale in favor of renewable energy.

There are a number of limitations for this study. One of the main limitations is the missing dataset. Due to the continuing COVID-19 pandemic, there are missing and uncompleted sustainable development indicators such as the "number of hospital beds", "attendance at school", "inequality in education", "life expectancy", "gender inequality", etc. Further study will reevaluate with a different type of sustainable indicators. Another limitation of the study is that it only takes into account the impact of the pandemic on OECD countries' sustainable development performances. In the future study, new research is planned with different countries included in OPEC, G20, and BRIC countries.

Appendix

Table A1. Theoretical Evaluation Matrix (Tp)

Countries	I1	I2	I3	I4	I5	I6	I7	I8
Australia	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Austria	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Belgium	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Canada	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Chile	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Czech Republic	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Denmark	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Estonia	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Finland	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
France	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Germany	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Greece	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Hungary	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Iceland	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Ireland	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Italy	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Japan	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Korea	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Latvia	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Lithuania	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Mexico	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Netherlands	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Norway	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Poland	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Portugal	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Slovak Republic	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Slovenia	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Spain	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Sweden	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038

Switzerland	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Turkey	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
United Kingdom	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
United States	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038

Table A2. Real Evaluation Matrix (Tr)

Countries	I1	I2	I3	I4	I5	I6	I7	I8
Australia	0.0002	0.0002	0.0006	0.0035	0.0030	0.0036	0.0033	0.0030
Austria	0.0001	0.0003	0.0004	0.0035	0.0021	0.0037	0.0035	0.0032
Belgium	0.0001	0.0001	0.0010	0.0034	0.0029	0.0037	0.0032	0.0029
Canada	0.0005	0.0016	0.0011	0.0034	0.0028	0.0035	0.0035	0.0029
Chile	0.0001	0.0001	0.0001	0.0032	0.0018	0.0037	0.0034	0.0026
Czech Republic	0.0001	0.0000	0.0005	0.0034	0.0024	0.0037	0.0036	0.0038
Denmark	0.0000	0.0001	0.0002	0.0037	0.0028	0.0037	0.0035	0.0031
Estonia	0.0000	0.0000	0.0000	0.0032	0.0008	0.0038	0.0033	0.0031
Finland	0.0001	0.0001	0.0002	0.0037	0.0025	0.0037	0.0035	0.0026
France	0.0005	0.0005	0.0013	0.0036	0.0031	0.0032	0.0036	0.0022
Germany	0.0005	0.0010	0.0034	0.0035	0.0028	0.0030	0.0035	0.0035
Greece	0.0000	0.0001	0.0001	0.0038	0.0038	0.0037	0.0035	0.0000
Hungary	0.0000	0.0000	0.0003	0.0033	0.0014	0.0037	0.0031	0.0034
Iceland	0.0000	0.0001	0.0000	0.0033	0.0016	0.0038	0.0038	0.0034
Ireland	0.0000	0.0000	0.0004	0.0038	0.0020	0.0037	0.0037	0.0030
Italy	0.0002	0.0005	0.0012	0.0037	0.0031	0.0033	0.0036	0.0018
Japan	0.0008	0.0018	0.0017	0.0038	0.0032	0.0028	0.0037	0.0037
Korea	0.0005	0.0001	0.0013	0.0036	0.0029	0.0034	0.0036	0.0033
Latvia	0.0000	0.0000	0.0000	0.0033	0.0026	0.0038	0.0033	0.0027
Lithuania	0.0000	0.0000	0.0001	0.0032	0.0012	0.0038	0.0034	0.0028
Mexico	0.0003	0.0003	0.0011	0.0027	0.0024	0.0033	0.0026	0.0034
Netherlands	0.0001	0.0001	0.0016	0.0035	0.0026	0.0036	0.0033	0.0035
Norway	0.0001	0.0005	0.0002	0.0032	0.0026	0.0037	0.0031	0.0034
Poland	0.0001	0.0001	0.0006	0.0035	0.0022	0.0036	0.0033	0.0035
Portugal	0.0000	0.0001	0.0001	0.0036	0.0026	0.0037	0.0035	0.0026
Slovak Republic	0.0000	0.0000	0.0002	0.0035	0.0031	0.0038	0.0036	0.0029
Slovenia	0.0000	0.0000	0.0001	0.0035	0.0018	0.0038	0.0036	0.0032
Spain	0.0002	0.0004	0.0008	0.0036	0.0030	0.0035	0.0035	0.0008
Sweden	0.0001	0.0004	0.0004	0.0035	0.0029	0.0037	0.0032	0.0027
Switzerland	0.0001	0.0002	0.0006	0.0038	0.0030	0.0037	0.0037	0.0032
Turkey	0.0003	0.0007	0.0004	0.0000	0.0000	0.0033	0.0000	0.0009
United Kingdom	0.0003	0.0004	0.0010	0.0034	0.0029	0.0032	0.0032	0.0033
United States	0.0038	0.0038	0.0038	0.0034	0.0020	0.0000	0.0034	0.0034

Table A3. Total Gap Matrix

Countries	I1	I2	I3	I4	I5	I6	I7	I8
Australia	0.0036	0.0036	0.0032	0.0003	0.0008	0.0002	0.0005	0.0008
Austria	0.0037	0.0035	0.0034	0.0003	0.0017	0.0001	0.0003	0.0006
Belgium	0.0037	0.0037	0.0028	0.0004	0.0009	0.0001	0.0006	0.0009
Canada	0.0033	0.0022	0.0027	0.0004	0.0010	0.0003	0.0003	0.0009
Chile	0.0037	0.0037	0.0036	0.0006	0.0020	0.0001	0.0004	0.0012
Czech Republic	0.0037	0.0037	0.0033	0.0004	0.0014	0.0001	0.0002	0.0000
Denmark	0.0038	0.0037	0.0035	0.0001	0.0010	0.0001	0.0003	0.0007
Estonia	0.0038	0.0038	0.0038	0.0005	0.0030	0.0000	0.0005	0.0007
Finland	0.0037	0.0036	0.0036	0.0001	0.0012	0.0000	0.0002	0.0012

France	0.0033	0.0033	0.0024	0.0002	0.0007	0.0006	0.0002	0.0016
Germany	0.0033	0.0028	0.0003	0.0002	0.0010	0.0008	0.0003	0.0003
Greece	0.0038	0.0037	0.0037	0.0000	0.0000	0.0001	0.0002	0.0038
Hungary	0.0038	0.0038	0.0035	0.0005	0.0024	0.0001	0.0007	0.0004
Iceland	0.0038	0.0037	0.0038	0.0005	0.0021	0.0000	0.0000	0.0003
Ireland	0.0038	0.0038	0.0034	0.0000	0.0018	0.0001	0.0001	0.0008
Italy	0.0035	0.0033	0.0026	0.0001	0.0007	0.0004	0.0002	0.0020
Japan	0.0030	0.0019	0.0021	0.0000	0.0006	0.0010	0.0001	0.0001
Korea	0.0033	0.0036	0.0025	0.0002	0.0009	0.0004	0.0002	0.0005
Latvia	0.0038	0.0038	0.0038	0.0005	0.0011	0.0000	0.0005	0.0011
Lithuania	0.0038	0.0038	0.0037	0.0006	0.0026	0.0000	0.0004	0.0010
Mexico	0.0035	0.0035	0.0027	0.0011	0.0014	0.0005	0.0012	0.0004
Netherlands	0.0037	0.0037	0.0022	0.0003	0.0012	0.0002	0.0005	0.0003
Norway	0.0037	0.0033	0.0036	0.0006	0.0012	0.0001	0.0007	0.0004
Poland	0.0037	0.0037	0.0032	0.0003	0.0016	0.0002	0.0005	0.0003
Portugal	0.0037	0.0037	0.0036	0.0002	0.0012	0.0001	0.0003	0.0011
Slovak Republic	0.0038	0.0038	0.0036	0.0003	0.0007	0.0000	0.0002	0.0009
Slovenia	0.0038	0.0038	0.0037	0.0002	0.0020	0.0000	0.0002	0.0006
Spain	0.0036	0.0033	0.0030	0.0002	0.0008	0.0003	0.0003	0.0030
Sweden	0.0036	0.0034	0.0034	0.0003	0.0009	0.0001	0.0006	0.0011
Switzerland	0.0037	0.0036	0.0032	0.0000	0.0008	0.0001	0.0001	0.0006
Turkey	0.0035	0.0031	0.0034	0.0038	0.0038	0.0004	0.0038	0.0029
United Kingdom	0.0035	0.0034	0.0028	0.0004	0.0009	0.0006	0.0005	0.0004
United States	0.0000	0.0000	0.0000	0.0004	0.0018	0.0038	0.0003	0.0004

References

Arsić, S.N., Pamučar, D., Suknović, M., Janošević, M., (2019). Menu evaluation based on rough MAIRCA and BW methods. Serbian Journal of Management 14, 27–48. https://doi.org/10.5937/sjm14-18736

AYÇİN, E., (2020). Using CRITIC and MAIRCA Methods in Personnel Selection Process. The Business Journal 1, 1–12.

Badi, I., Ballem, M., (2018). Supplier selection using the rough BWM-MAIRCA model: A case study in pharmaceutical supplying in Libya. Decision Making: Applications in Management and Engineering 1, 16–33.

Balcerzak, A.P., Pietrzak, M.B., (2016). Application of TOPSIS Method for Analysis of Sustainable Development in European Union Countries Institute of Economic Research Working Papers.

Bali Swain, R., Yang-Wallentin, F., (2020). Achieving sustainable development goals: predicaments and strategies. International Journal of Sustainable Development & World Ecology 27, 96–106.

Bedford, J., Enria, D., Giesecke, J., Heymann, D.L., Ihekweazu, C., Kobinger, G., Lane, H.C., Memish, Z., Oh, M., Sall, A.A., Schuchat, A., Ungchusak, K., Wieler, L.H., (2020). COVID-

19: towards controlling of a pandemic. The Lancet 395, 1015–1018. https://doi.org/10.1016/S0140-6736(20)30673-5

Boral, S., Howard, I., Chaturvedi, S.K., McKee, K., Naikan, V.N.A., (2020). An integrated approach for fuzzy failure modes and effects analysis using fuzzy AHP and fuzzy MAIRCA. Engineering Failure Analysis 108, 104195.

CDC, (2020). International Locations with Confirmed COVID-19 Cases. Centers for Disease Control and Prevention. Available at: https://www.cdc.gov/coronavirus/2019-ncov/global-covid-19/world-map.html (accessed 5.29.20).

Chatterjee, K., Pamucar, D., Zavadskas, E.K., (2018). Evaluating the performance of suppliers based on using the R'AMATEL-MAIRCA method for green supply chain implementation in electronics industry. Journal of Cleaner Production 184, 101–129. https://doi.org/10.1016/j.jclepro.2018.02.186

Chatterjee, P., Mandal, N., Dhar, S., Chatterjee, S., Chakraborty, S., (2020). A novel decision-making approach for light weight environment friendly material selection. Materials Today: Proceedings, 2nd International Conference on Materials Manufacturing and Modelling, ICMMM – 2019, VIT University, Vellore, 29th - 31st March 2019 22, 1460–1469. https://doi.org/10.1016/j.matpr.2020.01.504

Chen, N., Zhou, M., Dong, X., Qu, J., Gong, F., Han, Y., Qiu, Y., Wang, J., Liu, Y., Wei, Y., (2020). Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. The Lancet 395, 507–513.

Coronavirus Update (Live): 13,612,973 Cases and 584,165 Deaths from COVID-19 Virus Pandemic - Worldometer, Available at: https://www.worldometers.info/coronavirus/?utm_campaign=homeADemocracynow(2020)%20dvegas1? (Accessed 7.15.2020).

COVID-19, (2020). IEA. URL https://www.iea.org/topics/covid-19 (accessed 7.16.20).

Deloitte Annual Turkish M&A Review, 2019. URL https://www2.deloitte.com/tr/en.html (accessed 5.29.20).

Ding, L., Shao, Z., Zhang, H., Xu, C., Wu, D., (2016). A comprehensive evaluation of urban sustainable development in China based on the TOPSIS-entropy method. Sustainability 8, 746.

Ekinci, E.B.M., Can, G.F., (2018). Evaluation of Workers' Ergonomıc Rısk Levels Consıderıng Workıng Postures And Perceıved Workload Wıth Multı-Crıterıa Decısıon Makıng Approach. Ergonomics 1(2), 77–91.

Gang Kou, Yanqun Lu, Yi Peng, Yong Shı, (2012). Evaluation of Classification Algorithms Using MCDM and Rank Correlation. International Journal of Information Technology & Decision Making 11, 197–225.

Gaspar, J. dos S., Marques, A.C., Fuinhas, J.A., (2017). The traditional energy-growth nexus: A comparison between sustainable development and economic growth approaches. Ecological Indicators 75, 286–296.

Gigović, L., Pamučar, D., Bajić, Z., Milićević, M., (2016). The combination of expert judgment and GIS-MAIRCA analysis for the selection of sites for ammunition depots. Sustainability 8, 372.

Gul, M., Ak, M.F., (2020). Assessment of occupational risks from human health and environmental perspectives: a new integrated approach and its application using fuzzy BWM and fuzzy MAIRCA. Stochastic Environmental Research And Rısk Assessment.

Hui, D.S., Azhar, E.I., Madani, T.A., Ntoumi, F., Kock, R., Dar, O., Ippolito, G., Mchugh, T.D., Memish, Z.A., Drosten, C., Zumla, A., Petersen, E., (2020). The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health — The latest 2019 novel coronavirus outbreak in Wuhan, China. International Journal of Infectious Diseases 91, 264–266. https://doi.org/10.1016/j.ijid.2020.01.009

Kothari, R., Tyagi, V.V., Pathak, A., (2010). Waste-to-energy: A way from renewable energy sources to sustainable development. Renewable and Sustainable Energy Reviews 14, 3164–3170.

Lai, C.-C., Shih, T.-P., Ko, W.-C., Tang, H.-J., Hsueh, P.-R., (2020). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. International Journal of Antimicrobial Agents 55, 105924.

Li, Q., Guan, X., Wu, P., Wang, X., Zhou, L., Tong, Y., Ren, R., Leung, K.S.M., Lau, E.H.Y., Wong, J.Y., Xing, X., Xiang, N., Wu, Y., Li, C., Chen, Q., Li, D., Liu, T., Zhao, J., Liu, M., Tu, W., Chen, C., Jin, L., Yang, R., Wang, Q., Zhou, S., Wang, R., Liu, H., Luo, Y., Liu, Y., Shao, G., Li, H., Tao, Z., Yang, Y., Deng, Z., Liu, B., Ma, Z., Zhang, Y., Shi, G., Lam, T.T.Y., Wu, J.T., Gao, G.F., Cowling, B.J., Yang, B., Leung, G.M., Feng, Z., (2020). Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. New England Journal of Medicine 382, 1199–1207. https://doi.org/10.1056/NEJMoa2001316

Mateusz, P., Danuta, M., Ma\lgorzata, \Latuszyńska, Mariusz, B., Kesra, N., (2018). TOPSIS and VIKOR methods in study of sustainable development in the EU countries. Procedia Computer Science 126, 1683–1692.

News Article | World Travel & Tourism Council (WTTC), (2020). World Travel Tourism Council, UK.

What is OECD?, (2020). Ekonomist. Available at: https://www.ekonomist.com.tr/ekonomist/oecd-nedir.html (Accessed 6.20.2020).

Pamučar, D., Mihajlović, M., Obradović, R., Atanasković, P., (2017a). Novel approach to group multi-criteria decision making based on interval rough numbers: Hybrid DEMATEL-ANP-MAIRCA model. Expert Systems with Applications 88, 58–80.

Pamučar, D., Mihajlović, M., Obradović, R., Atanasković, P., (2017b). Novel approach to group multi-criteria decision making based on interval rough numbers: Hybrid DEMATEL-ANP-MAIRCA model. Expert Systems with Applications 88, 58–80. https://doi.org/10.1016/j.eswa.2017.06.037

Pamučar, D.S., Ćirović, G., Božanić, D., (2019). Application of interval valued fuzzy-rough numbers in multi-criteria decision making: the IVFRN-MAIRCA model. Yugoslav Journal of Operations Research 29, 221–247.

Pamucar, D.S., Pejcic Tarle, S., Parezanovic, T., (2018a). New hybrid multi-criteria decision-making DEMATEL MAIRCA model: sustainable selection of a location for the development of multimodal logistics centre. Economic research-Ekonomska istraživanja 31, 1641–1665.

Pamučar, D.S., Savin, L.M., (2020). Multiple-criteria model for optimal off-road vehicle selection for passenger transportation: BWM-COPRAS model. Vojnotehnički glasnik 68, 28–64.

Pirbasti, F.R.H., Modiri, M., Hafashjani, K.F., Komijan, A.R., (2020). Location of Hospital Waste Disposal Site With FSWARA-GIS-MAIRCA Hybrid Algorithm.

Sathaye, J., Lucon, O., Rahman, A., Christensen, J., Denton, F., Fujino, J., Heath, G., Mirza, M., Rudnick, H., Schlaepfer, A., Shmakin, A., Angerer, G., Bauer, C., Bazilian, M., Brecha, R., Burgherr, P., Clarke, L., Creutzig, F., Edmonds, J., Hagelüken, C., Hansen, G., Hultman, N., Jakob, M., Kadner, S., Lenzen, M., Macknick, J., Masanet, E., Nagai, Y., Olhoff, A., Olsen, K., Pahle, M., Rabl, A., Richels, R., Roy, J., Schei, T., Stechow, C. von, Steckel, J., Warner, E., Wilbanks, T., Zhang, Y., (2011). Renewable Energy in the Context of Sustainable Development. Renewable Energy Sources and Climate Change Mitigation.

Sustainable Development Goals, (2020). United Nations Sustainable Development. URL Available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 11.21.20).

Ulutaş, A., (2019). The Selection of Caterıng Fırm with Swara And Maırca Methods.Business & Management Studies: An International Journal. 7(4), 1467–1479. https://doi.org/10.15295/bmij.v7i4.1166

UNDP, (2020). UNDP. URL Available at: https://www.tr.undp.org/content/turkey/tr/home/presscenter/pressreleases/2020/04/COVID19-haritasi.html (accessed 7.16.20).

Wang, C., PW. Horby, FG Hayden, GF Gao, (2020). A novel coronavirus outbreak of global health concern. The Lancet 395, 470-473.

WHO, (2020). Naming the coronavirus disease (COVID-19) and the virus that causes it. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it (Accessed 7.8.20).

World Economic Outlook, (2020). The Great Lockdown, Available at: https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020 (accessed 5.31.20).

Zavadskas, E.K., Cavallaro, F., Podvezko, V., Ubarte, I., Kaklauskas, A., (2017). MCDM Assessment of a Healthy and Safe Built Environment According to Sustainable Development Principles: A Practical Neighborhood Approach in Vilnius. Sustainability 9, 702. https://doi.org/10.3390/su9050702

CALL FOR PAPERS AND ARTICLE FORMATTING INSTRUCTIONS

The instructions to authors about the article preparation for publication in the *Operational Research in Engineering Sciences: Theory and Applications (ORESTA)* are based on the Act on scientific journal editing of the Ministry of Science and Technological Development of the Republic of Serbia, No 110-00-17/2009-01 of 9th July 2009. This Act aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange. It is based on international standards ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999 and ISO 5122 and their national equivalents.

ORESTA publishes high quality scientific papers that contribute significantly to the fields of operational research in engineering science. *Operational Research in Engineering Sciences: Theory and Applications* (ORESTA) is an international peer-reviewed journal covering main aspects of operational research in engineering sciences. ORESTA publishes high quality, scientific papers that contribute to the fields of operational research. The journal covers new theories, applications, and reviews of optimization methods, decision-making, stochastic models, mathematical programming, simulation, game theory, queueing systems, inventory, scheduling, project management, decision-support systems, artificial intelligence, neural network, fuzzy logic, expert systems.

Articles present new theoretical insights and developments, as well as real-world case studies illustrating the practical implementation of operational research models. Full experimental and methodical details must be provided so that the results can be reproduced.

This is a unique feature of *ORESTA* compared to other existing operational research journals, providing a means to explore new directions in engineering research in a interdisciplinary context. Overview papers from eminent scientists in significant fields of engineering that review the state-of-the-art in these fields, are also welcome.

Manuscripts for *Operational Research in Engineering Sciences: Theory and Applications* should be submitted online at www.oresta.rabek.org. The submitting author, who is generally the corresponding author, is responsible for the manuscript during the submission and peer-review process. The submitting author must ensure that all eligible co-authors have been included in the author list and that they all have read and approved the submitted version of the manuscript. To submit your manuscript, register and log in to the submission page.

Accepted File Formats

Authors must use the Microsoft Word template (www.oresta.rabek.org) to prepare their manuscript. Using the template file will substantially shorten the time to complete copy-editing and publication of accepted manuscripts. Accepted file formats are:

- *Microsoft Word:* Manuscripts prepared in Microsoft Word must be converted into a single file before submission. When preparing manuscripts in Microsoft Word, the ORESTA template file must be used. Please insert your graphics (schemes, figures, *etc.*) in the main text after the paragraph of its first citation.
- *Supplementary files:* May be any format, but it is recommended that you use common, non-proprietary formats where possible.

All necessary files have been uploaded:

Manuscript:

- Include keywords;
- All figures (include relevant captions);
- All tables (including titles, description, footnotes);
- Ensure all figure and table citations in the text match the files provided;
- Indicate clearly if color should be used for any figures in print; Supplemental files (where applicable).

Reproducing Published Material from other Publishers

It is absolutely essential that authors obtain permission to reproduce any published material (figures, schemes, tables or any extract of a text) which does not fall into the public domain, or for which they do not hold the copyright. Permission should be requested by the authors from the copyrightholder (usually the Publisher, please refer to the imprint of the individual publications to identify the copyrightholder). Permission is required for: Your own works published by other Publishers and for which you did not retain copyright; Substantial extracts from anyones' works or a series of works; Use of Tables, Graphs, Charts, Schemes and Artworks if they are unaltered or slightly modified and Photographs for which you do not hold copyright.

Permission is not required for: (1) Reconstruction of your *own* table with data already published elsewhere. Please notice that in this case you must cite the source of the data in the form of either "Data from..." or "Adapted from..."; (2) Reasonably short quotes are considered *fair use* and therefore do not require permission; (3) Graphs, Charts, Schemes and Artworks that are completely redrawn by the authors and significantly changed beyond recognition do not require permission.

In order to avoid unnecessary delays in the publication process, you should start obtaining permissions as early as possible. If in any doubt about the copyright, apply for permission. ORESTA cannot publish material from other publications without permission.

The copyright holder may give you instructions on the form of acknowledgement to be followed; otherwise follow the style: "Reproduced with permission from [author], [book/journal title]; published by [publisher], [year].' at the end of the caption of the Table, Figure or Scheme.

Publication Ethics Statement

The editors of this journal enforce a rigorous peer-review process together with strict ethical policies and standards to ensure to add high quality scientific works to the field of scholarly publication. Unfortunately, cases of plagiarism, data falsification, image manipulation, inappropriate authorship credit, and the like, do arise. The editors of *Operational Research in Engineering Sciences: Theory and Applications* take such publishing ethics issues very seriously and are trained to proceed in such cases with a zero tolerance policy.

Authors wishing to publish their papers in *Operational Research in Engineering Sciences: Theory and Applications* must abide to the following:

- Any facts that might be perceived as a possible conflict of interest of the author(s) must be disclosed in the paper prior to submission.
- Authors should accurately present their research findings and include an objective discussion of the significance of their findings.
- Data and methods used in the research need to be presented in sufficient detail in the paper, so that other researchers can replicate the work.

- Raw data should preferably be publicly deposited by the authors before submission of their manuscript. Authors need to at least have the raw data readily available for presentation to the referees and the editors of the journal, if requested. Authors need to ensure appropriate measures are taken so that raw data is retained in full for a reasonable time after publication.
- Simultaneous submission of manuscripts to more than one journal is not tolerated.
- Republishing content that is not novel is not tolerated (for example, an English translation of a paper that is already published in another language will not be accepted).
- If errors and inaccuracies are found by the authors after publication of their paper, they need to be promptly communicated to the editors of this journal so that appropriate actions can be taken.
- Your manuscript should not contain any information that has already been published. If you include already published figures or images, please obtain the necessary permission from the copyright holder to publish under the CC-BY license.
- Plagiarism, data fabrication and image manipulation are not tolerated.

Plagiarism is not acceptable in *Operational Research in Engineering Sciences: Theory and Applications* submissions.

Plagiarism includes copying text, ideas, images, or data from another source, even from your own publications, without giving any credit to the original source.

Reuse of text that is copied from another source must be between quotes and the original source must be cited. If a study's design or the manuscript's structure or language has been inspired by previous works, these works must be explicitly cited.

If plagiarism is detected during the peer review process, the manuscript may be rejected. If plagiarism is detected after publication, we may publish a correction or retract the paper.

Image files must not be manipulated or adjusted in any way that could lead to misinterpretation of the information provided by the original image.

Irregular manipulation includes: 1) introduction, enhancement, moving, or removing features from the original image; 2) grouping of images that should obviously be presented separately (e.g., from different parts of the same gel, or from different gels); or 3) modifying the contrast, brightness or color balance to obscure, eliminate or enhance some information.

If irregular image manipulation is identified and confirmed during the peer review process, we may reject the manuscript. If irregular image manipulation is identified and confirmed after publication, we may correct or retract the paper.

Our editors will investigate any allegations of publication misconduct and may contact the authors' institutions or funders if necessary. If evidence of misconduct is found, appropriate action will be taken to correct or retract the publication. Authors are expected to comply with the best ethical publication practices when publishing in *Operational Research in Engineering Sciences: Theory and Applications* journal.

Preparation of a Manuscript

- *Research manuscripts* should comprise:
  - Front matter: Title, Author list, Affiliations, Abstract, Keywords
  - Research manuscript sections: Introduction, Materials and Methods, Results, Discussion, Conclusions (optional).

- Back matter: Supplementary Materials, Acknowledgments, Author Contributions, Conflicts of Interest, References.

– *Review manuscripts* should comprise the front matter, literature review sections and the back matter. The template file can also be used to prepare the front and back matter of your review manuscript.
– *Abbreviations* should be defined in parentheses the first time they appear in the abstract, main text, and in figure or table captions.
– *SI Units* (International System of Units) should be used. Imperial, US customary and other units should be converted to SI units whenever possible.
– *Equations*: If you are using Word, please use either the Microsoft Equation Editor or the MathType add-on. Equations should be editable by the editorial office and not appear in a picture format.
– *Research Data and supplementary materials*: Note that publication of your manuscript implies that you must make all materials, data, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information.

Front Matter

These sections should appear in all manuscript types

– *Title*: The title of your manuscript should be concise, specific and relevant. When decision making model names are included, the abbreviated name rather than full name should be used.
– *Author List and Affiliations*: Authors' full first and last names must be provided. The initials of any middle names can be added. The PubMed/MEDLINE standard format is used for affiliations: complete address information including city, zip code, state/province, country, and all email addresses. At least one author should be designated as corresponding author, and his or her email address and other details should be included at the end of the affiliation section..
– *Abstract*: The abstract should be a total of about 200 words maximum. The abstract should be a single paragraph and should follow the style of structured abstracts, but without headings: 1) Background: Place the question addressed in a broad context and highlight the purpose of the study; 2) Methods: Describe briefly the main methods or treatments applied. Include any relevant preregistration numbers, and species and strains of any animals used. 3) Results: Summarize the article's main findings; and 4) Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article: it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.
– *Keywords*: Three to ten pertinent keywords need to be added after the abstract. We recommend that the keywords are specific to the article, yet reasonably common within the subject discipline.

Research Manuscript Sections

– *Introduction*: The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance, including specific hypotheses being tested. The current state of the research field should be reviewed carefully and key publications cited.

Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the main conclusions.

- *Materials and Methods*: They should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.
- *Results*: Provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.
- *Discussion*: Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible and limitations of the work highlighted. Future research directions should also be mentioned. This section may be combined with Results.
- *Conclusions*: This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

Back Matter

- *Supplementary Materials*: Describe any supplementary material published online alongside the manuscript (figure, tables, etc.). Please indicate the name and title of each element as follows Figure S1: title, Table S1: title, etc.
- *Acknowledgments*: All sources of funding of the study should be disclosed. Clearly indicate grants that you have received in support of your research work and if you received funds to cover publication costs.
- *Author Contributions*: Each author is expected to have made substantial contributions to the paper and has approved the submitted version. Authorship must include and be limited to those who have contributed substantially to the work.
- *Conflicts of Interest*: Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. If there is no conflict of interest, please state "The authors declare no conflict of interest."
- *References*: References must be numbered in order of appearance in the text (including table captions and figure legends) and listed individually at the end of the manuscript. Include the digital object identifier (DOI) for all references where available.

References

Citation in text

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Web references

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

Data references

This journal encourages you to cite underlying or relevant datasets in your manuscript by citing them in your text and including a data reference in your Reference List. Data references should include the following elements: author name(s), dataset title, data repository, version (where available), year, and global persistent identifier. Add [dataset] immediately before the reference so we can properly identify it as a data reference. The [dataset] identifier will not appear in your published article.

Text: Citations in the text should follow the referencing style used by the American Psychological Association.

List: references should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.

Examples:

Reference to a journal publication:

Van der Geer, J., Hanraads, J. A. J., & Lupton, R. A. (2010). The art of writing a scientific article. Journal of Scientific Communications, 163, 51–59.

Reference to a book:

Strunk, W., Jr., & White, E. B. (2000). The elements of style. (4th ed.). New York: Longman, (Chapter 4). *Reference to a chapter in an edited book*:

Mettam, G. R., & Adams, L. B. (2009). How to prepare an electronic version of your article. In B. S. Jones, & R. Z. Smith (Eds.), Introduction to the electronic age (pp. 281–304). New York: E-Publishing Inc.

Reference to a website:

Cancer Research UK. Cancer statistics reports for the UK. (2003). http://www.cancerresearchuk.org/aboutcancer/statistics/cancerstatsreport/ Accessed 13 March 2003.

Reference to a dataset:

[dataset] Oguro, M., Imahiro, S., Saito, S., Nakashizuka, T. (2015). Mortality data for Japanese oak wilt disease and surrounding forest compositions. Mendeley Data, v1. https://doi.org/10.17632/ xwj98nb39r.1.

Journal abbreviations source

Journal names should be abbreviated according to the List of Title Word Abbreviations.

Preparing Figures, Schemes and Tables

- File for Figures and schemes must be provided during submission in a single zip archive and at a sufficiently high resolution (minimum 1000 pixels width/height, or a resolution of 300 dpi or higher). Common formats are accepted, however, TIFF, JPEG, EPS and PDF are preferred.
- All Figures, Schemes and Tables should be inserted into the main text close to their first citation and must be numbered following their number of appearance (Figure 1, Scheme I, Figure 2, Scheme II, Table 1,).
- All Figures, Schemes and Tables should have a short explanatory title and caption.
- All table columns should have an explanatory heading. To facilitate the copy-editing of larger tables, smaller fonts may be used, but no less than 8 pt. in size. Authors should use the Table option of Microsoft Word to create tables.
- Authors are encouraged to prepare figures and schemes in color (RGB at 8-bit per channel). There is no additional cost for publishing full color graphics.

Supplementary Materials and Software Source Code

Data Availability

In order to maintain the integrity, transparency and reproducibility of research records, authors must make their experimental and research data openly available either by depositing into data repositories or by publishing the data and files as supplementary information in this journal.

Computer Code and Software

For work where novel computer code was developed, authors should release the code either by depositing in a recognized, public repository or uploading as supplementary information to the publication. The name and version of all software used should be clearly indicated.

Supplementary Material

Additional data and files can be uploaded as "Supplementary Files" during the manuscript submission process. The supplementary files will also be available to the referees as part of the peer-review process. Any file format is acceptable, however we recommend that common, non-proprietary formats are used where possible.

References in Supplementary Files

Citations and References in Supplementary files are permitted provided that they also appear in the reference list of the main text.

Publishers:
Regional Association for Security and crisis management (RABEK) –
European Centre for Operational research (ECOR)

Graphic design
Mihailo Aleksić

Copy editing
Marija Starčević, RABEK

English translation and polishing
Željka Nedić *e-mail:* zeljka_nedic@yahoo.com

Supporting institutions:
Faculty of architecture, civil engineering and geodesy, University of Banja Luka and Serbian OR Society, the Member of IFORS

Financial support:
Regional Association for Security and crisis management (RABEK) –
European Centre for Operational research (ECOR)

Printing:
C-Štampa, Radomira Markovića 27, 11000, Belgrade
www.cprint.rs
e-mail: cprint.stampa@gmail.com

Printed in 30 copies

Frequency:

CIP - Catalogisation in the publication:
National Library of Serbia, Belgrade

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

62

OPERATIONAL Research in Engineering Sciences : Theory and Applications / editor-in-chief Željko Stević. - [Štampano izd.] . - Vol. 3, issue 3 (2020)- . - Belgrade : Regional Association for Security and crisis management : European Centre for Operational research, 2020- (Belgrade : C štampa). - 25 cm

Tri puta godišnje.
ISSN 2620-1607 = ORESTA. Operational Research in Engineering Sciences. Theory and Applications (Štampano izd.)
COBISS.SR-ID 270766604

UDC: National Library of Serbia, Belgrade