# ORESTA

ISSN: 2620-1607

eISSN: 2620-1747

DOI: 10.31181/oresta190101s

Editor in Chief:

Željko Stević

# OPERATIONAL RESEARCH IN ENGINEERING SCIENCES: THEORY AND APPLICATIONS

REGIONAL ASSOCIATION FOR SECURITY AND CRISIS MANAGEMENT - (RASEC)

EUROPEAN CENTRE FOR OPERATIONAL RESEARCH - (ECOR)

Volume 5, Issue 1

ISSN: 2620-1607

eISSN: 2620-1747

DOI: 10.31181/oresta190101s

Published: April 2022



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Publishers:

REGIONAL ASSOCIATION FOR SECURITY AND CRISIS MANAGEMENT - (RASEC)

EUROPEAN CENTRE FOR OPERATIONAL RESEARCH - (ECOR)

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 1-19*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta290122001e*

# DEMOGRAPHIC AND INSTITUTIONAL DETERMINANTS AFFECTING MANPOWER'S DEVELOPMENT AT THE GOVERNMENT SECTOR (A COMPARATIVE STUDY)

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Received: 07 October 2021
Accepted: 24 December 2021
First online: 29 January 2022

*Research paper*

**Abstract:** *This study aimed to apply the measurement of the impact of determinants of the change management process (CMP) on the competitive performance (CP) of the employees at the government sector in a practical environment by comparison between the employees' expectation at the Government of Ras Al-Khaimah compared to the expectation of employees at Ajman Government. Thus, the Emirate of Ajman within the UAE was selected to apply the same scale of measuring which has same conditions of the work of the government sector and similar geographical aspects like the Emirate of RAK. The results have shown a significant impact of the role of direct determinants which were assumed by the current study in the influence of improving the competitiveness of the employees during the implementation to any change management process planned at the level of government sectors. There were five key determinants respectively in terms of impact strength, and those determinants were creation and innovation, institutional values, quality and excellence systems, administrative and legal aspects and finally, the role of leadership.*

**Key words**: *Demographic, government sector, Competitive Performance, CMP.*

## 1. Introduction

The determinants of change management have a significant role in developing the competitive performance of the manpower within the organizations. Both of management commitment and quantitative evaluation are considered important factors to resist potential change to reinforce employees' performance (Rees et al., 2007). There is a positive relationship between leadership style, human resource practices, and involvement in cultural traits of organization in the achievement of change management. Application of the change process may improve decision areas such as benchmarking, executing best practices, adopting quality practices, and human resource policies (Oon & Ahmad, 2014). The Association of Change

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Management Professionals (ACMP) defines change management as the practice of applying a structured approach to transition an organization from a current state to a future state to achieve expected benefits. Change management is considered a process used for managing the transition of the organizational culture of change to the employees' side in any organization based on critical factors like the incentives and motivation systems in order to guarantee that each change within the organization produces the planned outcomes (Shah, 2016).

Generally, the report of Global Competitiveness in 2018 has ranked the governments according to 12 pillars that were weighted equally. These pillars including the following: institutions, infrastructure, information, and communication technology (ICT) adoption, macroeconomic stability, health, skills, product market, labor market, financial system, market size, business dynamism, and innovation capability. Although the vital impact of the change process on the competitive performance inside the institutions has targeted by some literature, its competitive environment facing new challenges unfolds over time and requires more to examine (Finger et al., 2014). Concerning the concept of competitiveness is defined as the ability to provide any organization more effectively and efficiently than the relevant counterparts or competitors in the same field and at the industry level. The competitiveness was defined as the ability of the organizations to achieve sustained success compared to its competitors (Enright et al., 1996). The competitive performance means the best performance that an organization pursues in order to be more productive than its rivals or competitors. In order to earn and maintain its leading advantage among other organizations, it must be able to remark a higher comparative or differential value than its counterparts in the same field of the comparison at the national or international level. The concept of competitiveness is a distinctive position of the organization where its competition will be at its greatest possible level compared to the other organizations (Schwab, 2017).

It was noted a seldom found of academic endeavors that be related to any paper or research clearly can shed the light on examining the possible drivers of change management affecting the performance of the government sector in the Arabic countries and UAE specially. It also did not address which one of these drivers has the most impact on the performance of government sector employees. Yet, it is noted that the link between direct and indirect drivers of change management doesn't sufficiently examine to determine it affecting the perceptions and convictions of the employees inside this sector, so the impact of these drivers was assessed from the perspective of the employees as they are considered the focus of any meaningful change of institutional development. Thus, this study pursued seriously to create more meaningful value to decision makers and programs planners regarding the role of these determinates of change management in the government sector in order to reinforce the possibilities and enablers for optimizing the competitive performance of the employees in an optimal manner.

The employees are considered as one of the stakeholder's categories inside each organization that they have needs and contribute to the effectiveness and the efficiency of the organization's performance to be more valuable at the highest level of the competitiveness desired by the decision-makers. Indeed, any organization needs a new level of competitive performance, and thus it will require a change process within the workplace to improve the performance of employees until they reach the desired competitive performance that led to increased competition and demands on institutions to continuously, in particular, this insight is still suffering from lack of interest in the MENA region in both of private and public sectors alike. Consequently, this paper aimed at applying the measurement of the impact of determinants of the change management process (CMP) on the competitive performance (CP) of the employees at the government sector in a practical environment by comparison between the employees' expectation at the Government of Ras Al-Khaimah compared to the expectation of employees at Ajman Government. Thus, the Emirate of Ajman within the UAE was selected to apply the same scale of measuring which has same conditions of the work of the government sector and similar geographical aspects like the Emirate of RAK.

The main objective of this study to reach a confirmation or disprove about the most decisive determinants targeted in the statistical analysis of this study. And the extent of the effectiveness the experimental group of the employees at the government sector of the Ras Al Khaimah.

Briefly, this study will consist of eight sections in terms of Section 1 explains introduction about the importance of examining the change management determinants within the organizations to increase the competitive performance of the employees, then section 2 presents an overview about the case study groups including the key characteristics and features, then section 3 will touch a base regarding some literature review shed the light on the importance of addressing this topic by the current study, while section 4 has focused on showing how using case study for practical implication at the government sector to realize the target determinants of change management affecting on the competitive performance of employees, then section 5 shares the main results and findings which has reached by this comparative study based on both control and experimental groups, then section 6 provides in-depth managerial implications regarding this study, then section 7 discovers the most important conclusions and limitations facing the researcher, then finally section 8 discloses the figures and tables are relevance to main results.

## 2. Case study groups overview

This study will pursue to test if there are close results about the perspectives of the employees at the government sector about the impact of direct determinants of the CMP on their performance for both of the control group, which representing the Ajman Government employees of and the experimental group, which representing the RAK Government employees.

The future scope of using the finding and conclusions of this study about the potential key beneficiaries could be summarized by listing the prospective recipients for the research, as follows:

- Decision-makers at the government sectors in the UAE and Arab countries
- Institutional Excellence programs adopted by the governments
- Government sector employees
- Professional development programs within government entities.
- Private sector institutions have productive partnerships.
- Civil society organizations for competitiveness and global leadership.
- International organizations interested in human, sustainable development.
- Committees of innovation and creativity.

- Community, partners, and clients for the government sector.
- Experts and planners interested in the development of the public sector.
- Professional organizations accredited to international standards

## 3. Literature Review

The literature review does not ensure coherent recommendations for adopting determinants or drivers regarding CM; obviously, the most specific area of CM in the United Arab Emirates (UAE) that has an impact on the employees' performance has not been studied yet. As well as, less specific literature was addressed by the CM in Arab countries in general. Consequently, few articles and studies were discussed the consequences and drivers of change management that may be effective to affect such as the following: One of studies has been demonstrated that using both of the management commitment and quantitative evaluation methods are important factors to resist possible change by employees (Rees et al., 2007). A study investigated the relationship between some factors in the change management process such as leadership, human resource and organization's culture from one side and the operational excellence of the organization from the other side (Fok-Yew & Ahmad, 2014).

Another study has shown a challenge regarding the lack of research previous studies about the change management inside the UAE and examining the implications for government and business, and decision makers (Baddah, 2016). There is another study that it has also referred that process re-engineering programs in the business have an impact on corporate change strategy, and the organizational change process has not received adequate attention inside many business institutions (Sikdar, 2014). There is one of the studies that urges the role of CMP to adopt the organizational strategy developed where this kind of strategy has supported many organizations to become successful example as in the UAE, and contribute in creating the positive impact on overall organizational performance as well (Al-Khouri, 2012). On top of that, one study has revealed that change is a vital issue in all types of organizations, and improving the performance of business is the focus of change. It has emphasized on the need to examine the similarities and differences among the determinants of CM (Bashir and Soomro, 2012). Leadership is considered the main champion in causing change and the top of key determinants to each organization, as the leader is willing to take the risk and establish an environment conducive to the change in a competitive world. Leadership is an important driver of the change that can take place and build the momentum required to improve the performance of the employees (Ragaa, 2005). Leaders need to be trained and educated to limit the resistance to change within the organizations (Bateh et al., 2013).

Effective work environment provides the basis for CMP that includes the development of the knowledge sharing culture among the employees as well as the development of their performance and skills that needed to enable effective knowledge management for the ideal competitiveness (Damodaran and Olphert, 2000). The use of a continuous improvement system in the development of institutions, the government organizations in particular, directly depends on applying the Quality and Excellence Systems (QES) as one of the success factors to support CM culture towards the planned outcomes (Trkman, 2010). The Innovation and Creation (IC) can put a different climate of competitiveness among the employees that could be contributed to enhance the performance (Al adwani, 2001).

Change is necessary for organizations that are seeking to raise low performance by improving their Motivations and Incentives (MI) systems over all units and employees. Thus, the organizations will be able to stay competitive and gain more market share but are usually faced with obstacles and problems that apply these systems unfairly or inequitable (Al Hawi, 2014). Teamwork have been widely acknowledged as a critical success factor (CSF) in CMP for each organization adopted the change for the development of institutional performance (Apostolou et al., 2011). It has noted that CMP should be reactive through responding to the new changes by reinforcing the Institutional Values (IV) imposed on the employees to accept and support the culture of the organization. Thus, the officials should be proactive to deal with all challenges including the resistance of employees in order to achieve the target objectives (Sacheva, 2009). This era has new institutions adopted the change processes through continuous trials to reinforce their internal operations, including Administrative and Legal Aspects (ALA) that has a critical effect on the performance of individuals or institutions for the competition according to industry criteria (Stamatis, 2015).

One of the studies have shown that over 33% of employees have failed to meet their stated objectives were considered poorly performing due insufficient resources or not Availability of Resources to achieve the desired change appropriately (Sayers and Al-Hajj, 2014). One of the studies has shown that Training and Organizational Learning should be so important for ensuring the effectiveness of CMP within modern enterprises, and to quantify the importance of this factor for the improvement the performance of employees and for the institutional development as well (Stamatis, 2015). Not only is CMP a popular culture within the institutional performance methodology, but also it has not yet been properly theoretically or practically grounded over the government institutions in developing countries according to established standards and bases to support the institutional development systems optimally (Trkman, 2010). As it has noted the effects of change management on the performance of firms where there is a relationship between management change and organizational effectiveness. Management of change connects to people's encounter and the organizational process, and it has been referred that the change is inevitable and managers all over the world are adapting to changing market conditions and at the same time facing the need for creating a proactive rather than a reactive managerial system (Daniel, 2020).

In addition, another recent study has noted that leadership plays an important role in accepting changes and challenges so that company can attain predetermined goals or objectives in a more effective manner, especially in unpredicted global pandemics situations. It has highlighted the importance of effective leadership and people management in the transformation of an organization and the workforce as the source of competitive advantages and as a contributor to achieving a high level of performance and purposes even in the worst pandemic situations. this study has concluded that leadership is an important resource of the business organization, in the implementation of changes forces by the external environment. To meet the aspirations of the organization, resilient leadership (Junnaid et al., 2011).

## 4. Case study for practical implication

The case study was applied on the Finance Department as a one of the government entities in the Emirate of Ajman. The selection process to this entity was based on a set of certain factors in favor of the application at this department in Ajman. Firstly, it has the same nature of work and the conditions of regulations that the entities are witnessing at the government sector of RAK. This entity is a listed in the government of Ajman, which the classification of all entities of Ajman are based on that have effective partnership relationship with the RAK Government. As well as the research sample of employees was considered in order to match the criteria of the randomly selection by the survey to ensure the effective comparison between both two groups of study whether experimental or control alike. Thereby, this institution meets all the basic and formal requirements requested by the current study conditions. The statistical analysis based on the survey has been done without the participation of this entity at the scope of this analysis. Thus, the same questionnaire of survey was conducted only at Finance Department of Ajman to determine if this selected entity is convenient for the case study. The survey aimed to apply on all level management at this entity where employees were selected randomly to involve in this questionnaire. The random sample was 30 employees for control group (Ajman Government employees) while the random sample was 100 employees for experimental group (RAK Government employees) whose were selected randomly to involve in this questionnaire during a specific time and a certain period, which began from mid of November to the end of December 2020. As this questionnaire was distributed and collected to covers the sample size required for the purpose of statistically acceptable analysis so that it was not allowed to be less than 30 units for the purpose of statistical analysis to both control and experimental groups in separately, especially the normality distribution condition. Table 1 shows the overview of all background characteristics of the target group for case study employees involved in evaluating of the decisive factors or determinants affecting the performance of employees at the government sector.

*Table 1. The background characteristics for the respondents' sample of case study employees "Control group targeted to compare with the Experimental group"*

| Basic Variables | | Freq. | % |
|---|---|---|---|
| Gender | | | |
| | Males | 21 | 70% |
| | Females | 9 | 30% |
| Age | | | |
| | From 18- | 9 | 70% |
| | From 31-45 | 21 | 30% |
| Nationality | | | |
| | National | 11 | 37% |
| | Expatriate | 19 | 63% |
| Education | | | |
| | Bachelor Level | 17 | 57% |
| | Higher Studies Level | 13 | 43% |
| No. of Experience | | | |
| | From 5-10 years | 10 | 33% |
| | More than 10 years | 20 | 67% |
| Level of Expertise | | | |
| | Local Expertise | 14 | 47% |
| | Regional Expertise | 16 | 53% |
| Monthly Income | | | |
| | More than 15000 AED | 18 | 60% |
| | From 15000-8000 AED | 12 | 40% |

Source: SPSS outputs.

The results of table 1 revealed the main features of the control group in the case study that the percentage of male employees was the highest by 70%, while female employees by %. And the percentage of expatriate employees was the highest (63%) and nationals (37%). In general, the results try to reflect the demographic characteristics of the survey sample in the case study targeted.

To acquire more confidence regarding sustainability to the reliability of the questionnaire tool used in the case study which is the same used in the main survey. The reliability of this tool was again calculated based on the size of the target group in the survey of case study. The value of the reliability of questionnaire has amounted for (0.985) using the α-Cronbach method and the results of this analysis can discover in the Appendix no.7 at the end of the current study. This value of this coefficient has asserted on the power of stability of this tool to measure what the purpose of this study in which there was more reliable about the potential results from this survey.

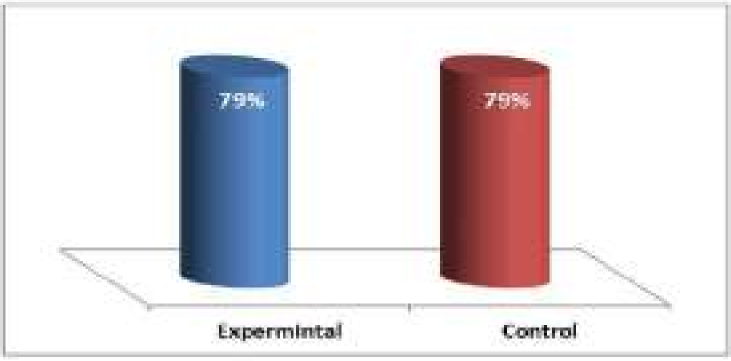


*Figure 1. the total percentage to the impact of direct determinants of CMP affecting the competitive performance CP for both of control and experimental groups*

The figure 1 shows that there was not huge difference between the evaluations of employees to the impact of direct determinants of CMP in both of two groups whether experimental or control in which the delta of means derived by the assessments of both groups at only zero value clearly. There is only one way to compare the averages of evaluations for both control and empirical groups on the expected impact of direct determinants of change management process on the competitive performance of employees at the government sector by examining if there is a significant difference between those averages for each one of direct determinants separately.

The figure 2 shows the evaluations about impact of the target direct determinants of CMP have large similarities in connection with the point of views to both of two groups based on the percentages of impact for each factor separately. This could lead to the conclusion the case study is typical direction to confirm on the results of main sample or survey. Accordingly, the next figure shows the comparison of the percentages of the evaluations of the employees for the impact of the direct determinants (10 drivers of CMP) on their expected performance.

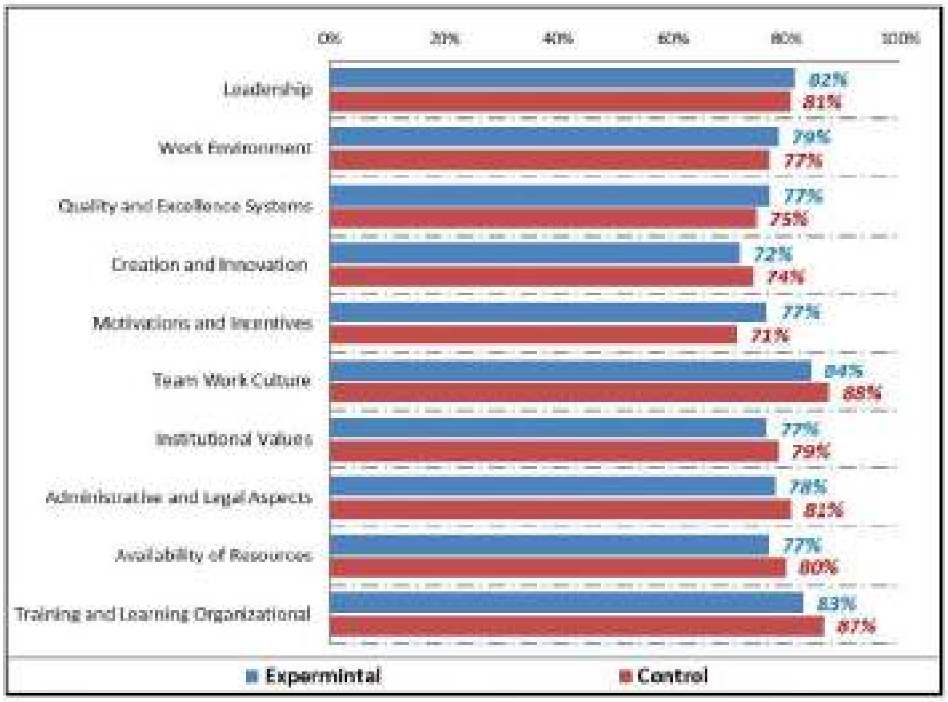


*Figure 2. the relative importance of direct determinants of CMP affecting the competitive performance CP according to the comparison between control and experimental groups*

The figure 2 shows that the percentages of employees' evaluations for the impact of direct determinants of CMP reflect somewhat how the extent of congruence in these evaluations between two samples whether experimental or control. From the previous figure, these percentages have shown that the highest percentage for the expected impact of direct determinants of CMP affecting the performance of employees was for training, learning organizational, teamwork culture, and leadership, respectively, in terms of the power of impact to improve the competitive performance of employees within the government sector, according to the perspectives to both of the control group represented for the case study and the experimental group which is relevant to the main survey application alike.

The table 2 shows the % of change rate in the means values of evaluations for the impact of these direct determinants through the evaluations of the experimental group sample and then after re-applied process again based on the control sample evaluations. Both samples have homogeneous evaluation of answers about the impact of those direct determinants in terms of there were three determinants had highest ranked and two had lowest ranked are identic over the assessment scale, and there is no noticeable change rate in the averages of evaluations regarding the total score of the impact over the change from group to other.

*Table 2. Comparison the change % of Experimental group to Control Group in decisive factors*

| Decisive factors | Experimental Group | Control Group | % of Change Rate | Evaluation Change |
|---|---|---|---|---|
| Leadership | 12.2 | 12.1 | 1% | ▲ |
| Work Environment | 11.8 | 11.6 | 2% | ▲ |
| Quality and Excellence Systems | 11.6 | 11.2 | 3% | ▲ |
| Creation and Innovation | 10.8 | 11.1 | -3% | ▼ |
| Motivations and Incentives | 11.5 | 10.7 | 7% | ▲ |
| Teamwork Culture | 12.7 | 13.1 | -3% | ▼ |
| Institutional Values | 11.5 | 11.8 | -3% | ▼ |
| Administrative and Legal Aspects | 11.7 | 12.1 | -4% | ▼ |
| Availability of Resources | 11.6 | 12.0 | -3% | ▼ |
| Training and Learning Organizational | 12.5 | 13.0 | -4% | ▼ |
| Total Score | 117.8 | 117.8 | 0% | ⇔ |

In general, the results in above confirms the same conclusion of the experimental group applied to the CMP including the direct determinants targeted by the main survey, compared to the control group results to which this system was not applied. Thus, this indicates at the same time to the importance of those determinants in particular when adopting any change process aimed at developing of staff performance within the government sector of the United Arab Emirates, especially as the scope of application of the survey tool was different in the application of the control group which is representative of the case study compared to the experimental group, which represents the main scope of the current study, and both groups approximately reached for close averages in the assessment scores according to the use of the same tool in order to determine the impact of those factors or determinants of change.

### 4.1 Case study explanation

One of the main motivations that led the researcher to re-examine the determinants of the change management process based on the case study approach is to check to which extent of the positive impact of both direct and indirect determinants of change management in a new scope away from the main scope of this study. As well as to eliminate the bias factor resulting from the interest of implementation the change management systems within the government of Ras Al Khaimah, and to ensure the ability of those determinants of the study target to bring about the desired change which aimed at developing the competitive performance of government employees optimally.

Further, the application to case study will consider the potential influence of the researcher caused to the initiative to select RAK as a practical field to test the hypotheses of study compared to another location. As the same time, the case study has to consider both of the time for implementation and reducing the volume of complexity during the analysis derived that leads to efficient findings to be easy to interpret in comparison with the main survey.

This section supports the basics of upcoming parts that contribute to study the differences between the averages' evaluation of case study group as a control group to study the impact of planned factors or determinants which were considered at the beginning of the study by determining how those averages differ statistically with the averages' evaluation of main sample of survey as an experimental group.

Besides the criteria for selection the organization to apply this survey as a case study were determined without the researcher could influence the activities planned to implement this approach. This initiative has a set of key points that make it useful to select any organization for the implementation purpose to this tool as control group involved in the case study effectively as follows:

- The minimum size acceptable of control group to study the impact of direct determinants of change affecting a group of employees should be employees in only one institution.

- The researcher should be able to apply this method using the tool of scale based on his professional expertise in the research and development field as a project manager to ensure the controlling and implementation of the required activities and tasks in line with the measurement process planned.

- Consider the general direction and the flexibility of the organization selected for the case study before the implementation to prevent any external impact impeding the achievement of the goal of the application or effect on the employees participated to accept a unified specific orientation.

- The need to increase the employees' awareness before the application of case study approach about the importance and purpose of this survey and what are the expected benefits at the short and long term for their performance alike.

- The researcher should thereby change his approach in light of the differences resulting from any feedback of case study to identify and note the requirement specifications to develop the hypotheses of the study in favor of the competitive performance desired of the employees at the government sector.

- The organization during selection should pursue to save more support and transparency for the researcher without any visible monetary return or any expected resistance at the implementation of case study according to the target scope by the survey.

- Develop the tool of measurement was generated by the objective of case study in order to increase accuracy and calculability of timeline allowed to achieve along with administrative conditions of the alternative location to apply the case study.

The organization selected as a case study have to adhere in the application of transparency during the selection for staff involved in the survey in order to ensure effective channels to adjust and prioritize tasks for the continuous improvement purpose.

To recognize the scope of the change management process towards developing the competitiveness of employees based on the direct determinants at each organization that has the ability to apply this system, there is a need to illustrate listing of factors incurred through the implementation of this system within the government sectors. Therefore, the organization targeted in the case study should take over these factors that:

- Measure the impact for change management process needs the sufficient allocation of required resources such as a lot of time/efforts/ staff.

- Ensure the direct determinants of CMP should be measured and quantified according to the same tool used before in the main survey.

- Ensure that there is no any direction affecting on the answers of employees regarding each question.

- Determine a specific time to distribute and collect the sample size required so that it was not allowed to be less than units for the purpose of statistical analysis, especially the normality distribution condition.

- Conduct the comparisons between both of the experimental and control group that are suitable to test the statistically differences in appropriate manner to check validity of the positive impact for the direct determinants of CMP.

### 4.2 Methodology of case study

The forthright objective from the use of case study survey was determining the extent of effectivity of the direct determinants in the change management process as decisive drivers affecting on the competitive performance on the employees at the government sector in a different location far way about the main scope of the current study. The survey of case study was done using the same questionnaire distributed to the participants in the main survey.

As such, two surveys were used by this study, to examine and test the importance of the direct determinants of CMP, the first survey at the beginning to apply on the target employees as an experimental group, while the second survey at the late phase of this study through the case study as a control group. Therefore, the comparison was conducted between both of these groups to determine statistically differences of the averages' evaluation of the employees about the impact of the direct determinants, thus the valued importance of these drivers could be determined in affecting on the performance of employees.

On this way, throughout the effective implementation of case study based on the comparison with the results of main survey at the same time, the officials and planners at the government sector can notice the importance of the most important determinants of change management process which will be able to develop the performance of employees. Thus, this could enable them to generate more appropriate plans, activities, and policies supporting the directions regarding these factors optimally.

To ensure the effective participation of the target employees during the survey as a case study, and to avoid ambiguities could be raised when filling out the questionnaire used, the objective of this survey was provided to all employees randomly by e-mail to interact and to increase their awareness before the time determined to conduct the survey in an adequate period of actual implementation. All questions formulated in the first survey based on a 5-point Likert scale were the same questions in the second questionnaire used for the case study without any change in the formulation or measurement.

Thus, it was expected that this will generate significant differences in the responses of the employees between the first and second round of using the same survey twice in two different geographic areas so that government sector entities were targeted. So, there is no any difference of scales that could break inconsistency of the measurement tool used, in addition to the content of the questionnaire for both groups are completely similar while the size of both samples was differ according to the type of each group. The survey of this case study was conducted by a research fellow to avoid the factor of biased and affecting the employees participated or their directions as well. Whereas the researcher was just a supervisor on the data collection process in order to ensure the right procedures in place to facilitate the data entry phase. Then SPSS Program was used to code and analyze the data collected by the sample of case study and then was combined with the data of main survey considering the unique code which was allocated to each sample for the purpose of statistical methods that will be used.

### 4.3 Data analysis of a case study

The data analysis in this phase has focused on the processing of data derived from the employees electronically in line with the nature of statistical tests targeted to be applied to test the differences statistically between the two groups whether experimental and control in connection with the impact of direct determinants of CMP. As a result, all questions were coded to analyze the data which were ranged from negative evaluation of the impact of factor (= 1 or "strongly disagree") to totally important impact of factor (= 5 or "strongly agree"). All analyses were related to the calculation of the frequencies of responses and the averages of values to each factor or determinant targeted by the scale.

T-test for independent samples was used to examine the significant differences between the two groups which were drawn from two different populations or locations, and this will be by determining the differences in the averages of employees' evaluations in both groups with regard to each direct determinant.

Furthermore, multiple regression analysis was used only according to the survey data of the case study in order to identify the most important determinants within the change management process affecting on improving the performance of employees. Then the results derived from this analysis should be compared with the results of the main survey which are subject to the researcher's experience, to strongly emphasize on the role of those determinants derived from Regression analysis based on the same results of both groups, and the importance of targeting them urgently in any system of change management at the level of government institutions to serve decision-making within this sector specifically.

## 5. Results and Findings

In this part, the study pursues seriously to compare the impact of direct determinants on the experimental group that could be exposed to the interest by the change management culture with another group that did not receive this interest to prove definitely the importance of these determinants in influencing on the competitive performance of employees within the government sector.

Hence, T-test of independent samples was precisely used to examine the existence of statistically significant differences in determining the values of arithmetic averages or not and that may reflect the positive impact of direct determinants of change management process between both of control and experimental groups. The result of this testing will be fruitful ideally in favor of the decision- making at the government sector of RAK in particular.

So, the hypothesis testing of t-test of independent samples was formulated to investigate the source of difference in the evaluation process by the target employees either by case study or by main survey according to the kind of group, as follows:

There are no significant differences in the evaluation process for the impact of direct determinant of CMP according to the type of group of employees (Control / Experimental).

Consequently, two sub-hypotheses were derived from the main hypothesis testing in- above for the data analysis purpose, and then were also formulated as follows:

Null Hypothesis H0: ($\mu 1$ the mean of Control group = $\mu 2$ the mean of Experimental group)

Alternative Hypothesis Ha: ($\mu 1$ the mean of Control group = $\mu 2$ the mean of Experimental group)

The use of this test resulted in the data analysis outputs as in table3.

The results of Table 3 have shown that there was no any statistically significant difference at a level less than 0.05 between the averages evaluations of two groups of employees according to the type of group (control/ experimental) about measuring the expected impact of each one of the direct determinants of the change management process affecting the overall performance of employees at the government sector. Further there was no statistically significant difference in the total scores of scales as a whole between both of groups as well.

This result clearly indicates the convergence of the point of views between the employees in both groups about the percentage of the impact of each one of the direct determinants separately within any change process targeted on enhancing their performance and leading them to the desired competitiveness over the level of government organizations. At the same time, it has emphasized the importance of the findings concluded of this study using the experimental group in the main survey. This will greatly enhance the confidence in the results of this research by the decision makers, officials, planners and those interested in issues of excellence and institutional development and human resources development both within the government sector in Ras Al Khaimah in particular or at the level of the United Arab Emirates in general.

*Table 3. T-test of independent samples to examine relative differences in the impact level of the direct determinants of CMP on the competitiveness performance according to case study group*

| Determinants | Case Study Group | N | Mean | SD | t. test | Sig. |
|---|---|---|---|---|---|---|
| Leadership | Control | 30 | 12.1 | 2.9 | -0.259 | 0.796 |
| | Experimental | 100 | 12.2 | 2.2 | | |
| Work Environment | Control | 30 | 11.6 | 2.7 | -0.451 | 0.653 |
| | Experimental | 100 | 11.8 | 2.3 | | |
| Quality and Excellence Systems | Control | 30 | 11.2 | 2.8 | -0.706 | 0.481 |
| | Experimental | 100 | 11.6 | 2.4 | | |
| Creation and Innovation | Control | 30 | 11.1 | 2.8 | 0.635 | 0.527 |
| | Experimental | 100 | 10.8 | 2.5 | | |
| Motivations and Incentives | Control | 30 | 10.7 | 2.0 | -1.512 | 0.133 |
| | Experimental | 100 | 11.5 | 2.7 | | |
| Teamwork Culture | Control | 30 | 13.1 | 2.3 | 1.165 | 0.246 |
| | Experimental | 100 | 12.7 | 1.8 | | |
| Institutional Values | Control | 30 | 11.8 | 2.9 | 0.653 | 0.515 |
| | Experimental | 100 | 11.5 | 2.2 | | |
| Administrative and Legal Aspects | Control | 30 | 12.1 | 2.8 | 0.882 | 0.379 |
| | Experimental | 100 | 11.7 | 2.2 | | |
| Availability of Resources | Control | 30 | 12.0 | 3.1 | 0.900 | 0.370 |
| | Experimental | 100 | 11.6 | 2.1 | | |
| Training and Learning Organizational | Control | 30 | 13.0 | 2.5 | 1.175 | 0.242 |
| | Experimental | 100 | 12.5 | 2.1 | | |
| Total Score | Control | 30 | 118.8 | 24.4 | 0.267 | 0.790 |
| | Experimental | 100 | 117.8 | 15.9 | | |

(*) Significant at the level less than 0.05.
- **Source**: Outputs of SPSS Program.

For further in-depth analysis, the most important determinants of change management will be identified from the viewpoints of the sample of control group which represents the case study, in which these determinants have a significant role in predicting the level of improvement of the employees' performance. So, this will be clearly compared with the results of the experimental group involved in the main survey. Therefore, Multi Regression analysis was used by the "Stepwise" method to determine which the most important determinants of the change management process have the highest significant role in predicting the expect performance of the government employees for developing the competitiveness level.

Besides, this method will derive a multi regression model that includes a set of independent variables which have the highest impact in predicting the value of the dependent variable (overall performance level of the employees), while some independent variables will be removed from this proposed model which have either multicollinearity or less impact on the dependent variable targeted by this model. As the findings of this analysis will show in Table 4.

*Table 4. The Coefficients of regression model equation using stepwise method for examining the impact of the most important determinants in predicting the level of competitiveness performance of the case study employees*

| Variables | B | Std. Error | Beta | T | Sig. |
|---|---|---|---|---|---|
| The fit of proposed model $R^2$ = 0.988, F = 791.951* | | | | | |
| (Constant) | 13.501 | .140 | - | 96.101 | .000* |
| Institutional Values | 3.719 | .072 | .447 | 51.4 | .000* |
| Administrative and Legal Aspects | 2.655 | .020 | .299 | 132.139 | .000* |
| Creation and Innovation | 4.371 | .037 | .495 | 116.638 | .000* |
| Quality and Excellence Systems | 2.9 | .038 | .337 | 78.0 | .000* |
| Leadership | 1.101 | .080 | .132 | 13.790 | .000* |

(*) Significant at the level less than 0.05.
- **Source**: Outputs of SPSS Program.

The results of multi-regression method in table 4 indicate that the value of R2 amounted for 98% and was statistically significant at a level less than 0.05. This value of R2 means that this proposed model has the ability to interpret about 98% of the total variance in the expected performance of employees and predict it very well for the next years. Moreover, the results show the significantly of regression model using the ANOVA variance test where the value of F 791.951 is statistically significant at a level less than 0.05, which indicates the significance of the proposed model of regression to study the relationship of the explanatory variables and the response variable in order to predict the expect performance of employees. Thence, the equation of multi regression model can be formulated as follows:

The expected performance of employees:

$$13.501+(3.719*IV)+(2.655*ALA)+(4.371*CI)+(2.930*QES)+(1.101*LSHP)$$

Regression analysis showed that there was a consensus among the employees in both control and experimental groups about only five key direct determinants without the rest variables or determinants that have the ability to influence and predict the level of competitive performance of employees within the government sector institutions. Those five key determinants were creation and innovation, institutional values, quality and excellence systems, administrative and legal aspects and leadership respectively, in terms of their power of impact in predicting the value of the dependent variable.

This conclusion will strongly confirm to the decision makers on the role that these determinants in particular can play in any process of change at the level of government institutions aimed at working to develop the performance of employees and their capacity building in order to push them to the competitiveness required to be achieved at the level of the state. Especially in light of the UAE leads in advanced ranks at the international level in the reports of Global competitiveness in all fields, chiefly the key indicators supporting the development of human capital.

## 6. Managerial Implications

In a nutshell, the main findings of the case study can be summarized in the following key points:

- There were no statistically significant differences in the averages of the evaluations of employees about the impact of direct determinants of the change management process on their performance according to the type of group that was belonged them, whether control group of the case study or experimental group of the main survey.

- There was a very noticeable convergence of the perspectives of employees at both of control and experimental groups in identifying the most important direct determinants of the change management process, which has the ability to predict the value of competitive performance of government employees in terms of both groups have agreed on the importance of only five direct determinants in influencing and predicting the expected performance of the government employees.

- There was a difference between the control and experimental groups about the expected impact of each one of the direct determinants targeted by the study that should be included in any desired change process, based on the calculations of regression coefficients in the two multi-regression models within the study, the first model reflects the expectations of the experimental group or the main survey while the second survey reflecting the expectations of employees in the control group or case study.

There were slightly differences between control and experimental groups about the employees' expectations with regard to the value of impact of each one of the direct determinants within the change management process in predicting the expected competitive performance of employees. As a result, the following table will show the impact of those direct determinants in order by the values of regression analysis coefficients based on the data extracted to each group either a case study or main survey.

*Table 5. Power of impact of the direct determinants of CMP for both control and experimental groups in order by the values of multi-regression analysis coefficients*

| Experimental Group | The power | Control Group | The power |
|---|---|---|---|
| Administrative and Legal Aspects | ↑ | Creation and Innovation | ↑ |
| Work Environment | | Institutional Values | |
| Motivations and Incentives | | Quality and Excellence Systems | |
| Quality and Excellence Systems | | Administrative and Legal Aspects | |
| Training and Learning Organizational | | Leadership | |
| Availability of Resources | | | |
| Leadership | | | |
| Institutional Values | | | |
| Creation and Innovation | | | |

*Source: the researcher*

The table 5 shows the power of influence in predicting the expected performance of employees according to both case study approach and main survey. The determinant of creation and innovation has the highest value of impact in predicting by the dependent variable from the perspective of control group while the administrative and legal aspects was the highest impact value from the perspective of experimental group. Both of groups share in the same determinants which were only five as key drivers affecting the predicted improving in the performance of employees, but the experimental group has exceeded the control group in monitoring the effect of 4 additional determinants has significant role on the performance of the government sector employees.

## 7. Limitations and Conclusions

The case study has a certain set of limitations that could be affected to generalize its applicability on at a wider level away from the primary objective behind its use for the comparison purpose with the results of the basic survey. The sample size of this case study should be greater than units or employee to considerate the condition of normality distribution of the data as a key assumption to use specific statistical tests without other that will be suitable for the analysis purpose and comparisons. The researcher was aware of the minimum limit acceptable to collect data from participants and randomly selection process should include all the employees at the whole organization during the selection based on the records of employees at the target entity of case study in order to represent a systematic random sample that be appropriate to test the interventions and assumptions of this study. The case study only dealt with the culture of change management process; then its role based on some determinants whether demographic or institutional which only determined in the literature review and how it aimed to bringing out the radical change in the performance of employees towards the competitiveness desired. Thus, the findings could be limited to examine these determinants on the competitive performance of employees at the organizational structures within the government sector only.

Thus, monitoring the gap between experimental and control group shows which one of these determinants will have high importance and more priority in developing the performance of government employees. This in turn, it was limited to show a distinct area of improvement within only the organizations of the government sector regarding the optimal using of human resources management by the officials and planners to achieve the global objectives planned. Concerning to the statistical evaluation, the approach based on testing the impact of the same considered determinants to both two groups either experimental group of the RAK Government employees or control group of the Ajman Government employees.

Further to aforementioned previously, the factors affecting change management culture needs many future studies to make a stronger case and help decrease the failure rates of the organizations during managing change processes targeted. In short, there is a significant impact of the role of direct determinants which were assumed by the current study in the influence of improving the competitiveness of the employees during the implementation to any change management process planned at the level of government sector. This, in turn, reinforces the idea of adopting specific standards of change management culture at the beginning of any new project for human resources development within the government sector for supporting the competitive performance continuously as well.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 20-40*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta190222046c*

# DEVELOPMENT OF A ROUGH-MABAC-DoE-BASED METAMODEL FOR SUPPLIER SELECTION IN AN IRON AND STEEL INDUSTRY

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Received: 26 September 2021
Accepted: 09 December 2021
First online: 19 February 2022

*Research paper*

**Abstract:** *In the context of supply chain management, supplier selection can be defined as the process by which organizations score and evaluate a range of alternative suppliers to choose the best possible one who can provide superior quality of raw materials at cheaper rate and lesser lead time. It is a decision making process with multiple trade-offs between various conflicting criteria which in turn helps the organizations identify the suitable suppliers that would establish a robust supply chain assisting in maintaining a competitive edge. The main objective of supplier selection is thus focused on reducing purchase risk, maximizing overall value to the organization, and developing closeness and long-term relationships between the suppliers and the organization. In this paper, while selecting the most suitable supplier for gearboxes in an Indian iron and steel industry, assessments of three decision makers on the performance of five candidate suppliers with respect to five evaluation criteria are first aggregated using rough numbers. The definitive distances of those rough numbers are then treated as the inputs to a* $2^5$ *full-factorial design plan with the corresponding multi-attributivec border approximation area comparison (MABAC) scores as the output variables. Finally, a design of experiments (DoE)-based metamodel is formulated to interlink the computed MABAC scores with the considered criteria. The competing suppliers are ranked based on this rough-MABAC-DoE-based metamodel, which also easies out the computational steps when new suppliers are included in the decision making process.*

**Key words**: *Supplier selection; Rough numbers; MABAC; DoE; Metamodel*

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## 1. Introduction

In the light of present day COVID-19 pandemic situation, the importance of a robust supply chain management system has been reasserted. The goals of a supply chain have been newly oriented opting for a fair balance between the global and local networks. This has made industries in diverse sectors to reconsider their existing choices and identify the most reliable suppliers to keep their raw material supplies uninterrupted without compromising on quality, specially under uncertain environment. This problem has intensely been pronounced in the manufacturing sector which needs to keep up with its production to meet the global requirements irrespective of the prevailing situation (Vonderembse and Tracey, 1999). Iron and steel industry is one such important manufacturing sector that needs regular supplies of raw materials; therefore, a critical analysis is demanding while selecting an appropriate set of suppliers. It involves a well informed and rigorous research regarding the possible parameters based on which the candidate suppliers for a particular item should be evaluated to single out the most appropriate supplier while scraping out the unsuitable ones (Verma and Pullman, 1998). In this direction, application of any of the existing multi-criteria decision making (MCDM) techniques would be quite helpful as it has the ability to identify the most apposite supplier to provide the right quantity of material with right quality at right time and right price based on a set of conflicting evaluation criteria (Mukherjee, 2017).

The MCDM is the science which takes into account different criteria with varying degrees of importance to search out the most suitable option/course of action. The first step involves in development of the initial decision matrix exhibiting the relative performance of each of the candidate alternatives with respect to the considered criteria. In this step, there may be participation of a group of experts/decision makers, each opining and assigning performance scores to the available alternatives based on each criterion. In the second step, again based on the judgments of the decision makers, relative weights are allocated to all the criteria depending on their importance to the decision making problem under consideration. The final step involves in ranking of the set of alternatives from the best to the worst. The application potentiality of MCDM methodologies in solving complex manufacturing-related decision making problems has attracted attention of the researchers leading to the development of different innovative ranking techniques, like analytic hierarchy process (AHP) (Saaty, 1988), technique for order of preference by similarity to ideal solution (TOPSIS) (Behzadian et al., 2012), grey relational analysis (GRA) (Abdulshahed et al., 2017), multi-attributive border approximation area comparison (MABAC) (Pamučar and Ćirović, 2015), measurement of alternatives and ranking according to compromise solution (MARCOS) (Stević et al., 2020; Mahmutagić et al. 2021) etc. While all these methods have their unique mathematical foundations, their implementation in a manufacturing industry largely depends on the ease of implementation and ability to generate accurate ranking results. The MABAC is one such methodology which can provide a detailed analysis of the alternatives while partitioning them into upper, lower and border approximation areas along with identification of their relative strengths and weaknesses with respect to each of the criteria.

However, there is a major challenge associated with formulation of the decision matrix due to uncertainty/vagueness involved in human judgment. Usually, the criteria set based on which the candidate alternatives are assessed consists of both quantitative and qualitative attributes. For qualitative criteria, it becomes difficult for the team of decision makers to assign exact deterministic values. In these cases, performance scores of the alternatives with respect to the qualitative criteria are assigned based on imprecise linguistic judgments which greatly vary from one decision maker to the other. Although, it is remarkably important to account for this vagueness while solving critical decision making problems, like supplier selection, it cannot be denied that implementation of fuzzy MCDM techniques is more mathematically complex, involving choice of appropriate fuzzy membership functions affecting the final selection decision. In this direction, a lot of methodologies have already been proposed to aggregate the subjective performance scores of the alternatives. It has been noticed that application of rough numbers with uncomplicated mathematical steps can effectively resolve the problem of dealing with qualitative criteria in a decision making problem (Zhai et al., 2009). Rough numbers have efficiently been integrated with other MCDM tools, like analytic network process (ANP) and TOPSIS (Li et al., 2018), complex proportional assessment (COPRAS) (Matić et al., 2019), additive ratio assessment (ARAS) (Radović et al., 2018), AHP and MABAC (Roy et al., 2018; Pamučar et al., 2018a), best worst method (BWM) and weighted aggregated sum product assessment (WASPAS) (Stević et al., 2018; Stojić et al., 2018), BWM and simple additive weighting (SAW) (Stević et al., 2017), step-wise weight assessment ration analysis (SWARA) and WASPAS (Sremac et al., 2018), AHP and TOPSIS (Shojaei and Bolvardizadeh, 2020) etc.

In most of the MCDM techniques, the corresponding ranking results are derived based on pair-wise or relative comparisons between the candidate alternatives, which make the decision making process more tedious and time consuming. Whenever a new alternative enters into the decision making process or an existing alternative leaves the process, the entire computational procedure needs to be reinitiated from the scratch. In most of the practical situations, the set of alternatives always keeps on changing. For example, in an iron and steel industry, it has often been noticed that a new supplier may reach out, while an existing supplier may fall off the list due to poor/failing standards. Learning from the recent times of vulnerability and uncertainty, it is recommended to keep the list of participating suppliers always dynamic.

In this paper, an MCDM methodology integrating rough numbers, MABAC method and design of experiments (DoE) is proposed to account for the vagueness involved in the group decision making process while providing detailed analysis of the derived results at the same time. In an iron and steel industry, the relative performance of five participating suppliers is appraised by three decision makers with respect to five evaluation criteria based on a 1-9 scale. These subjective judgments of the decision makers are then aggregated to form the initial decision matrix using rough numbers. With five evaluation criteria, a $2^5$ full-factorial experimental design plan is formulated along with determination of the corresponding MABAC score for each of the experimental trials. In this methodology, different evaluation criteria and MABAC scores are respectively treated as the design parameters and responses in the DoE to develop a metamodel. Based on this metamodel, the composite score of any supplier can easily be calculated in a single step, thus relieving the decision maker from complex and time-consuming computational steps. In other MCDM techniques, the concerned decision maker needs to reinitiate the entire calculation steps when a new supplier enters into or leaves out the existing list of candidate alternatives. But, in this developed metamodel, the respective score along with the rank of a new supplier can easily be estimated while putting the corresponding performance values into the model. Similarly, the relative ranking of the suppliers can quickly be updated when an existing supplier leaves the appraisal process. Simply, the computational burden would be remarkably reduced using this metamodel in the supplier selection process.

The rest of this paper is organized as follows. Section 2 reviews the recent literature dealing with the application of different MCDM techniques in solving diverse supplier selection problems. In Section 3, mathematical details of rough numbers, MABAC method and DoE are presented. Section 4 deals with a case study where the proposed rough-MABAC-DoE method is adopted for identifying the most appropriate supplier in an Indian iron and steel industry. Conclusions are drawn in Section 5 along with the future directions.

## 2. Literature review

The present literature is flooded with the applications of various mathematical techniques, especially MCDM tools, for identification of the suitable suppliers to fulfill the requirements of a diverse range of organizations. The supplier selection process generally starts with listing the right set of criteria based on which the competing suppliers are appraised. This criteria set obviously varies from one industry to the other depending on the requirements and end products. The process terminates with the application of a suitable methodology to single out the most appropriate supplier for a given organization. Zimmer et al. (2016) conducted an exhaustive literature survey to list down all the possible criteria that can be accounted for selection of sustainable suppliers along with diverse methodologies implemented to rank them.

Luzon and El-Sayegh (2016) adopted Delphi method along with AHP to select suppliers for oil and gas projects, while classifying the considered criteria into techno-commercial and organizational aspects. Kumar et al. (2018) designed a capital procurement decision making model by integrating fuzzy-Delphi and AHP-decision making trial and evaluation laboratory (DEMATEL) methods for selecting suppliers for a given organization. Yazdani et al. (2017) proposed an integrated quality function deployment (QFD)-MCDM-based approach for green supplier selection while considering several important evaluation criteria, like quality adaptation, price, energy and natural resource consumption, and delivery speed. While treating cost of products, quality of products, service provided, capability of delivering on time, technology level, environmental management system and green packaging as the evaluation criteria, Abdullah et al. (2018) applied preference ranking organization method for enrichment of evaluations (PROMETHEE) for solving a green supplier selection problem. Badi et al. (2018) proposed the application of combinative distance-based assessment (CODAS) method for solving a supplier selection problem for a steel making industry in Libya, which considering quality, direct cost, lead time and logistics services as the main evaluation criteria. In a group decision making environment, Badi and Ballem (2018) integrated rough-BWM with multi-attribute ideal real comparative analysis (MAIRCA) to assess the performance of pharmaceutical suppliers based on cost, quality, supplier profile, delivery and flexibility criteria. A study was conducted by Banaeian et al. (2018) to evaluate and select green suppliers for an agri-food industry while combining fuzzy set theory with VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje), GRA and TOPSIS methods, and considering service level, quality, price and environmental management system as the evaluation criteria. Akcan and Güldeş (2019) applied several integrated MCDM methodologies, like AHP-TOPSIS, AHP-SAW, AHP-GRA and AHP-elimination et choice translating reality (ELECTRE) to rank suppliers based on logistics, cost, quality, flexibility and reliability criteria.

While accounting for the uncertainties involved in a group decision making process, Chattopadhyay et al. (2020) proposed the application of D-MARCOS method for solving a supplier selection problem in a steel industry with product quality, delivery compliance, price, technical capability, production capability, financial strength and electronic transaction capability as the evaluation criteria. In order to deal with both weighting of the criteria and uncertainty in group decision making, Javad et al. (2020) combined BWM with fuzzy TOPSIS to rank green suppliers in a steel company considering collaborations, environmental investments and economic benefits, resource availability, green competencies, environmental management initiatives, research and design initiatives, green purchasing capabilities, regulatory obligations, pressures and market demand as the major selection criteria. Stević et al. (2020) endeavored to prove the application potentiality of a new MCDM methodology in the form of MARCOS to assess and rank sustainable suppliers in healthcare sector with an exhaustive set of 21 criteria. Wang et al. (2020) first employed fuzzy-AHP method to determine weights of reliability, responsiveness, flexibility, cost and assets criteria, and later adopted PROMETHEE to rank the competing suppliers in a textile industry.

It has been revealed from the above-cited literature that selection of suppliers for varying organizations based on a set of conflicting evaluation criteria is really a complicated problem to solve, especially in group decision making environment involving a degree of uncertainty with respect to human judgments. To resolve this issue, several hybridized models have already been proposed. However, most of those models are computationally expensive which hinders their applications in real-time manufacturing scenario. In all those models, with the addition of a new alternative or deletion of an existing alternative from the set disrupts the entire calculation process and it needs to be reinitiated from the scratch in each occasion. Taking these drawbacks of the existing hybridized MCDM tools in solving supplier selection problems, this paper proposes to develop a DoE-based metamodel in the form of an regression equation while integrating rough numbers with the advantageous features of MABAC method. The performance scores of the alternative suppliers with respect to the evaluation criteria are aggregated using rough numbers in a group decision making environment having three participating decision makers and the competing suppliers are finally ranked from the best to the worst using the computed MABAC scores. Based on the developed metamodel, the performance score of a new supplier can easily be computed, thus relieving the concerned decision maker from lengthy repetitive calculation steps. Keeping in mind the requirements and importance of selection of suppliers, the applicability of this integrated rough-MABAC-DoE method is demonstrated here to appraise and rank five different suppliers in a leading steel manufacturer in India based on five pivotal criteria in a group decision making environment.

## 3. Methods

### 3.1. Rough numbers

One of the biggest challenges associated with group decision making is the uncertainty and vagueness involved in determining the relative weights of different criteria and performance appraisal of the candidate suppliers with respect to those criteria. In this direction, various methodologies, like fuzzy set theory, intuitionistic fuzzy set, D numbers etc. have been proposed. In this paper, the application potentiality of rough numbers in assessing the performance of the considered alternatives with regard to five evaluation criteria while solving a supplier selection problem is explored. Rough numbers have become popular due to their simplicity and adaptability while taking into account linguistic judgments of different decision makers based on boundary intervals using lower and upper limits (Zhai et al., 2008). Zhai et al. (2009) further introduced interval arithmetic to analyze and operate rough numbers.

Let $U$ be the universal set comprising all the objects, $X$ is an arbitrary object of $U$, and $R$ is a set of $n$ classes $R = (C_1, C_2, \ldots, C_n)$ covering all the objects in $U$. If these $n$ classes are ordered as $\{C_1 < C_2 < \ldots < C_n\}$, then $\forall X \in U, C_q \in R, 1 \leq q \leq n$, where $R(X)$ denotes the class to which the object belongs. The lower approximation $(\underline{Apr}(C_q))$, upper approximation $(\overline{Apr}(C_q))$ and boundary region $(Bnd(C_q))$ of class $C_q$ are given as below:

$$\overline{Apr}(C_q) = \cup\{X \in U / R(X) \geq C_q\} \tag{1}$$

$$\underline{Apr}(C_q) = \cup\{X \in U / R(X) \leq C_q\} \tag{2}$$

$$Bnd(C_q) = \{X \in U / R(X) > C_q\} \cup \{X \in U / R(X) < C_q\} \tag{3}$$

Thus, the class $C_q$ can be expressed as rough number $RN(C_q)$ with upper limit $(\overline{Lim}(C_q))$ and lower limit $(\underline{Lim}(C_q))$ defined as below (Chakraborty et al., 2020):

$$\overline{Lim}(C_q) = \frac{1}{M_U} \sum R(X) \mid X \in \overline{Apr}(C_q) \tag{4}$$

$$\underline{Lim}(C_q) = \frac{1}{M_L} \sum R(X) \mid X \in \underline{Apr}(C_q) \tag{5}$$

$$RN(C_q) = \left[\underline{Lim}(C_q), \overline{Lim}(C_q)\right] = \left[x_{ij}^L, x_{ij}^U\right] \tag{6}$$

where $M_U$ and $M_L$ are the number of objects in the upper and lower approximations respectively, and $x_{ij}^L$ and $x_{ij}^U$ are the lower and upper evaluation limits of $j^{th}$ criterion with respect to $i^{th}$ alternative respectively. The rough boundary interval (*RBnd*) can now be expressed as the difference between the upper and lower evaluation limits.

$$RBnd = \overline{Lim}(C_q) - \underline{Lim}(C_q) \quad (7)$$

A large value of *RBnd* symbolizes more vagueness, while, a small value represents more preciseness. It is often important to rank rough numbers to attain definitive results. Zhai et al. (2008) proposed a methodology for ranking of rough numbers. Let *RN*(*A*) and *RN*(*B*) be two rough numbers. If one rough boundary interval is not strictly bounded by the other, there may be two possibilities:

a) If $\overline{Lim}(A) > \overline{Lim}(B)$ and $\underline{Lim}(A) \geq \underline{Lim}(B)$ or
$\overline{Lim}(A) \geq \overline{Lim}(B)$ and $\underline{Lim}(A) > \underline{Lim}(B)$, then $RN(A) > RN(B)$.

b) If $\overline{Lim}(A) = \overline{Lim}(B)$ and $\overline{Lim}(A) = \overline{Lim}(B)$, then $RN(A) = RN(B)$.

However, if they are strictly bounded, they can be ranked based on their median values. Hence, the following three cases may be observed:

a) If $M(A) > M(B)$, then $RN(A) > RN(B)$
b) If $M(A) < M(B)$, then $RN(A) < RN(B)$
c) If $M(A) = M(B)$, then $RN(A) = RN(B)$

where *M*(*A*) and *M*(*B*) are the median values of rough numbers *RN*(*A*) and *RN*(*B*) respectively.

Let us assume $RN(\alpha) = [L_\alpha, U_\alpha]$ and $RN(\beta) = [L_\beta, U_\beta]$ where $L_\alpha$ and $L_\beta$ are the lower limits, and $U_\alpha$ and $U_\beta$ are the upper limits of the respective rough numbers. The following arithmetic rules can then be applied for interval analysis:

$$RN_\alpha + RN_\beta = [L_\alpha + L_\beta, U_\alpha + U_\beta] \quad (8)$$

$$RN_\alpha \times RN_\beta = [L_\alpha \times L_\beta, U_\alpha \times U_\beta] \quad (9)$$

$RN_\alpha \times k = [kL_\alpha, kU_\alpha]$, where *k* is a non-zero constant. (10)

In order to determine the distance between two rough numbers, the Euclidian distance equation is employed. Thus, *D*(*a*,*b*) represents the Euclidian distance between two rough numbers *RN*(*a*) and *RN*(*b*) such that $RN(a) = [a^-, a^+]$ and $RN(b) = [b^-, b^+]$.

$$D(a,b) = \sqrt{\frac{1}{2}\left(\left(a^- - b^-\right)^2 + \left(a^+ - b^+\right)^2\right)} \quad (11)$$

This property of rough numbers is employed to calculate the distance between the considered alternative for a given criterion and geometric aggregation value for that criterion. An illustration of the same can improve the understanding. Let us assume a decision matrix *X* having *n* alternatives ($A_1, A_2,...,A_i,...,A_n$) and *m* criteria ($C_1, C_2,...,C_j,...,C_m$) such that using rough numbers, the performance score for $i^{th}$ alternative against the considered set of criteria can be expressed as $A_i = \left(\left[x_{i1}^-, x_{i1}^+\right], \left[x_{i2}^-, x_{i2}^+\right], \Lambda, \left[x_{ij}^-, x_{ij}^+\right], \Lambda, \left[x_{im}^-, x_{im}^+\right]\right)$. The geometric aggregation value for $j^{th}$ criterion is given by $RN(f_j) = \left[f_j^-, f_j^+\right]$, where

$$f_j^- = \left( \prod_{i=1}^{n} x_{ij}^- \right)^{1/n} \tag{12}$$

$$f_j^+ = \left( \prod_{i=1}^{n} x_{ij}^+ \right)^{1/n} \tag{13}$$

This helps in formation of the distance matrix $Y = [y_{ij}]_{n \times m}$ from the initial matrix $X$ such that:

$$y_{ij} = \begin{cases} D(x_{ij}, f_j) \text{ if } RN(x_{ij}) > RN(f_j) \\ -D(x_{ij}, f_j) \text{ if } RN(x_{ij}) < RN(f_j) \end{cases} \quad \text{for beneficial criterion} \tag{14.a}$$

$$y_{ij} = \begin{cases} -D(x_{ij}, f_j) \text{ if } RN(x_{ij}) > RN(f_j) \\ D(x_{ij}, f_j) \text{ if } RN(x_{ij}) < RN(f_j) \end{cases} \quad \text{for cost criterion} \tag{14.b}$$

where

$$D(x_{ij}, f_j) = \sqrt{\frac{1}{2}\left( \left(x_{ij}^- - f_j^-\right)^2 + \left(x_{ij}^+ - f_j^+\right)^2 \right)} \tag{15}$$

### 3.2. Rough MABAC

MABAC is a newly developed and widely accepted MCDM technique (Pamučar and Ćirović, 2015) which primarily ranks a set of alternatives based on their distances from the border approximation area for each criterion. However, it has been modified from time to time to develop more purposeful hybrid models. In this paper, MABAC is integrated with rough numbers which is further fed into a DoE model to provide a generalized metamodel for evaluation and ranking of a set of suppliers. Considering a decision problem having $n$ alternatives ($A_1, A_2, \ldots, A_i, \ldots, A_n$) and $m$ criteria ($C_1, C_2, \ldots, C_j, \ldots, C_m$), the procedural steps of rough MABAC method are enumerated as below (Chakraborty et al., 2020):

*Step 1:* The decision matrix $X$ is constructed using rough numbers while taking into account the judgments of a team of experts/decision makers in assessing the relative performance of the suppliers with regard to the evaluation criteria.

$$X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} RN(x_{11}) & RN(x_{12}) & \cdots & RN(x_{1m}) \\ RN(x_{21}) & RN(x_{22}) & \cdots & RN(x_{2m}) \\ \vdots & \vdots & \vdots & \vdots \\ RN(x_{n1}) & RN(x_{n2}) & \cdots & RN(x_{nm}) \end{bmatrix} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} [x_{11}^-, x_{11}^+] & [x_{12}^-, x_{12}^+] & \cdots & [x_{1m}^-, x_{1m}^+] \\ [x_{21}^-, x_{21}^+] & [x_{22}^-, x_{22}^+] & \cdots & [x_{2m}^-, x_{2m}^+] \\ \vdots & \vdots & \vdots & \vdots \\ [x_{n1}^-, x_{n1}^+] & [x_{n2}^-, x_{n2}^+] & \cdots & [x_{nm}^-, x_{nm}^+] \end{bmatrix} \tag{16}$$

where $RN(x_{ij}) = [x_{ij}^-, x_{ij}^+]$

*Step 2*: Depending on the type of the criterion, the initial decision matrix $X$ is normalized to obtain the corersponding normalized decision matrix $N = \left[n_{ij}^{L}, n_{ij}^{U}\right]_{n \times m}$

$$RN(n_{ij}) = \begin{Bmatrix} \left[\dfrac{x_{ij}^{L} - x_{j}^{-}}{x_{j}^{+} - x_{j}^{-}}, \dfrac{x_{ij}^{U} - x_{j}^{-}}{x_{j}^{+} - x_{j}^{-}}\right], \text{if } j \in B, \\ \left[\dfrac{x_{ij}^{U} - x_{j}^{+}}{x_{j}^{-} - x_{j}^{+}}, \dfrac{x_{ij}^{L} - x_{j}^{+}}{x_{j}^{-} - x_{j}^{+}}\right], \text{if } j \in C, \end{Bmatrix} \tag{17}$$

where $x_{j}^{+} = \max_{i}(x_{ij}^{U}), x_{j}^{-} = \min_{i}(x_{ij}^{L})$. $B$ is the set of beneficial criteria and $C$ is the set of cost criteria.

*Step 3*: Determine the weight assigned to each criterion $W = (w_1, w_2, \ldots, w_j, \ldots, w_m)$ such that $\sum_{j=1}^{m} w_j = 1$. The weighted normalized decision matrix $Y = \left[y_{ij}^{L}, y_{ij}^{U}\right]_{n \times m}$ is now calculated using Eq. (18).

$$y_{ij}^{L} = \left(n_{ij}^{L} + 1\right) w_j;\ y_{ij}^{U} = \left(n_{ij}^{U} + 1\right) w_j,\ i = 1,2,\ldots,n,\ j = 1,2,\ldots,m \tag{18}$$

*Step 4*: The border approximation area (BAA) matrix is derived based on geometric aggregation of the rough numbers.

$$Q = \left[RN(q_1)\quad RN(q_2)\quad \ldots\quad RN(q_m)\right]$$

$$q_{j}^{L} = \left(\prod_{i=1}^{n} y_{ij}^{L}\right)^{1/n},\ j = 1,2,\ldots,m$$
$$q_{j}^{U} = \left(\prod_{i=1}^{n} y_{ij}^{U}\right)^{1/n},\ j = 1,2,\ldots,m \tag{19}$$

*Step 5:* The Eucledian distance of an alternative from the BAA is evaluated based on the difference between the border approximation area and the weighted normalized matrix, and is represented by the matrix $K = \left[RN(k_{ij})\right]_{n \times m}$.

$$k_{ij} = D(y_{ij}, q_j) = \sqrt{\frac{1}{2}\left(\left(y_{ij}^{L} - q_{j}^{L}\right)^2 + \left(y_{ij}^{U} - q_{j}^{U}\right)^2\right)}\ \text{if}\ RN(y_{ij}) > RN(q_j) \tag{20}$$

$$k_{ij} = -D(y_{ij}, q_j) = -\sqrt{\frac{1}{2}\left(\left(y_{ij}^{L} - q_{j}^{L}\right)^2 + \left(y_{ij}^{U} - q_{j}^{U}\right)^2\right)}\ \text{if}\ RN(y_{ij}) < RN(q_j)$$

*Step 6*: The considered alternatives are finally ranked in descending order of $S_i$ values.

$$S_i = \sum_{j=1}^{m} k_{ij}\ (i = 1,2,\ldots,n) \tag{21}$$

### 3.3 Design of experiments

The DoE is a statistical methodology to help in determining the influence of independent factors/variables as well as effect of their interactions on the system response (dependent variable). Each of these factors can operate at different levels and hence, several experiments need to be performed to study the effects of factor level variations on the system under consideration. It has already established itself as a helpful tool for engineers and decision makers to develop strong mathematical metamodels based on experimental results. A full-factorial design proves to be exhaustive as it includes all the possible combinations for the factors at each of their corresponding levels. However, implementation of a full-factorial design plan is computationally expensive and time consuming. In these cases, a suitable subset of factor level combinations is selected resulting in a fractional factorial experiment design plan. In this paper, a two-level full-factorial experimental design plan is adopted to visualize how the considered evaluation criteria influence the MABAC scores for alternative suppliers. The metamodel linking the dependant variable (MABAC score) with *m* independent variables (criteria) is expressed as below:

$$Y = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \Lambda + \beta_m x_{im} + \varepsilon \tag{22}$$

where $Y$ is the response variable (MABAC score), $\beta_0$ is the $y$-intercept coefficient, $\beta_1$-$\beta_m$ are the effect coefficients for $m$ criteria, $x_1$-$x_m$ are the input variables and $\varepsilon$ is the error term. The main effect of each input variable is presumed to be independent of the other variables. In this metamodel, interaction effects can also be considered to explore the presence of interactions between the input variables.

In this paper, a two-level full-factorial design plan is adopted with $2^5$ combinations, where only the minimum and maximum intervals for each factor (criterion) are considered to develop the corresponding factorial design. The related distance values of these intervals are subsequently treated as the inputs and MABAC scores as the outputs to the DoE for development of the required metamodel.

## 4. Development of a rough-MABAC-DoE-based metamodel

It has already been noticed that the manufacturing industries often face problems while indentifying the best alternative/course of action amid a set of conflicting criteria. This paper proposes a new methodology for evaluation and ranking of competing suppliers based on a developed metamodel in an Indian iron and steel industry. The existing MCDM techniques suffer from a major drawback, i.e. when a new alternative is introduced in the decision making problem, the entire computational process needs to be reinitiated from the scratch to derive the ranking of the candidate alternatives, which often constrains their applications in real-time situations. In the proposed method, once the rough-MABAC-DoE-based metamodel is formulated, the concerned decision maker can easily estimate the corresponding MABAC score for a new supplier based on its performance and position it in the revised ranking list. The application potentiality of this method is illustrated as a case study in an Indian iron and steel industry with an annual production of around 2.4 million tonnes of crude steel. Like any other industry operating at such a large scale, it also houses a large number of machineries which need to be maintained from time to time for uninterrupted production. This creates requirement for large varieties of gearboxes to be procured from the suppliers across the globe. At this stage, it becomes essential to choose the most apposite supplier who can deliver the right quality of gearboxes at right quantity, right price and right time. It is worthwhile to mention here that while selecting the most suitable supplier for a manufacturing industry, the set of evaluation criteria usually varies depending on the item/product to be purchased. In a group decision making environment, assessment of the candidate suppliers with respect to the considered criteria also varies from one decision maker to the other depending on the experience and expertise of each of the participating decision makers. To deal with this problem, i.e. selection of suppliers for providing gearboxes in the iron and steel industry, the opinions of three decision makers ($DM_1$, $DM_2$ and $DM_3$) are sought. These decision makers have been respectively selected from the finance, materials management and mechanical technical bureau of the organization having 15, 20 and 15 years of job experience. Tables 1 and 2 exhibit the list of evaluation criteria and candidate suppliers considered for this supplier selection problem. For having replications in the experimental design plan while developing the corresponding metamodel, two sets of criteria weights are chosen based on the judgments of the decision makers. In this direction, other subjective techniques for criteria weight measurement, like BWM (Rezaei, 2015), full consistency method (FUCOM) (Pamučar et al., 2018b; Durmić et al. 2020), level based weight assessment (LBWA) (Žižović and Pamučar, 2019) etc. can also be applied. These criteria weights are so selected that their summation must be always one. Amongst these criteria, delivery compliance and price are non-beneficial (cost) attributes requiring their lower values, whereas, higher values are desired for the remaining three beneficial criteria.

*Table 1. Description of the evaluation criteria*

| Criterion | Description | Weight | |
|---|---|---|---|
| Product quality ($C_1$) | It accounts for credibility of the product with respect to its expected performance and quality. | 0.318 | 0.300 |
| Delivery compliance ($C_2$) | It considers the time taken to fulfill an order once it has been placed even in uncertain situations. Meeting the delivery schedule is extremely important to maintain uninterrupted production of the end products. | 0.226 | 0.240 |
| Price ($C_3$) | It is the monetary value of an item that the organization has to pay to the supplier against its delivery. | 0.206 | 0.200 |
| Technological capability ($C_4$) | It deals with the capability of a supplier to remain updated with the state-of-the-art technologies to fulfil the requirements of the modern day manufacturing organizations. | 0.132 | 0.138 |
| Production capability ($C_5$) | It focuses on the competence of a supplier to provide the required quality and quantity of products, especially in times of fluctuating demands. | 0.118 | 0.122 |

In order to single out the most suitable supplier for the identified product, the decision makers now appraise the performance of each of the candidate suppliers with respect to five evaluation criteria, while assigning scores based on a 1-9 scale, where 1-2 indicate poor performance, 3-7 denote moderate performance and 8-9 signify satisfactory performance. This performance appraisal process by the three participating suppliers is exhibited through Tables 3-5 in the form of evaluation matrixes. From Table 3, it can be revealed that $DM_1$ assesses the performance of supplier $S_1$ with respect to criteria $C_1$ = 4 (moderate), $C_2$ = 3 (moderate), $C_3$ = 2 (poor), $C_4$ = 6 (moderate) and $C_5$ = 8 (satisfactory). Rough numbers are now employed to aggregate the individual judgments of the three decision makers. For example, the set of performance ratings for supplier $S_1$ with respect to criterion $C_1$ as evaluated by the three decision makers is expressed as $x_{11} = \{4, 6, 7\}$. Based on Eqs. (4)-(6), this set of subjective linguistic information is converted into the corresponding rough numbers as below:

For element $x_{11} = \{4, 6, 7\}$

$$\underline{Lim}(4) = 4.00, \overline{Lim}(4) = \frac{1}{3}(4+6+7) = 5.67,$$

$$\underline{Lim}(6) = \frac{1}{2}(4+6) = 5.00, \overline{Lim}(6) = \frac{1}{2}(6+7) = 6.50$$

$$\underline{Lim}(7) = \frac{1}{3}(4+6+7) = 5.67, \overline{Lim}(7) = 7.00$$

$$RN(x_{11}^1) = [4.00, 5.67], RN(x_{11}^2) = [5.00, 6.50], RN(x_{11}^3) = [5.67, 7.00]$$

$$x_{11}^L = \frac{4.00 + 5.00 + 5.67}{3} = 4.88, \; x_{11}^U = \frac{5.67 + 6.50 + 7.00}{3} = 6.39$$

*Table 2. List of the candidate suppliers*

| Supplier | Description |
|---|---|
| $S_1$ | While this supplier proves to be a cheaper alternative with reputable delivery compliance, it does not appear to be the most suitable option under emergency situations. |
| $S_2$ | It is a public sector organization situated in the eastern India. While it is reputed for its technological strength and reliability, there are situations when it fails to meet the supply deadlines. |
| $S_3$ | This organization manufacturing premium gearboxes has customers all over the country. However, there is a substantial tradeoff with respect to robustness of its supply chains and adaption to changing technological scenario. |
| $S_4$ | It is a reputed organization established in the southern India, always adhering to the specified delivery schedules while supplying gearboxes of perfect quality. However, it offers higher price for its products as compared to other suppliers. |
| $S_5$ | It is a relatively new organization, yet to capture its reputation in the market and stabilize its delivery modes. |

In this way, all the performance assessment scores assigned by the three decision makers are aggregated using rough numbers to formulate the corresponding combined evaluation matrix, as shown in Table 6. In this table, the beneficial and cost criteria are also identified along with their best and worst rough intervals. For example, with respect to product quality, $S_4$ performs the best, $S_1$ ensures the best delivery compliance at the lowest price, $S_2$ has the highest technological capability and $S_1$ exhibits the highest production capability.

*Table 3. Evaluation matrix by $DM_1$*

| Criteria / Supplier | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $S_1$ | 4 | 3 | 2 | 6 | 8 |
| $S_2$ | 7 | 2 | 4 | 7 | 4 |
| $S_3$ | 8 | 3 | 2 | 5 | 6 |
| $S_4$ | 6 | 4 | 4 | 8 | 9 |
| $S_5$ | 7 | 5 | 3 | 6 | 5 |

*Table 4. Evaluation matrix by $DM_2$*

| Criteria / Supplier | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $S_1$ | 6 | 2 | 3 | 7 | 5 |
| $S_2$ | 7 | 3 | 3 | 8 | 6 |
| $S_3$ | 8 | 4 | 2 | 6 | 7 |
| $S_4$ | 7 | 2 | 4 | 5 | 8 |
| $S_5$ | 7 | 4 | 2 | 6 | 7 |

*Table 5. Evaluation matrix by $DM_3$*

| Criteria / Supplier | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $S_1$ | 7 | 2 | 3 | 8 | 6 |
| $S_2$ | 8 | 4 | 2 | 7 | 7 |
| $S_3$ | 7 | 3 | 4 | 6 | 6 |
| $S_4$ | 8 | 2 | 3 | 7 | 8 |
| $S_5$ | 6 | 3 | 4 | 5 | 5 |

*Table 6. Aggregated evaluation matrix*

| Criteria / Supplier | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $S_1$ | [4.88,6.39] | [2.11,2.55] | [2.44,2.88] | [6.50,7.50] | [5.61,7.11] |
| $S_2$ | [7.11,7.55] | [2.5,3.50] | [2.5,3.5] | [7.11.7.55] | [4.88,6.39] |
| $S_3$ | [7.44,7.88] | [3.11,3.55] | [2.22,3.11] | [5.44,5.88] | [6.11,6.55] |
| $S_4$ | [6.50,7.50] | [2.22,3.11] | [3.44,3.88] | [5.88,7.38] | [8.11,8.55] |
| $S_5$ | [6.44,6.88] | [3.50,4.50] | [2.50,3.50] | [5.44,5.88] | [5.22,6.11] |
| Min/Max | Max | Min | Min | Max | Max |
| Best | [7.44,7.88] | [2.11,2.55] | [2.44,2.88] | [7.11,7.55] | [8.11,8.55] |
| Worst | [4.88,6.39] | [3.50,4.50] | [3.44,3.88] | [5.44,5.88] | [4.88,6.39] |

In order to develop the corresponding metamodel, five supplier selection criteria are treated as the input variables, whereas, the computed MABAC score is the output variable. To represent the two-level combinations for these five input variables, a $2^5$ full-factorial design plan having 32 experiments is proposed in Table 7 while considering only the worst and best rough intervals of each input variable in the experiment plan. Now, employing Eqs. (12)-(15), the corresponding value of definitive distance for each of the rough intervals is computed, as shown in Table 8.

For example, in case of criterion $C_1$, the geometric aggregation is given as: $RN(f_1) = \left[f_1^-, f_1^+\right]$ where $f_1^- = (4.88 \times 7.11 \times 7.44 \times 6.50 \times 6.44)^{1/5} = 6.41$ and $f_1^+ = (6.39 \times 7.55 \times 7.88 \times 7.50 \times 6.88)^{1/5} = 7.22.$

*Table 7. $2^5$ full factorial design plan with rough intervals of the considered criteria*

| Experiment | Factor level | | | | |
|---|---|---|---|---|---|
| No. | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
| 1 | [7.44,7.88] | [2.11,2.55] | [2.44,2.88] | [7.11,7.55] | [8.11,8.55] |
| 2 | [4.88,6.39] | [2.11,2.55] | [2.44,2.88] | [7.11,7.55] | [8.11,8.55] |
| 3 | [7.44,7.88] | [3.50,4.50] | [2.44,2.88] | [7.11,7.55] | [8.11,8.55] |
| 4 | [4.88,6.39] | [3.50,4.50] | [2.44,2.88] | [7.11,7.55] | [8.11,8.55] |
| 5 | [7.44,7.88] | [2.11,2.55] | [3.44,3.88] | [7.11,7.55] | [8.11,8.55] |
| 6 | [4.88,6.39] | [2.11,2.55] | [3.44,3.88] | [7.11,7.55] | [8.11,8.55] |
| 7 | [7.44,7.88] | [3.50,4.50] | [3.44,3.88] | [7.11,7.55] | [8.11,8.55] |
| 8 | [4.88,6.39] | [3.50,4.50] | [3.44,3.88] | [7.11,7.55] | [8.11,8.55] |
| 9 | [7.44,7.88] | [2.11,2.55] | [2.44,2.88] | [5.44,5.88] | [8.11,8.55] |
| 10 | [4.88,6.39] | [2.11,2.55] | [2.44,2.88] | [5.44,5.88] | [8.11,8.55] |
| 11 | [7.44,7.88] | [3.50,4.50] | [2.44,2.88] | [5.44,5.88] | [8.11,8.55] |
| 12 | [4.88,6.39] | [3.50,4.50] | [2.44,2.88] | [5.44,5.88] | [8.11,8.55] |
| 13 | [7.44,7.88] | [2.11,2.55] | [3.44,3.88] | [5.44,5.88] | [8.11,8.55] |
| 14 | [4.88,6.39] | [2.11,2.55] | [3.44,3.88] | [5.44,5.88] | [8.11,8.55] |
| 15 | [7.44,7.88] | [3.50,4.50] | [3.44,3.88] | [5.44,5.88] | [8.11,8.55] |
| 16 | [4.88,6.39] | [3.50,4.50] | [3.44,3.88] | [5.44,5.88] | [8.11,8.55] |
| 17 | [7.44,7.88] | [2.11,2.55] | [2.44,2.88] | [7.11,7.55] | [4.88,6.39] |
| 18 | [4.88,6.39] | [2.11,2.55] | [2.44,2.88] | [7.11,7.55] | [4.88,6.39] |
| 19 | [7.44,7.88] | [3.50,4.50] | [2.44,2.88] | [7.11,7.55] | [4.88,6.39] |
| 20 | [4.88,6.39] | [3.50,4.50] | [2.44,2.88] | [7.11,7.55] | [4.88,6.39] |
| 21 | [7.44,7.88] | [2.11,2.55] | [3.44,3.88] | [7.11,7.55] | [4.88,6.39] |
| 22 | [4.88,6.39] | [2.11,2.55] | [3.44,3.88] | [7.11,7.55] | [4.88,6.39] |
| 23 | [7.44,7.88] | [3.50,4.50] | [3.44,3.88] | [7.11,7.55] | [4.88,6.39] |
| 24 | [4.88,6.39] | [3.50,4.50] | [3.44,3.88] | [7.11,7.55] | [4.88,6.39] |
| 25 | [7.44,7.88] | [2.11,2.55] | [2.44,2.88] | [5.44,5.88] | [4.88,6.39] |
| 26 | [4.88,6.39] | [2.11,2.55] | [2.44,2.88] | [5.44,5.88] | [4.88,6.39] |
| 27 | [7.44,7.88] | [3.50,4.50] | [2.44,2.88] | [5.44,5.88]] | [4.88,6.39] |
| 28 | [4.88,6.39] | [3.50,4.50] | [2.44,2.88] | [5.44,5.88] | [4.88,6.39] |
| 29 | [7.44,7.88] | [2.11,2.55] | [3.44,3.88] | [5.44,5.88] | [4.88,6.39] |
| 30 | [4.88,6.39] | [2.11,2.55] | [3.44,3.88] | [5.44,5.88] | [4.88,6.39] |
| 31 | [7.44,7.88] | [3.50,4.50] | [3.44,3.88] | [5.44,5.88] | [4.88,6.39] |
| 32 | [4.88,6.39] | [3.50,4.50] | [3.44,3.88] | [5.44,5.88] | [4.88,6.39] |

Based on Eq. (14), as [7.44,7.88] > [6.41,7.22], the definitive distance for the best interval of $C_1$ can be estimated as $D = \sqrt{\frac{1}{2}\left((7.44-6.41)^2 + (7.88-7.22)^2\right)} = 0.865$. Similarly, as [4.88,6.39] < [6.41,7.22], the definitive distance for the worst interval of $C_1$ can be calculated as $D = -\sqrt{\frac{1}{2}\left((4.88-6.41)^2 + (6.39-7.22)^2\right)} = -1.231.$

*Table 8. Definitive distance matrix along with the MABAC scores*

| Experiment No. | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | MABAC score | |
|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 |
| 1 | 0.865 | 0.696 | 0.355 | 0.928 | 1.960 | 0.345 | 0.345 |
| 2 | -1.231 | 0.696 | 0.355 | 0.928 | 1.960 | 0.124 | 0.135 |
| 3 | 0.865 | -0.998 | 0.355 | 0.928 | 1.960 | 0.184 | 0.174 |
| 4 | -1.231 | -0.998 | 0.355 | 0.928 | 1.960 | -0.037 | -0.036 |
| 5 | 0.865 | 0.696 | -0.704 | 0.928 | 1.960 | 0.215 | 0.220 |
| 6 | -1.231 | 0.696 | -0.704 | 0.928 | 1.960 | -0.006 | 0.010 |
| 7 | 0.865 | -0.998 | -0.704 | 0.928 | 1.960 | 0.054 | 0.049 |
| 8 | -1.231 | -0.998 | -0.704 | 0.928 | 1.960 | -0.167 | -0.161 |
| 9 | 0.865 | 0.696 | 0.355 | -0.771 | 1.960 | 0.239 | 0.235 |
| 10 | -1.231 | 0.696 | 0.355 | -0.771 | 1.960 | 0.018 | 0.025 |
| 11 | 0.865 | -0.998 | 0.355 | -0.771 | 1.960 | 0.078 | 0.064 |
| 12 | -1.231 | -0.998 | 0.355 | -0.771 | 1.960 | -0.143 | -0.146 |
| 13 | 0.865 | 0.696 | -0.704 | -0.771 | 1.960 | 0.109 | 0.110 |
| 14 | -1.231 | 0.696 | -0.704 | -0.771 | 1.960 | -0.112 | -0.100 |
| 15 | 0.865 | -0.998 | -0.704 | -0.771 | 1.960 | -0.052 | -0.061 |
| 16 | -1.231 | -0.998 | -0.704 | -0.771 | 1.960 | -0.273 | -0.271 |
| 17 | 0.865 | 0.696 | 0.355 | 0.928 | -0.797 | 0.256 | 0.254 |
| 18 | -1.231 | 0.696 | 0.355 | 0.928 | -0.797 | 0.035 | 0.044 |
| 19 | 0.865 | -0.998 | 0.355 | 0.928 | -0.797 | 0.095 | 0.083 |
| 20 | -1.231 | -0.998 | 0.355 | 0.928 | -0.797 | -0.126 | -0.127 |
| 21 | 0.865 | 0.696 | -0.704 | 0.928 | -0.797 | 0.126 | 0.129 |
| 22 | -1.231 | 0.696 | -0.704 | 0.928 | -0.797 | -0.095 | -0.081 |
| 23 | 0.865 | -0.998 | -0.704 | 0.928 | -0.797 | -0.035 | -0.042 |
| 24 | -1.231 | -0.998 | -0.704 | 0.928 | -0.797 | -0.256 | -0.252 |
| 25 | 0.865 | 0.696 | 0.355 | -0.771 | -0.797 | 0.150 | 0.144 |
| 26 | -1.231 | 0.696 | 0.355 | -0.771 | -0.797 | -0.071 | -0.066 |
| 27 | 0.865 | -0.998 | 0.355 | -0.771 | -0.797 | -0.011 | -0.027 |
| 28 | -1.231 | -0.998 | 0.355 | -0.771 | -0.797 | -0.232 | -0.237 |
| 29 | 0.865 | 0.696 | -0.704 | -0.771 | -0.797 | 0.020 | 0.019 |
| 30 | -1.231 | 0.696 | -0.704 | -0.771 | -0.797 | -0.201 | -0.191 |
| 31 | 0.865 | -0.998 | -0.704 | -0.771 | -0.797 | -0.141 | -0.152 |
| 32 | -1.231 | -0.998 | -0.704 | -0.771 | -0.797 | -0.362 | -0.362 |

Based on the procedural steps of MABAC method, the corresponding scores are computed for all the experimental trials using two different criteria weight sets. Thus, for each combination of factor levels, two MABAC scores are calculated at two replications. Assignment of different criteria weight sets results in different MABAC scores. This experimental design plan with definitive distance values as the inputs and MABAC scores as the responses is now analyzed using MINITAB (R17) software which results in subsequent development of the corresponding metamodal and analysis of variance (ANOVA) table. This metamodel in the following form can not only account for the main effects of different factors, but can also highlight the existent interactions among them.

$$Y = \beta_0 + \sum_{i=1}^{5} \beta_i x_i + \sum_i \sum_{j_{i<j}} \beta_{ij} x_i x_j + \sum_i \sum_j \sum_{k_{i<j<k}} \beta_{ijk} x_i x_j x_k + \sum_i \sum_j \sum_k \sum_{l_{i,j<k<l}} \beta_{ijkl} x_i x_j x_k x_l + \beta_{12345} x_1 x_2 x_3 x_4 x_5 \quad (23)$$

where $Y$ is the MABAC score, $\beta_0$ is the intercept coefficient or overall mean response, $\beta_i$ is the main or first-order effect of factor $i$, $\beta_{ij}$ is the two-factor interaction between factors $i$ and $j$ ($i \neq j$), $\beta_{ijk}$ is the three-factor interaction between $i$, $j$ and $k$ ($i \neq j \neq k$), $\beta_{ijkl}$ is the four-factor interaction between $i$, $j$, $k$ and $l$ ($i \neq j \neq k \neq l$), and $\beta_{12345}$ is the five-factor interaction between all the factors.

*Table 9. Estimated effects and coefficients*

| Term | Effect | Coefficient | SE of coefficient | $t$-value | $p$-value |
|---|---|---|---|---|---|
| **Constant** | | **-0.00597** | **0.00283** | **-2.11** | **0.043** |
| **$C_1$** | **0.21044** | **0.10522** | **0.00283** | **37.12** | **0.000** |
| **$C_2$** | **0.17106** | **0.08553** | **0.00283** | **30.18** | **0.000** |
| **$C_3$** | **0.12244** | **0.06122** | **0.00283** | **21.60** | **0.000** |
| **$C_4$** | **0.11306** | **0.05653** | **0.00283** | **19.94** | **0.000** |
| **$C_5$** | **0.08494** | **0.04247** | **0.00283** | **14.98** | **0.000** |
| $C_1 \times C_2$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_3$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_4$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_2 \times C_3$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_2 \times C_4$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_2 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_3 \times C_4$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_3 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_4 \times C_5$ | -0.0×0506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_2 \times C_3$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_2 \times C_4$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_2 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_3 \times C_4$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_3 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_4 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_2 \times C_3 \times C_4$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_2 \times C_3 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_2 \times C_4 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_3 \times C_4 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_2 \times C_3 \times C_4$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_2 \times C_3 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_1 \times C_2 \times C_4 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_3 \times C_4 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |
| $C_2 \times C_3 \times C_4 \times C_5$ | 0.00506 | 0.00253 | 0.00283 | 0.89 | 0.379 |
| $C_1 \times C_2 \times C_3 \times C_4 \times C_5$ | -0.00506 | -0.00253 | 0.00283 | -0.89 | 0.379 |

Table 9 shows the effects and coefficients of different factors along with their varied levels of interactions, while Table 10 exhibits the derived ANOVA results based on the calculated MABAC scores. These ANOVA results provide a summary of the main effects and interactions between various factors. In table 9, the $p$-values help in identifying statistically significant factors and interaction effects. Terms with $p$-value less than or equal to 0.05 are considered to be statistically significant, whereas, those with $p$-value greater than 0.05 can be neglected while developing the corresponding metamodel. In this table, the column 'Term' depicts the main effects and all the possible interactions among the factors. The 'Effect' column shows the relative strength of a particular factor or interaction. The $\beta$ coefficients and their standard errors (SE) are provided in the third and fourth columns respectively. The last two columns highlight the calculated $t$- and $p$-values. In Tables 9-10, the rows of all the significant factors ($p \leq 0.05$) are shown in bold face. Based on the derived results, it can be concluded that all the two-way, three-way, four-way and five-way interactions are statistically insignificant, whereas, all the main effects due to criteria $C_1$, $C_2$, $C_3$, $C_4$ and $C_5$ have independently significant contributions in calculating the MABAC score. Thus, the metamodel for obtaining the MABAC score for a given supplier based on the evaluation criteria can be expressed as below:

$$Y = -0.00597 + 0.10522\times C_1 + 0.08553\times C_2 + 0.06122\times C_3 + 0.05653\times C_4 + 0.04247\times C_5 \quad (24)$$

In Table 10, the $R^2$ value is the square of correlation coefficient indicating the percentage of variation explained by the developed metamodel out of the total variation. On the other hand, the value of $R^2$(adj) represents the proportion of variation in the target variable contributed by the statistically significant terms. It can be concluded that 99.07% of the variation in the dependant variable $Y$ (MABAC score) can be explained by the variation of the independent variables in this metamodel. Extremely high values of both $R^2$ and $R^2$(adj) as 99.07% and 98.16% respectively thus confirm the acceptance of the developed metamodel in exhibiting the relationship between MABAC score and supplier selection criteria.

*Table 10. ANOVA results*

| Source | DoF | Adj. SS | Adj. MS | $t$-value | $p$-value |
|---|---|---|---|---|---|
| **Linear** | **5** | **1.73656** | **0.347311** | **675.46** | **0.000** |
| 2-way interaction | 10 | 0.00410 | 0.000410 | 0.80 | 0.632 |
| 3-way interaction | 10 | 0.00410 | 0.000410 | 0.80 | 0.632 |
| 4-way interaction | 5 | 0.00205 | 0.000410 | 0.80 | 0.560 |
| 5-way interaction | 1 | 0.00041 | 0.000410 | 0.80 | 0.379 |
| Error | 32 | 0.01645 | 0.000514 | | |
| Total | 63 | 1.76367 | | | |
| $R^2$ = 99.07%, $R^2$(adj) = 98.16% | | | | | |

Now, based on this model, the corresponding MABAC scores for the five alternative suppliers are determined as $Y_1$ = -0.0301, $Y_2$ = 0.0746, $Y_3$ = 0.0175, $Y_4$ = 0.1100 and $Y_5$ = -0.1990 (where $Y_i$ is the MABAC score for $i^{th}$ supplier). When these MABAC scores are arranged in descending order, a complete ranking of the competing suppliers from the best to the worst can be derived. Thus, $S_4$ emerges out as the most competent supplier for providing gearboxes to the iron and steel industry under consideration, followed by suppliers $S_2$ and $S_3$. In the derived ranking list of the suppliers, $S_5$ performs the worst. In Table 11, the rankings of the considered suppliers derived using rough-MABAC-DoE-based metamodel are contrasted with those obtained using rough-TOPSIS, rough-EDAS, rough-ARAS and rough-WASPAS-DoE-based metamodels. It can be revealed that except rough-EDAS, the ranking of the most favoured supplier ($S_4$) matches for all the remaining rough-MCDM-DoE-based metamodels. High Spearman's rank correlation coefficients ($r_s$) prove the application potentiality of rough-MABAC-DoE-based metamodel in solving supplier selection problems.

*Table 11. Comparison of rankings of the suppliers using different rough MCDM methods*

| Supplier | MABAC | TOPSIS | EDAS | ARAS | WASPAS |
|---|---|---|---|---|---|
| $S_1$ | 4 | 5 | 5 | 5 | 5 |
| $S_2$ | 2 | 2 | 1 | 2 | 2 |
| $S_3$ | 3 | 3 | 3 | 3 | 3 |
| $S_4$ | 1 | 1 | 2 | 1 | 1 |
| $S_5$ | 5 | 4 | 4 | 4 | 4 |
| $r_s$ | - | 0.90 | 0.80 | 0.90 | 0.90 |

## 4. Conclusions

This paper proposes a novel approach to solve a supplier selection problem in an Indian iron and steel industry while integrating rough numbers with MABAC method and DoE leading to the development of a metamodel. Its application starts with aggregation of the relative performance scores of five competing suppliers using rough numbers considering the uncertainty involved in the decision making process. Based on the worst and best rough number intervals, a $2^5$ full-factorial experimental design plan is formulated with subsequent conversion of those rough intervals into the corresponding definitive distances. Using two different criteria weight sets as the replications, the related MABAC scores are computed for all the experiment trials. Finally, a metamodel is developed interlinking the MABAC scores and supplier evaluation criteria, which is finally employed to rank the competing suppliers. Its main advantage lies on easy computation of the performance score (in terms of MABAC score) for a new supplier to be included in the decision making process, thus relieving the decision maker from reinitiating the entire calculation from the scratch. Besides its application in iron and steel industry, it can also be efficiently employed in other sectors, like healthcare, tourism, food, textile etc. The possibility of similar hybridization with other MCDM techniques, like MARICA, MARCOS, combined compromise solution (CoCoSo) etc. for solving supplier selection problems can be explored as the future scope of this paper. Two sets of criteria weights are considered here based on the opinions of the decision makers, helping in replication of the MABAC scores. Other subjective methods, like BWM, FUCOM or LBWA can also be applied for estimating the corresponding criteria weights. The main limitation of the proposed approach is that its computational complexity would monotonically increase for high-dimensional decision making problems having large number of evaluation criteria.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 41-55*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta190222061s*

# CRITERIA SELECTION AND DECISION MAKING OF HOTELS USING DOMINANCE BASED ROUGH SET THEORY

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Received: 16 June 2021
Accepted: 24 December 2021
First online: 19 February 2022

*Research article*

***Abstract:*** *Accommodation is one of the necessities of tourists and travel agencies' significant responsibilities. With the growing competition and profit-making various tour organising companies have started providing attractive accommodation options to the travellers to win their choices. Present research performs a case study on accommodation providing hotels through designing a strategy to enhance their profit earrings by welcoming more and more tourists. The methodology comprises rough set theory (RST) using the Dominance Based rough set theory (DRST) on the collected data of selected variables such as location, facility, value for money, etc., of hotels. Correspondingly, if and then decision rule has been used to classify these variables. The statistical methods regression analysis has also been used to define each variable's relationship and influence on concerned authorities' decision-making. The results show that hotels and tourists can benefit from the proposed strategy and help in decision making by understanding tourist behaviour, increasing profit, improving services, and quality of hotels.*

**Keywords**: *Hotel criteria, Dominance-based rough set theory, regression analysis, decision making.*

## 1. Introduction

The Indian tourism industry has been growing rapidly in the past decades. The tourism places attract tourists from all over the world, which makes Indian Tourism a direct contributor to the Economy. According to the Indian Ministry of Tourism Annual report, the tourism industry contributed 6.23% to National Gross Domestic Product (GDP) in the year 2018-2019, where the tourism industry growth rate is

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increased from 3.0 to 14.12% percent from the year 2014 to 2019 respectively. This growth rate supports the rise in competition in hotels which are one of the main contributors to the tourism industry. The tourism industry became another crucial source of foreign exchange and new job creation by providing 8.78% of jobs in India. The global trends show that the Indian tourism sector is one of the fast-growing industries which will proliferate in future (Sharma and Kalotra, 2016). In 2019, Travel & Tourism Competitiveness Index (2019) had confirmed that India secures at 34th place in the travel and tourism business. In contrast, in terms of cost-effectiveness and business environment, it lies at 13 and 39 positions in worldwide competitiveness.

There has been a progressive growth of tourism and hospitality management worldwide in the past decade (Mohajerani and Miremadi, 2012). As well as growing competition in the tourism business, management systems are trying to create equilibrium between the ethics of the business world and customer accommodation without compromising the quality of services to the customers in the hotels business (Sohrabi et al., 2012). In other words, priority must be given to customer satisfaction. With increased competition in the hotel and tourism industry, the hotel management system must find the opportunity and threats of the quality of service they provided to their customers (Chu and Choi, 2000). The hotel business can proliferate only when the hotel offers high-quality services to their customers, which promotes long-term relationships among customers and the hotel management system (Martin, 1986; Croby et al., 1990).

Further, consider the creating steadiness of actual customer state of mind with customer ratings, i.e., establishing the linkage among actual customer ratings given by the customers to hotels management system with genuine customer sentiments (Geetha et al., 2017). As tourism is considered an essential business activity for the hotel and tourism industry thus hotel management and tour agencies should introduce new advancements initiatives like adequate and flexible customer services for promoting business and attracting more customers (Hsieh and Lin, 2010). It shows that customer satisfaction is a vital measurement and essential to hotels. Thus to maintain customer services and to satisfy customers, hotel management and tourism agencies have to keep their adequate flexibility in their services and also introduce promotional activities which can attract maximum customers (Sohrabi et al., 2012).

In literature, many studies have been conducted to analyse to explore the quality of hotels by using various research methodologies like factor analysis, descriptive statistics, and regression techniques ( Ren et al., 2016; Xu and Li 2016; Lahap et al., 2016; Li et al.,2017; Lai and Hitchcock, 2017; Patiar et al., 2017 ). Hua and Yang (2017) applied econometric models to identify factors of crime on the overall hotel performance of Houston hotels. Alptekin and Büyüközkan (2011) identify influencing factors for the hotel industry by using exploratory factor analysis mixed with fuzzy logic. The regression model has been developed to analyse the effect of localised competition on the hotel industry by considering demographic variables, prize and population density as independent variables (Joel and Mezias, 1992).

In the literature, there are several studies of rough set theory and its application in diverse domains. Stević et al. (2017) formulated a multicriteria decision model with eight criteria and eight alternatives for an internal transport logistics of a paper manufacturing company. They used the simple additive weighting (SAW) method and rough numbers, which is used for ranking the potential solutions and selecting the most suitable one. Roy et al. (2019) has proposed an integrated uneven number based COPRAS Model to evaluate the ranking of Delhi hotels. Sharma et al. (2019) has offered a rough set based double exponential smoothing model for forecasting air passengers data. Žižović & Pamucar (2019) has suggested level based weight assessment (LBWA) based multicriteria decision-making model for the investigation of criteria weightage. Popov (2020) applied Johnson–Kendall–Roberts (JKR) theory to find the relation between smooth and rough elastic bodies. Božanić et al. (2020) used a rough interval-based Level Based Weight Assessment and Multi Attributive Ideal-Real Comparative Analysis method (LBEA-IR-MAIRCA) model to determine constructive elements of new weapons. Pamucar et al. (2022) has utilised FUll COnsistency Method (FUCOM) and Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) methods as integrated rough group analysis for and prioritisation of railway infrastructure project evaluation. Sharma et al. (2021) hybrid rough set model-based analysis has been performed to forecast the sugarcane yield of India. Kazemitash et al. (2021) has used the data of Biofuel Company's supplier selection for the information system performance calculation by the integration of rough set theory through the Best-Worst method (BWM). The authors have also employed the rough BWM to determine the weight values of the criteria. Hu et al. (2021) proposed the weighted neighbourhood rough set (WNRS) and accordingly introduced a unique attribute reduction technique. Subsequently, Yu et al. (2021) demonstrated that the concept refinement in topology is too abstract to elucidate the variability of the rough set model along with the variation in granules. Here, the authors proposed two novel granule cover refinements, including point-set topology and rough set theory. Ye et al. (2021) also introduced a novel decision-making method based on a fuzzy rough set. They applied the technique in a real-world scenario to illustrate the feasibility of the proposed method. After that, Kusunoki et al. (2021) considered two parametric dominance-based rough set approaches (DRSA) and offered variable precision DRSA (VP-DRSA) and variable consistency DRSA (VC-DRSA). Following this, Błaszczyński et al. (2021) examined a new data set for auto loan applications using a technique not yet explored for financial fraud prediction, namely the Dominance-based Rough Set Balanced Rule Ensemble (DRSA-BRE).

Pawlak (1982) established an effective method known as Rough Set theory for extracting the facts from the information system. However, the traditional rough set methodology is not adequate to study the relationship among preference order arising from attributes like debt ratio (Blaszczynski et al. 2007), service strategies, product quality, and business indicators (Couto and Gaiado, 2015). Therefore, this study proposes applying the Dominance-based Rough Set theory (DRST) to solve preference-ordered situations. According to Greco et al. (2000), DRST approach has been anticipated to solve the preference-ordered situations in data mining. It is a powerful tool for attribute reduction in the qualitative-based data set. The dominance based rough set theory has been successfully employed in a variety of areas. Chakhar and Saad (2012) proposed a DRST approach to study groups in the multicriteria class study. The dominance-based rough set methodology has been used to develop the model for limiting the speed of vehicles in speed-controlling zones (Augeri et al., 2015). Chakhar et al. (2016) suggested that DRST has been used to derive rules in multicriteria group decision-making based on several case studies. Sawicki and Zak (2014) have reported that DRST based analysis is done on transportation problems by producing decision rules depending on customer view and expectations. Moreover, it has also been used in different uncertain multicriteria decision-making applications (Kazemitash et al., 2021; Pamučar and Janković, 2020; Pamučar et al., 2018; Dalić et al. 2020).

The study has been organised as follows. The basic concepts and some related properties of DRST are discussed in section' Dominance based RST'. A case study of hotel data and analysis of hotel data using DRST for multicriteria decision model is presented in case study section. The comparison purpose statistical analysis of hotel data is discussed in regression analyses section. Finally, the result and discussion, conclusion, and future scope of our study are stated in section result and discussion, and conclusion'.

## 2. Dominance based rough set theory (DRST)

DRST extends the Classical Rough Set theory (CRST) introduced by Pawlak in 1982. The multicriteria decision representation used in this research applies the concept of DRST. Thus, the RST methodology is an efficient mathematical mechanism to dealing with uncertainty and vagueness. However, Classical rough set theory (CRST) is restricted to sort problems where the preferences-orders in the set of attributes (criteria) are considered. These are the inconsistencies generated due to the violation of the dominance principle that eventually cannot be handled by the model. Hence in case of such inconsistencies, some methodological changes to CRST are required. Greco et al. (2000) have proposed an expansion of the RST depending on the dominance concept that would allow it to handle the inconsistency. This idea relies on replacing the indiscernibility relation for a dominance relation in the rough approximation theory of the decision category.

### 2.1. Information system

Sample The information concerning the objects is often structured in the form of an information table whose different rows mention distinct actions (objects) and whose columns mention the other criteria or attributes considered.

Formally, an information table is structured in a 4-tuple information system $S = (U, Q, V, F)$. Where $U$ is a non-empty finite set of objects (universe) and $Q = \{q_1, q_2, \cdots\cdots, q_m\}$ is a non-empty finite set of attributes or criteria such that $q: U \to V_q$ for every $q \in Q$. $V_q$ is the domain of the attributes or criteria q. $V = \cup_{q \in Q} V_q$ and $f: U \times Q \to V$ is the information function determined such that $f(x, q) \in V_q$ for every attributes q $\in Q; x \in U$. The set Q is often separated into a set C ≠ $\emptyset$ of condition attributes, and a set D ≠ $\emptyset$ of decision attributes such that $C \cap D = \emptyset$ and $C \cup D = Q$. In such a situation, S is called an information table.

### 2.2. RST with dominance relation

If the scale of the condition attribute is arranged in increasing or decreasing preference, then it is called criterion. Alternatively, it is known as regular condition attributes. DRST exponents suppose that the preference increases with the value of $f(\cdot, q)$ for every criterion $q \in C$. We also suppose that the set of decision attribute

$D$ (perhaps a singleton {d}) create a parting of universe U into a set of decision classes, let $Cl = \{Cl_t, t \in T\}$, $T =$ {1,...,n} be a finite set of classes of universe U such that every $x \in U$ belongs to one and only one class $Cl_t \in Cl$. We assume that classes are preference-ordered, i.e., for all $r, s \in T$, such that $r > s$, the objects from $Cl_r$ are more preferred to the objects from $Cl_s$. Suppose P ⊆ C is a subset of condition attributes. The dominance relation $\nabla_P$ allied with P is described for every pair of Objects x and y so; $x\nabla_P y \Leftrightarrow f(x,q) \geqslant f(y,q), \forall q \in P$.

The letter "$\geqslant$" should be changed with "$\leqslant$" for criteria according to the decreasing preference. We associate pair of a sets with every object $x \in U$: (i) P-dominating set $\nabla_P^+(x) = \{y \in U: y\nabla_P x\}$ having objects that dominate x and (ii) P-dominated set $\nabla_P^-(x) = \{y \in U: x\nabla_P y\}$ having objects dominated by x. These pair of sets are familiar with approximate decision classes.

The P-lower approximation of $Cl_t^{\geq}$ (upward union), ($\underline{P}(Cl_t^{\geq})$), is constituted of total objects x from $U$ such that all members y, contain at least the similar assessment on all of the examined criteria from $P$, also member of a class $Cl_t$ or better. In another way, if any object y has at least as good an analysis based on the criteria from $P$ as object x member of $\underline{P}(Cl_t^{\geq})$, then indeed, y is a member of a class $Cl_t$ or preferable class. The P-upper approximation of $Cl_t^{\geq}$ (upward union), which involves all objects with a P-dominating set, is allocated to a class at least as good as $Cl_t$.

Similarly, the P-lower and P-upper $Cl_t^{\leq}$ approximation with respect to $P \subseteq C$respectively represented as $\underline{P}(Cl_t^{\leq})$ and $\overline{P}(Cl_t^{\leq})$, are defined as:

$$\underline{P}(Cl_t^{\leq}) = \{x \in U: \nabla_P^-(x) \subseteq Cl_t^{\leq}\}, \quad (1)$$

$$\overline{P}(Cl_t^{\leq}) = \cup_{x \in Cl_t^{\leq}} \nabla_P^-(x) = \{x \in U: \nabla_P^+(x) \cap Cl_t^{\leq} \neq \emptyset\}. \quad (2)$$

### 2.3. Accuracy of approximation and quality of classification

For all $t \in \{1, \ldots, n\}$ and each, $P \subseteq C$ we described the accuracy of the approximation of $Cl_t^{\geq}$ and $Cl_t^{\leq}$, respectively, as follow:

$$\alpha_P(Cl_t^{\geq}) = \frac{card(\underline{P}(Cl_t^{\geq}))}{card(\overline{P}(Cl_t^{\geq}))}, \alpha_P(Cl_t^{\leq}) = \frac{card(\underline{P}(Cl_t^{\leq}))}{card(\overline{P}(Cl_t^{\leq}))} \quad (3)$$

The coefficient $\gamma_P(Cl) = \frac{card(U - ((\cup_{t \in T} Bn_P(Cl_t^{\leq})) \cup (\cup_{t \in T} Bn_P(Cl_t^{\geq}))))}{card(U)}$ (4)

is known as the quality of approximation of partition Cl using attribute set $P \subseteq C$.

### 2.4. Decision rules

On the foundation of the approximations found by the use of the dominance relation, it is viable to set off a generalised explanation of the preferential knowledge contained in the information table, such description of the preferential knowledge we can write in the form of "if ..., then..." decision rules. The algorithms for induction related to regulations are acquired by using 4eMka2 software (Poznan University of Technology, Poland, Laboratory of Intelligent Decision Support System 2006).

All the decision rules can be considered in the following three ways:

1. $D_{\geq}$ -decision rules which are having the following form:

If $f(x, q_1) \geq r_{q1}$ and $f(x, q_2) \geq r_{q2}$ and ...... $f(x, q_p) \geq r_{qp}$, then $x \in Cl_t^{\geq}$ ,

These decision rules are assisted by the member of the universe that belongs to the P-lower approximation $Cl_t^{\geq}$.

2. $D_{\leq}$ -decision rules which have the following form:

If $f(x, q_1) \leq r_{q1}$ and $f(x, q_2) \leq r_{q2}$ and ...... $f(x, q_p) \leq r_{qp}$, then $\in Cl_t^{\leq}$ ,

These decision rules are assisted by a member of the universe that belongs to the P-lower approximation of $Cl_q^{\leq}$.

3. $D_{\geq\leq}$ -decision rules which have the following form:

If $f(x, q_1) \geq r_{q1}$ and $f(x, q_2) \geq r_{q2}$ and ...... $f(x, q_k) \geq r_{qk}$, and $f(x, q_{k+1}) \leq r_{qk+1}$ and ..... $f(x, q_p) \leq r_{qp}$, then $x \in Cl_s \cup Cl_{s+1} \cup \ldots \cup Cl_t$

These decision rules assisted by a member of the universe that belongs to the boundary region of the union of classes $Cl_s^{\leq}$ and $Cl_t^{\geq}$, where $P = \{q_1, q_2, \ldots \ldots, q_p\} \subseteq C$ ,$(r_{q1}, r_{q2}, \ldots \ldots, r_{qp}) \in V_{q1} \times V_{q2} \times \ldots \ldots \times V_{qp}$, and $t \in \{1, \ldots, n\}$.

## 3. Case Study

The hospitality industry is one of the major contributors of growth among the all-service sector industries in India. Since, India is a country of diversity with its rich culture and heritage, hence the tourism contributes a significant source of foreign exchange. As, tourism is the integral part which has a considerable effect on the hotel industry. This indicates that the digital advancement in tourism sector also affect hospitality industry. The digital enhancement in tourism of India through digital tools used for planning, booking, and experiencing a journey have significant effect over hospitality industry. The empirical study focuses on the Indian hospitality industry includes data collected from various online platforms in the hotels. Since customer satisfaction harms the hotel industry, the possibility of getting a hotel that satisfies customers' needs is maximised by selecting specific attributes which are related to the hotel industry. The following study scrutinises the influence of overall rating (O) on location (LO), hospitality (HT), facilities (FT), sanitation and Cleanliness (SC), the value of money (V), food quality (FD), and price (PR) using both Indian and international tourists' hotel data. Criteria descriptions are listed in table 1. The study's objectivity has been kept in mind, and all variables are used according to data availability. Online reviews play an essential role in the hotel selection process as websites provide customer reviews based on their personal experiences with provided hotel services. These websites give the travelers an overall idea to select the best hotel which satisfies their needs based on others' experiences. Sometimes decision-making becomes difficult as there are different reviews based on one's perspective. The data related to the hospitality industry are extracted from tourism websites. The presented approach assists the hotel selection process based on the influence of overall rating on location, hospitality, facilities provided, sanitation and cleanliness, the value of money, food, and price. The proposed study is used to select the best hotel based on existing data.

*Table 1. Criteria Description*

| Criteria | Description |
|---|---|
| Location (LO) | The geographical location of the hotel has been considered according to the convenience of tourists. |
| Hospitality (HT) | It includes a friendly and generous welcome and entertainment for tourists. |
| Facilities (FT) | It includes a Travel desk, eating place, parking, pieces of equipment, or services provided to tourists for their stay. |
| Sanitation and Cleanliness (SC) | Sanitation and Cleanliness include the sanitary condition of a hotel. |
| Value for money (V) | A beneficial combination of sustainability, cost, and quality to meet tourist requirements. |
| Food Quality (FD) | The acceptable standard quality of food served. |
| Price (PR) | Convenient fare according to traveler and hotel management |
| Overall Rating (O) | It includes the net classification of hotels based on the different quality scale. |

The objective of this case study is to extract the decision rules to show the hotel features and classify the different characteristics of the tourist industry. It has been found that the Rough set theory is the most suitable approach for criteria selection in decision-making problems. For this study, data has been collected from the best tourism website (https://www.makemytrip.com), and it will help the tourism management for analysis of significant criteria of the hotel industry. The model must provide relevant information to hotel management for improvement of their service quality.

## 4. DRST analysis

Based on several studies such as (Geetha et al., 2017; Li et al. (2017) of hotel tourism, and expert interviews of hotel managers and their management teams, tourism and travelling management of India has conclusively given higher priority to the eight essential criteria/attributes given in section 3 of 609 best Indian hotels. Because according to experts, these selected eights criteria are preferred mainly by the maximum tourists while making their hotel selection decision. In eight attributes, seven attributes are called condition criteria, and another one is decision criteria were investigated for analysis. In this study, we have applied the DRST technique for rule generation. DRST toolkit 4eMka2 software from Poland, Laboratory of Intelligent Decision Support System 2006, is used for constructing the decision rules.

### 4.1. Accuracy approximation and quality of classification

Table 2, provides approximation accuracy for all decision classes, as approximation sets (specifically lower and upper approximation) and accuracy of approximation has been already explained in section 2.2 and 2.3. The selected criteria can be adequate to approximate the classification if the classification quality and accuracy of the approximation. The class "at most medium" means class related to "overall hotel rating will be medium and lower values". The decision class "at most good" contains the two classes, which are "good" and "medium". Further, the decision class" at least good" represents the class "overall hotel rating will be good or excellent". Finally, the decision class "at least excellent" consists of only one class, i.e. overall rating of the hotel be will be excellent.

*Table 2. Accuracy of approximation*

| | At most medium | At most Good | At least Good | At least Excellent |
|---|---|---|---|---|
| Lower approximation | 10 | 17 | 99 | 20 |
| Upper approximation | 510 | 589 | 599 | 592 |
| Boundary | 510 | 572 | 500 | 572 |
| Accuracy of approximation | 0.636 | 0.0290 | 0.17 | 0.0340 |
| Quality of classification | | 0.049 | | |

*Table 3. Certain decision rules of hotel data set*

| Decision Rules | Support |
|---|---|
| If (food ≥ Excellent) & (hospitality ≥ excellent) Then (overall rating≥ good) | 61 |
| If (food ≥ Excellent) & (facilities ≥ medium) Then (overall rating ≥ good) | 83 |
| If (food ≥ excellent) & (sanitation and Cleanliness≥ excellent) Then (overall rating ≥ good) | 89 |
| If (food ≥ Excellent) & (price ≥ medium) & (value for money ≥ excellent) Then (overall rating ≥ excellent) | 18 |
| If (food ≥ Excellent) & (price ≥ high) Then (overall rating ≥ excellent) | 6 |
| If (food ≤ poor) & (price ≤ low) & (location ≤ bad) Then (overall rating ≤ good) | 11 |
| If (hospitality ≤ poor) & (facilities ≤ medium) Then (overall rating ≤ good) | 6 |
| If (sanitation and cleanliness ≤ poor) Then (overall rating ≤ good) | 5 |
| If (food ≤ poor) & (price ≤ low) & (facilities ≤ good) & location ≤good) Then (overall rating ≤ medium) | 5 |
| If (value for money ≤ poor) & (facilities ≤ good) Then (overall rating ≤ medium) | 6 |
| If (location ≤ bad) & (sanitation and cleanliness ≤ good) Then (overall rating ≤ medium) | 3 |

As clarified in the section as mentioned above 2.4, the decision rules were formed by analysing the training data of dominance-based rough set theory. These rules were applied to relationships among conditions and decision attributes.

Furthermore, 11 certain decision rules were obtained from the information system. Total 5 decision rules are found to be more accurate since support is greater than 10. Based on these decisions rule, we can analyse which criteria are significant for hotel management. The estimated results of reduced rules are presented in Table 3.

Table 3 shows the 11 minimum cover rules generated from the hotel data set. The minimal cover certain decision rules can be written in the form of IF-THEN statement. Here is some example to illustrate IF-THEN rules:

IF food is excellent AND hospitality is excellent, THEN the decision criteria overall rating will be perfect.

From table 3, it is clear that if the hotel's food is excellent and Cleanliness is excellent, then the overall rating will be excellent with maximum support of 89 (cf. rule 3). It means that food and cleanliness are essential factors for travellers. If the hotel's food is excellent and facilities are medium, and above medium then the overall rating will be excellent with support of 83 (cf. rule 2). If food quality is excellent and hospitality is best then the overall rating will be excellent with support of 61 (cf. rule 1). These decision rules indicate that food, Cleanliness, hospitality, and facilities are essential attributes for travelers. Therefore, it can be suggested that most tourists select their hotel based on food, Cleanliness, hospitality, and facilities. The different stages of analysis are depicted in Figure 2.

## 5. Regression analysis

By analysing the literature review (Sheather, S., 2009; Ren et al., 2016; Patiar et al., 2017; Hua and Yan., 2017), the regression model is obtained by using the following framework:

$$\text{Overall rating (O)} = \alpha+\alpha 1\ LO+\alpha 2\ HT+\alpha 3\ FT+\alpha 4\ SC-\alpha 5\ V-\ \alpha 6\ FD+\alpha 7\ PR+\ \varepsilon \qquad (5)$$

Where $\varepsilon$ is the error, $\alpha$, $\alpha 1$, ..., $\alpha 7$ are the coefficients of considered variables (LO, HT, ..., PR), O is the overall rating; LO is the location of the hotel, HT is the hospitality, FT is the facilities provided by the hotel, SC is the sanitation and Cleanliness, V is the value of money, FD is food quality, and PR is for the price of the hotel's room. The estimated regression results are described in Table 3. The acquired result indicates that the hotel's location, hospitality, sanitation and cleanliness, and performance and effectiveness of money charges, i.e. the value of money, has a significant positive effect on overall ratings of the hotel. Whereas, facilities provided, i.e. physical characteristics associated with a hotel-like travel desk, eating place, parking, etc., food quality and hotel price don't seem to have a significant effect on the overall ratings of the hotel. Moreover, the F- statistics results confirmed that the regression model is essential for criterion for hotel selection process since the p-value is 2.2e-16 $\approx$0.000, which is significant. Estimating sturdiness of the model by using R2, which is 0.8459, i.e. all variables have an approximate 84.59% effect on overall ratings of the hotel for criterion for the hotel selection process, which is considerably good. Therefore, the considered regression model is relevant for the empirical study. Also, from figure1, it is clear that the relationship between overall rating with location, hospitality, facilities, sanitation, and cleanliness, the value of money, food, and the price is linear. The linear line indicates is that the best-fitted model with the curve for the multivariate analysis. Our data are independent and follow Gaussian distribution, then the model is accepted within the robustness test. Figure 1, shows a normal probability plot to decide whether it is reasonable to consider. The accuracy measure derived using regression analysis of hotel data set is sampled from a population, follows a normal distribution.

The regression equation for the variables is:

Overall rating = 0.538+0.1854 Location+0.6706 Hospitality+0.3821 Facalities+0.21935anitation and cleanliness-0.01933 Value of Money-0.1549 Food+0.000005004 Price+ ε (6)

*Table 4. Regression analysis results*

| Variables | Coefficients | Standard error | t- value | Pr(>\|t\|) |
|---|---|---|---|---|
| Constant | 5.388e-01 | 7.654e-02 | 7.039 | 5.29e-12 *** |
| Location | 1.854e-01 | 1.922e-02 | 9.646 | <2e-12*** |
| Hospitality | 6.706e-01 | 1.995e-02 | 33.619 | <2e-16*** |
| Facilities | 3.821e-03 | 2.380e-03 | 1.606 | 0.1088 |
| Sanitation and cleanliness | 2.193e-01 | 2.071e-02 | 10.589 | <2e-16*** |
| Value of money | -1.933e-01 | 1.954e-02 | -9.938 | <2e-16*** |
| Food | -1.549e-01 | 1.439e-02 | -1.076 | 0.2822 |
| Price | 5.004e-06 | 2.784e-06 | 1.797 | 0.0728 |
| Adjusted R2 | 0.8459 | | | |
| F-statistics | 477.8 | | | |

**Residual standard error:** 0.1673 on 601 degree of freedom
**Multiple R-squared:** 0.8477, p- value < 2.2e-16

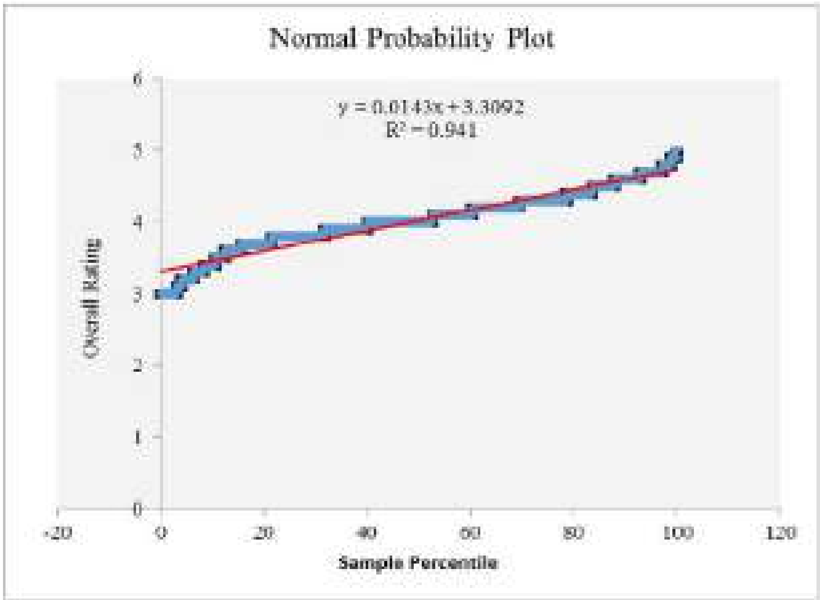


*Figure 1. Normal probability plot of statistical analysis*

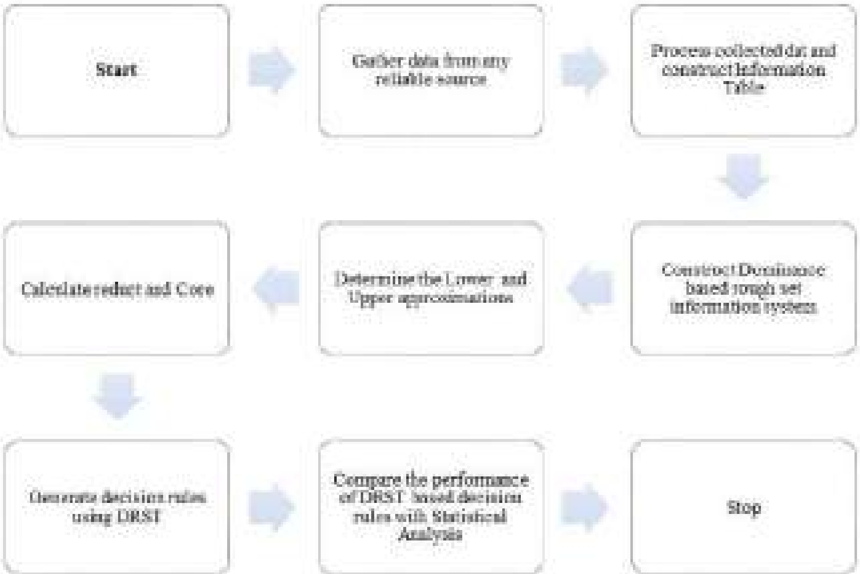


*Figure 2. Stages for air transport passengers forecasting*

## 6. Results, discussion and conclusion

This research focuses on hotel selection and estimation through a hybrid method of Dominance rough set theory and regression analysis. This estimated model has been analysed under uncertainty in which DRST is employed in acquiring the information related to significant attributes of the hotel business. Furthermore, a case study on real-life data of Indian hotels has been performed using the DRST approach on the selected attributes.

The foremost suggestion resulting from this study are (i) Food, facilities, Cleanliness, and hospitality are the most significant attributes for any hotel selection as uncovered in decision rule and the expert's opinion based on customer prioritization and feedback. (ii) Hotel management has been turn-up with a clear picture of the hotel's criteria to improve performance according to the current business market. This facilitates the hotel management system to make appropriate decisions regarding the quality and services up-gradation of the hotel. (iii) It can be said that the DRST is a knowledge-based decision-making system that can evaluate the effective and appropriate attributes by the comparison of collected data with secondary data obtained from tourism websites.

Hence, this research leads to a robust hybrid method, 'DRST-Regression', which confirms the accuracy and firmness of the decision making outcomes. It is a unique approach contributed by this study because it gives rise to the most precise and reliable outcomes without any statistical assumptions. Comparatively, DRST-Regression is more preferable to the statistical method due to its dynamic and advanced approach. Therefore, this study resulted in an empirical model that can be preferred over the statistical model because it divulges the consequential decision rules are easy to understand as compared to statistical methods without any distributional assumption.

The main limitations of the DRST are that the approximation sets (upper/lower) depend only on the choice of attributes, which may be regarded as disadvantage, since there may not be enough flexibility for some applications. In future, similar case studies can be considered and analysed using rough sets and different machine learning algorithms, including decision tree, random forest, support vector machine and elastic net.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 56-68*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta190222076h*

# SINGLE-DIGIT TIME: TOWARD A QUICK CHANGE-OVER PROCESS WITH THE SMED METHOD USING THE VISION SYSTEM

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Received: 21 August 2021
Accepted: 29 October 2021
First online: 19 February 2022

*Research paper*

**Abstract:** *Increasing the speed of the product change-over process is critical by implementing the Single Minute Exchange of Dies (SMED) effectively. The smallest activity variation between operators, activity speed, and process accuracy are identified research targets. This research was developed in the electronic component industry, where the Define-Measure-Analyze-Improve-Control (DMAIC) and Hierarchy Task Analysis (HTA) methods can describe the most crucial and key activities. Therefore, it takes accuracy and reliability between operators to carry out this activity. This paper presents the acceleration of the product change-over process by developing an automated non-contact inspection method in the assembly area using a vision system. The results of the study illustrate that the change-over process can be carried out in single-digit minutes (7 minutes), or reduced by 81%, and the speed of change-over activities between operators is the same.*

**Key words**: *SMED, Vision System, Automation, Inspection, Capability process, Electronics component.*

## 1. Introduction

Image processing techniques used for robot guidance and automatic inspection are called vision systems widely used in the industrial field (Semeniuta et al., 2018). The assembly inspection process is a crucial procedure to perform measurements and detect errors. The dimensional inspection assembly unit is still done manually using a caliper and micrometer that takes a long time, physical contact, and potential difference in measurement between operators (Frustaci et al., 2020). Connolly stated vision system is mighty, compact, and easy to operate even though it is not a programmer, and this is very interesting for the industry (Connolly, 2003). Machine vision has been successfully applied to electronic component companies so that the

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level of automation can be increased (Hendi Herlambang et al., 2021). Therefore, the vision system is an image processing technique that is easy to use in industry, fast, without physical contact, can avoid measurement errors, and can increase the level of automation.

Every organization looking to speed up the transition from one product to another focuses on low cost, speed of delivery, and superior quality. Single Minute Exchange of Dies (SMED) is a lean manufacturing tool that can shorten change-over activities by converting internal time to external time, then streamlining both (Shingo, 1985). Research conducted by Michels concluded that SMED can speed up the change-over process so that direct labor is reduced as a finding (Michels, 2007). Research conducted by Demeter found that inventory can be reduced by applying the SMED method effectively (Demeter & Matyusz, 2011). Several studies have revealed that the combination of equipment repair and development with the 5S program is the goal so that SMED can be implemented effectively (Cakmakci, 2009). There have been several investigations found that the application of SMED can reduce change-over activity by 41% in the press line (Hendi Herlambang, 2020b), 30% in the pharmaceutical industry (Karam et al., 2018), 42.3% in the injection molding industry (Bhade & Hegde, 2020), and 43% in the cork industry (Sousa et al., 2018). To reduce change-over activity significantly, several tools were used to conduct testing by researchers, Rapid Entire Body Assessment (REBA) analysis (Brito et al., 2017), time study method (Simões, 2010), visual stream mapping (Azizi, 2015), and the geometrically based methodology (Nakeenopakun & Aue-u-lan, 2019). Therefore, the acceleration of the transition process from one product to another can be done by choosing the right equipment and technology according to the company's needs.

Based on the description above, there has been little discussion about accelerating the change-over process with the objective of single-digit minutes in the electronic component industry. Therefore, researchers are interested in implementing a system vision to accelerate change-over activities in electronic component companies using the SMED method. At the internal process, the streamline stage is inserted technology elements to achieve the speed of change-over activity in single-digit units of minutes. This study's results can provide an overview of the change-over process that can be automated using vision systems quickly.

## 2. Materials and Methods

The study stages of completion use the Define-Measure-Analyze-Improve-Control method used by researchers to produce reliable SMED application research (Shingo, 1985)(Roth & Franchetti, 2010) (H Herlambang, 2020b).

### 2.1. Define

This research was conducted in electronic component companies in Indonesia, with connector output. Electrical connectors are electrical appliances that connect between electrical circuits, most connectors can be removed or reattached, but some can be permanent.

*Figure 1. Connector part*

Connectors make electronic products easier to assemble and manufacture and make it easier to repair electrical circuits and allow flexibility in design and modification. Connectors are widely used in electrical circuits for communications, computers, industrial machinery, and electronic equipment used by everyone, as seen in Figure 1.

Most connectors consist of two main parts, namely housing and terminals. Housing is a cage or structure used to hold the terminals, stabilize the connection, and protect the contact from short circuits and various hazards caused by the environment. Housing usually consists of several types of printed plastic but can be made of all kinds of insulator materials, as seen in Figure 2, the flow process of connector made.


*Figure 2. The process flow of making electronic connectors*

Production data for one year has been collected to find out productivity indicators. It was found that the 5th process in the change-over activity is the most crucial activity carried out during the change of product type one to another, as seen in figure 2. This activity is carried out repeatedly by the operator manual, and there is physical contact on the product with an average time of 30 minutes. This is in line with Herlambang et al., which states that the product detection system through physical contact can have a large measurement deviation between operators and takes a long time (Hendi Herlambang et al., 2021).

### 2.2. Measure

At this stage, secondary data collection from each operator is carried out during the change-over process. Data is processed by using Minitab software to find out the ability of the process. The data found that the process capability is still not satisfied with a Cp value of 0.84 and a Cpk value of 0.76, as seen in Figure 3. It is also strengthened that in the Capability Histogram chart, two hills indicate there are two different populations between operators that perform the change-over process.

Initial data analysis is also carried out to determine the direction of Continous Improvement in the future as input to top management. Four blocks of technology and control diagrams are used to visualize current conditions by calculating the value of Z Shift and Z It at this time. It was found that the current state of technology factors still need to be improved for the capability of the process to increase, as seen in Figure 4.

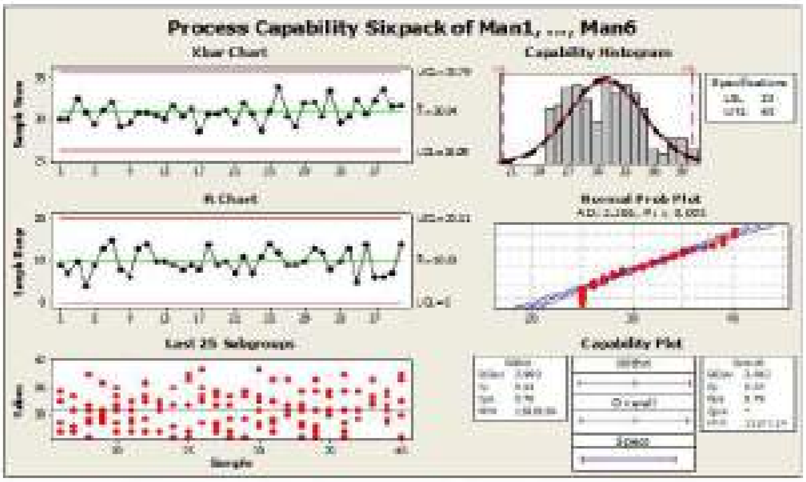


*Figure 3. Capability process change-Over activity*

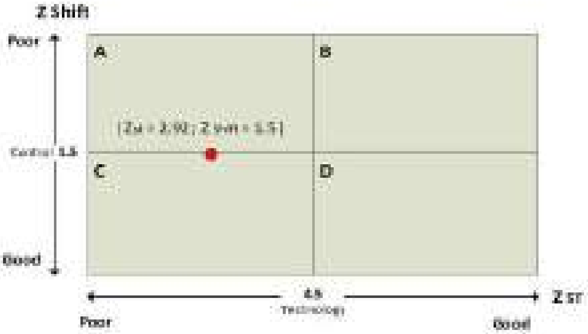


*Figure 4. Four Blok diagram Assembly process Activity*

### 2.3. Analyze

At the analysis stage, the authors conducted a more in-depth examination by taking videos to determine the real activities carried out for each operator. To obtain consistency of the observed subjects' natural movements can be recorded using video (Asan & Montague, 2014). This can help the author analyze the operator's movement and then decomposition each activity in detail to see the potential occurrence of errors. Analytical techniques are used to determine human error potential at each work level using Hierarchy Task Analysis (HTA) (Shorrock & Kirwan, 2002). As seen in figure 5, the activity of the change-over process of the replacement checker.

HTA for checker change process has been done decomposition and followed by identifying errors in each activity caused by errors sourced in people and on the information system. As seen in Figure 5, sub-tasks given different colors are the most crucial activities with the most potential for errors.

Task 2.4 and 3.4: Insert parts one by one. Insert small box sticks one by one into the block stick, according to the product to be produced. This process is done manually, and the number of box sticks should not be more or less. The following errors have been identified in this activity :

1. Box sticks amount more or less if done with a decreased concentration level. The operator must calculate the number of box sticks manually and align with the product set up, which will significantly help part installation errors.
2. The box stick is jammed because it is rusty. To prevent this from happening, the operator must perform cleaning and lubrication on the box sticks and stick blocks.

Task 4.1: Manual positioning product with the checker. Alignment process by aligning the product with box sticks, with the aim of optimal checker detection process.

Task 4.2: Check the straightness visually. Inspection using eye visualization is the most important.

If Task 4.1 and 4.2 are not appropriately done, then :

1. Detection of less than maximum wasted products, but products that do not fit the requirements will still be wasted to the scrap box.
2. The machine's ability will go down because often the machine trouble caused by the alignment is not good.

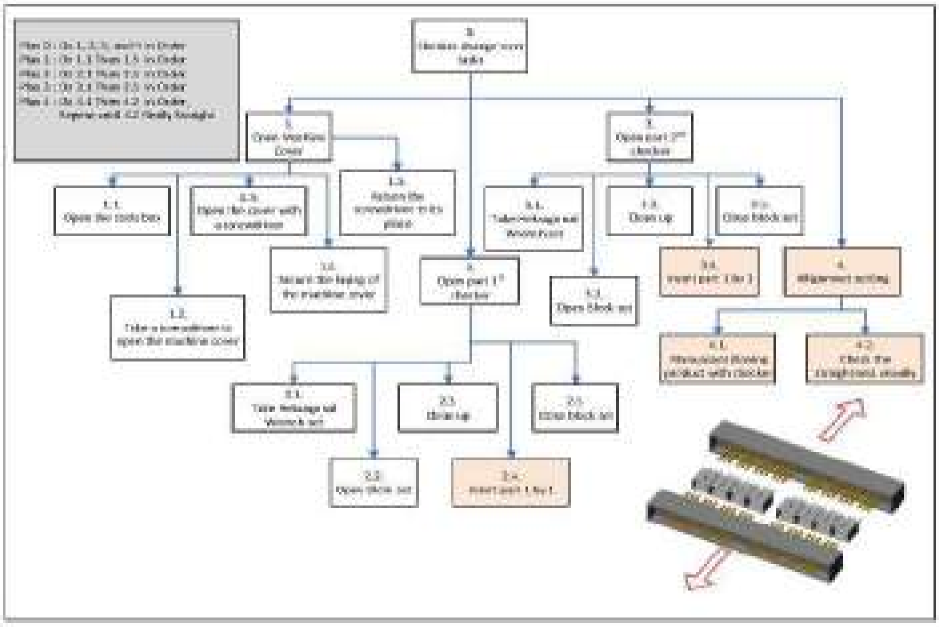

*Figure 5. Hierarchy Task Analysis change-over activity*

This checker change activity is an activity that authors say requires a high level of concentration and work experience. To prove this hypothesis, the authors conducted tests on two operator populations. The first operator with a working period of more than two years, and the second is with an operational period of fewer than two years, with a hypothesis:

Ho: There is no difference in the speed of change-over activity above 2 years and below 2 years.

H1: There is a difference in the speed of change-over activity above 2 years and below 2 years.

It was found that the Ho hypothesis was rejected, and the H1 hypothesis was accepted, with a p-value< 0.05 as seen in Figure 6, For easier visualization of speed differences between operators, display the plot box diagram for total time change over, as seen in Figure 7, and the detail as seen in Figure 8.

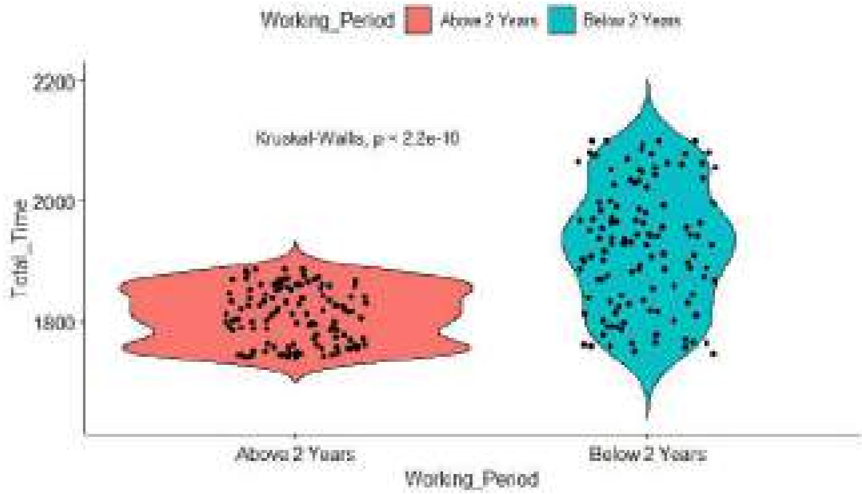


*Figure 6. Compare Means Test*

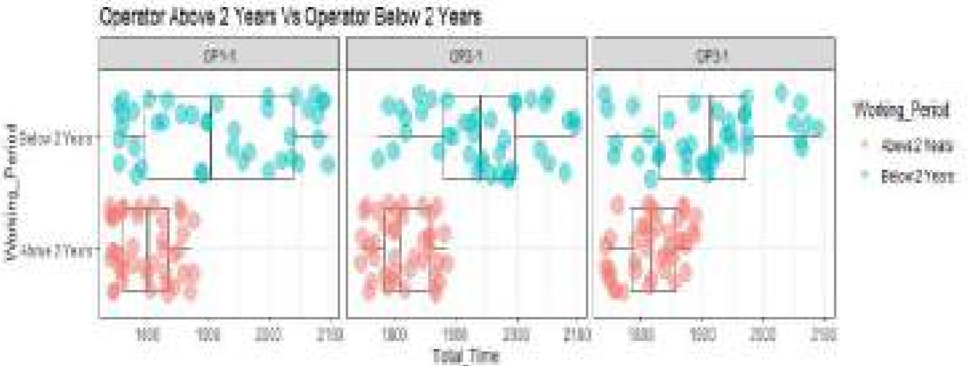


*Figure 7. Box Plot Operator Capability*

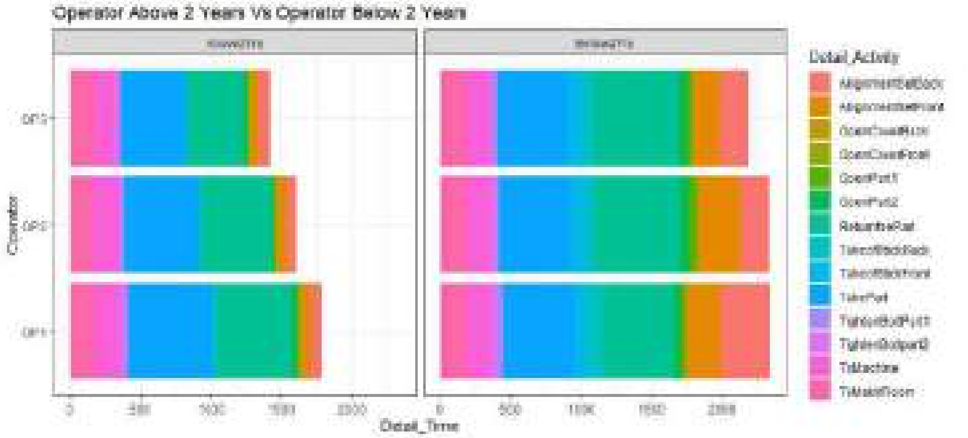


*Figure 8. Detail time checker change-over activity*

After a more in-depth data check of each operator's activities, it was found that there were significant differences with some operators. As seen in figure 6, the average operator speed of group 1 (Above 2 Years) when doing the change-over activity is 29.7 minutes, and the 2nd group is 37 minutes. Then the standard deviation value of the 1st Operator group is better than the 2nd operator group. So from the analysis of this data, the speed of the 1st group operator and the 2nd group operator is better than group 1 is caused by more extended group 1 operator experience. Although there are already guidelines for the change-over process, skills must be continuously trained so that the operator's ability continues to improve.

## 2.4. Improve

Internal activities by streamlining change-over activities choose the vision system's application to eliminate the risk of errors, maintain quality factors, and speed up the change-over process. The vision system consists of an object detection module with the sensor head (camera), sensor amplifier, programmable logic controller (PLC), and power supply. As seen in Figure 9 is the configuration system applied to this research.

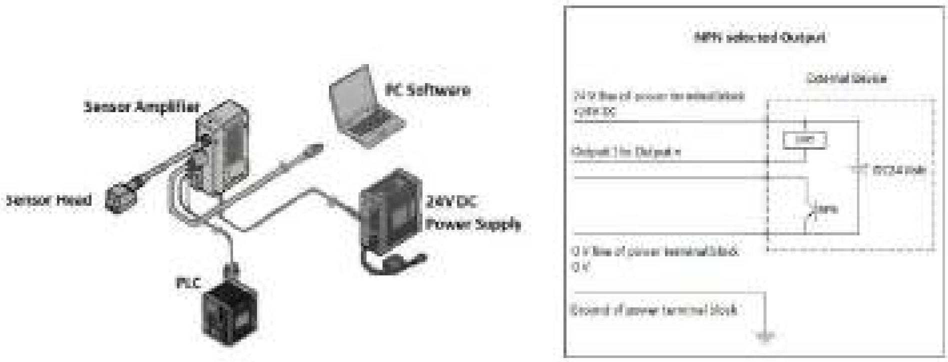


*Figure 9. Configuration system Vision System (Keyence, 2019)*

Lighting techniques and lights are already integrated with the camera making it easier for researchers to conduct experiments quickly. The camera is mounted at a distance of 220 mm from the object to be detected. The detected object's size is 25 mm, and the system will be mounted on the machine at a speed set by the pneumatic system. The camera acquisition configuration system uses a camera integrated with a led light with a size of 0.5 Megapixels. Objects detected by the vision system are the structure's quality (incomplete part) and the quality of dimensions (following the requirements standards). Experiments for image capture are carried out several times to measure the process's stability, as seen in Figure 11. The detection step with the vision sensor includes;

Step 1. The setting of image optimization

Set the image optimization for clearly imaging the target. Adjust the image for defining the differences in the high and low-quality- target. Set the trigger option, adjust the brightness, and imaging focus, as seen in Figure 10, an external trigger time chart is selected.

(1) Start imaging by inputting the trigger at an arbitrary timing. When the trigger delay interval is set, the imaging start time will be delayed in the specified period.
(2) Performs internal processing after imaging.
(3) Outputs the status result.

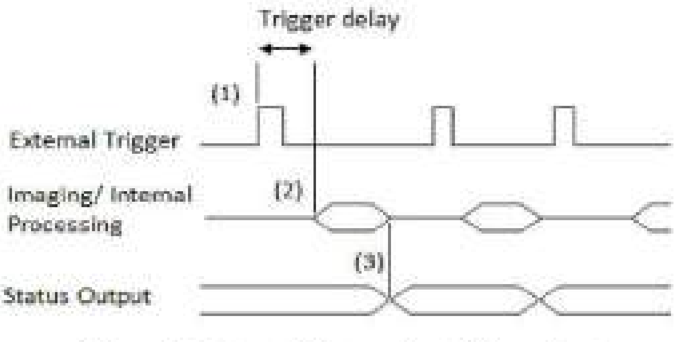


*Figure 10. External trigger selected time chart*

Step 2. Registration of master image, image the high-quality target, and register the master image to serve as the reference of judgment.

Step3. Tool settings, set the tool to judge a target, set the tool onto the master image, and set the threshold for judgment.

Step 4. Output assignment, assign the function to output to each output line.

The quality of image processing will be better if the field of view (FoV) size is 18 mm x 25 mm with vision sensor distance to objects as far as 50 mm, and field of view (FoV) size of 157 mm x 210 mm with vision sensor distance with objects as far as 500 mm. Not only does the quality of the structure have to be detected by the system, but the quality of the dimensions is also absolutely detected, with the allowed tolerance being below 0.1 mm.

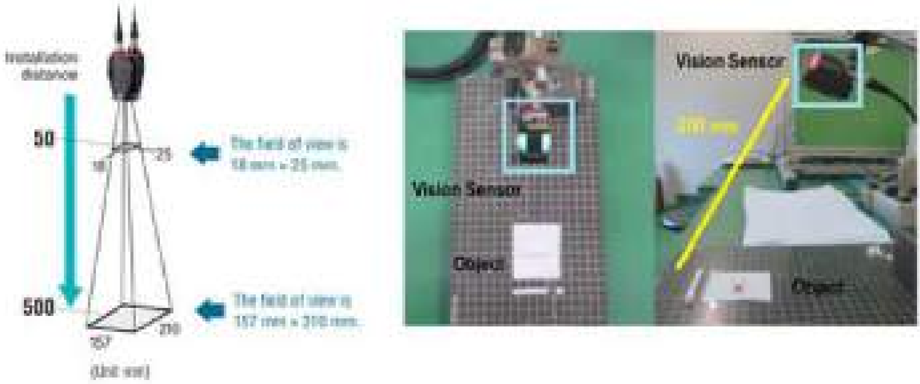


*Figure 11. Experiment illustration*

### 2.5. Control

External activities (activities performed while the machine is still running) and convert internal to external processes have been implemented by the company. Eliminating unwritten activities in the order in which the change-over process is intended to make the process run effectively and efficiently (Oakland, 2008)(Hendi Herlambang, 2020a). All change-over activities are documented on the computer by creating graphic visualizations for easy translation by operators.

## 3. Result and discussion

The experiment has been completed with each product damage results can be well detected by vision sensors. Then the author checks the accuracy of output data from the Vision sensor by using the statistic test with gage study, as seen in Figure 12.

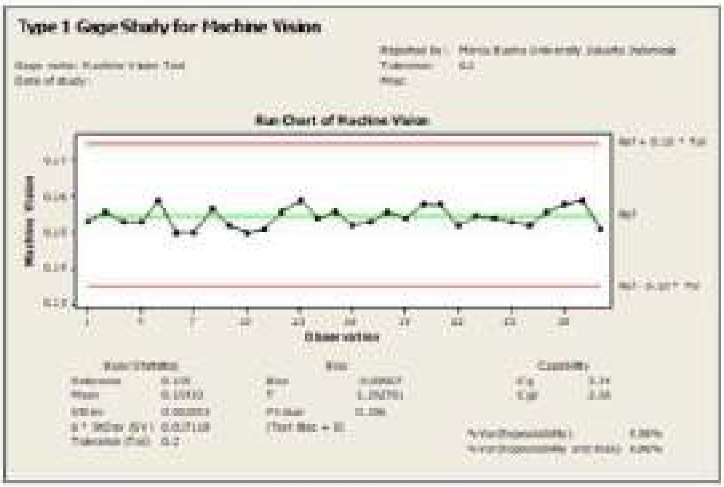


*Figure 12. Gage Study Vision system*

As seen in figure 12, data stability testing on dimensional measurement is excellent, with a Cg value of 2.34 and a Cgk value of 2.26. Furthermore, this is strengthened by repeatability and repeatability-bias values with 8.56% and 8.86% values, respectively. The structure's quality is collected from the findings of the findings that have occurred and done grouping each product defect's quality. As seen in Figure 13, the output of the vision system can capture well the standard product (A), defects in the product structure in the housing (B), and defects in the product structure on the pin (C).


*Figure 13. Output vision sensor*

The total time required to change one type of product to another is 6 minutes. So that change-over checker activity can be reduced significantly with detection level also increased to non-contact detection. Thus, the HTA table activities, as seen in figure 5, ranging from the 1st activity to the 4th activity, can be eliminated, with minimal risk of failure. After the experiment is complete, the authors validate each operator's measurement results using a new method of system vision. This is done to find out the shift in Z value from technology and control factors. From the results of data processing, it is seen that there is an increase in the level of quality in the quadrant of technological factors as seen in figure 14.

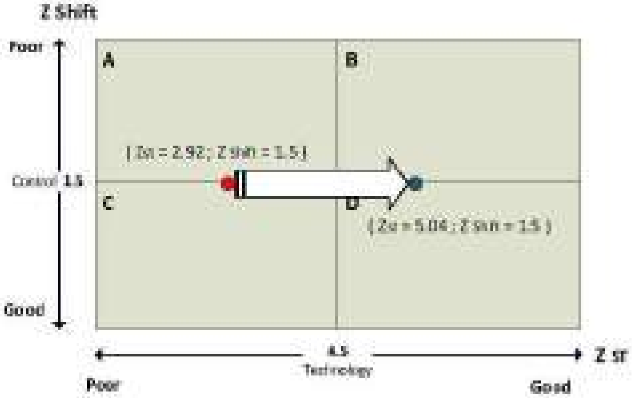


*Figure 14. Four blocks quadrant after evaluation using the Vision system*

## 3. Conclusion

The purpose of this study was to determine the effect of adding elements of technology (vision system) to the speed of the change-over process carried out by operators with different working periods. The findings of this study make several contributions to the current literature. First, the use of a vision system in electronic companies can speed up the change-over process within 7 minutes, previously it was 37 minutes, as seen in figure 15. This achievement succeeded in achieving the single-digit minute target. Second, the use of the vision system can be done easily for operators with different working periods. Third, the variation in the speed of both change-over activities is small, so it can be said that the speed of the change-over process is the same for both. The change over process activity has been explained using the Hierarchy Task Analysis (HTA) method. Fourth, four main manual activities can be eliminated after implementation with the vision system, so that measurement errors and measurement bias can be avoided. This research is limited by the size of the target object. One source of weakness in this study that can affect the length of change-over activity is the size of the product detected. Thus, further research is required for a vision system that can be used for common product sizes but has an optimal Field of View (FoV) value.

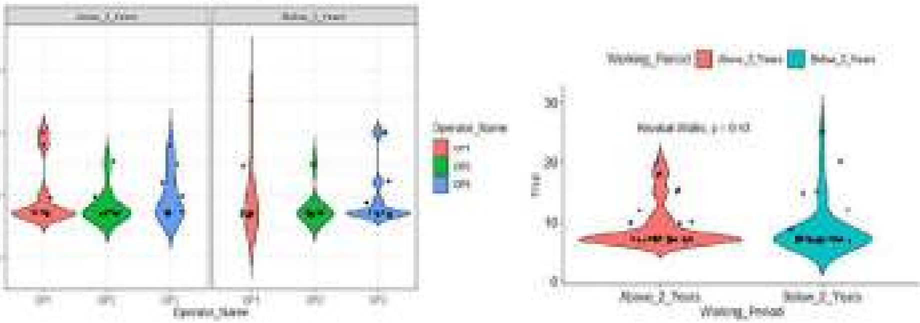

*Figure 15. Result chart after improvement implementation*

***Acknowledgment:*** The authors would like to express deepest gratitude and appreciation to all parties who have helped during this research, including the editors and reviewers.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 69-89*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta210322091b*

ORESTA

# ENHANCING RESILIENCE OF OIL SUPPLY CHAINS IN THE CONTEXT OF DEVELOPING COUNTRIES

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Received: 20 October 2021
Accepted: 31 January 2022
First online: 21 March 2022

*Research paper*

**Abstract:** *Oil supply chains play a vital role in the day-to-day functioning of national economies and obstruction in its services can lead to dire consequences. For this purpose, it is imperative for oil supply chains to be on guard against all probable vulnerabilities and develop adequate protection mechanisms. This research study aims to identify the most important vulnerabilities for oil supply chains in the context of Pakistan, a developing country. Subsequently, these identified vulnerabilities were used to design a protection framework, embodying different supply chain capabilities. For this purpose, this study employs a hybrid Multi-Criteria Decision Making approach. Full Consistency Method (FUCOM) has been used to prioritise vulnerabilities and Fuzzy Quality Function Deployment (QFD) has been used to identify those capabilities that can ensure protection against these vulnerabilities. This study utilizes secondary data for the identification of vulnerabilities and capabilities through a comprehensive literature review. In addition, primary data has been incorporated as relevant experts were asked to rate the importance of these identified vulnerabilities and capabilities. Results indicate that crude oil price instability, fuel price shocks, unpredictable demand, and information and communication disruptions are the most important and catastrophic vulnerabilities in the context of Pakistan's oil industry. For mitigation of these vulnerabilities, oil supply chains need to incorporate real-time information sharing, visibility, e-procurement, traceability, and transparency as resilience measures. These recommendations are of considerable importance to Pakistan's oil industry and policy-making authorities. Moreover, this study fulfils the research gap by focusing on enhancing the resilience of Pakistan's oil supply chains, with the aid of MCDM techniques.*

**Key words**: *Oil Industry, Supply Chain, Resilience, Fuzzy Set Theory, FUCOM, QFD*

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# 1. Introduction

The oil industry is one of the key contributors to the global and national economies, as it is one of the most significant and commonly dealt products. The worth of the oil development, production, and distribution have a handsome share in a country's economy. Numerous economic sectors count on petroleum products as it drives the generation of electrical energy, transport sector, heating in homes, industrial operations, and fulfils residential needs. Globally, in 2016, it was estimated that global annual and daily consumption of oil stood at 35,442,913,090 and 97,103,871 barrels respectively (worldometers, 2021). The economic worth of a country can be estimated by its production, refinement, transportation, as well as consumption of petroleum products. Pakistan is a developing country, and like other countries, its economic advent also relies on the active role of the oil industry. Its petroleum sector faces frequent disruptions due to various policy, administrative, market-based, and financial issues. The effect of these disruptions is realized in the form of losses to national GDP and deterioration of the quality of life of citizens.

The effective and smooth operations of oil supply chains are often threatened on account of their vulnerabilities, which are exploited by potential disasters. Thus, huge losses to revenue, operations, quality, and other attributes are caused (Ponomarov & Holcomb, 2009). These vulnerabilities are both intrinsic and extrinsic in nature. The disruptions can be realized due to the occurrence of natural disasters, pandemics, epidemics, and internal forces such as failure to incorporate different functions of the supply chain. Moreover, the modern day's turbulent and uncertain business environment has also rendered supply chains more prone to looming disasters. The traditional mechanisms to become profitable supply chains is also exposing companies to new vulnerabilities (Tarei, et al., 2020). The increased number of threats and risks associated with the vulnerabilities can destabilize the entire supply chain. The cascading effect of this destabilization drives the company to a greater extent, and the economic sector to a lesser extent, into chaos (Sheffi, 2005). Recently, the coronavirus pandemic (COVID-19) has posed a serious threat to the sales and market share of each industry. These increased disruptions and vulnerabilities ask for the inclusion of Supply Chain Capabilities (SCCs) to become resilient (Christopher & Lee, 2004). Because if vulnerabilities are not timely mitigated, the consequences could halt the supply chain operations which would, in turn, result in loss of revenue (Ponomarov & Holcomb, 2009). The dilemma of vulnerabilities and disruptions is also existent in oil supply chains. However, due to the crucial role of petroleum products in national and global economies, the implications of these disruptions are more execrable in nature.

The SCCs have the potential to act as resilient features and either prevent disruptions or help the supply chain resume normal operations right after disruptions (Pettit, et al., 2011). The concept of resilient supply chains is a universally accepted and recognized agenda due to the prevalent vulnerabilities and complexities of the global supply chains. The SCCs should be organized in such a way that they not only mitigate risks but also deliver a sufficient amount of petroleum products in a reasonable, reliable, effective, environmentally friendly, proactively administered and socially acceptable manner (Sovacool, et al., 2011). A real-world application of mitigating Supply Chain Vulnerabilities (SCVs) through SCCs enhances not only the financial performance of the oil industry (Fan, et al., 2017) but also the overall performance of the established supply chains (Thun & Hoenig, 2011).

There are numerous SCCs and it is usually difficult and costly for supply chains to adopt all SCCs. There is a need for a mechanism that can be employed to determine which SCCs are most pertinent and relevant for respective supply chains. Thus, supply chains would be able to identify the important SCCs and incorporate a limited number of these SCCs or focus on these SCCs in order of their impact. This study proposes that SCCs can be viewed as a tool to combat vulnerabilities. Therefore, SCVs can be used to prioritise SCCs and thus supply chains can focus on these prioritised CCs according to their importance.

This research study aims to identify and prioritize the supply chain vulnerabilities with regard to Pakistan's oil industry. Furthermore, these prioritized vulnerabilities have then been employed to design a resilience framework, comprising supply chain capabilities. These capabilities are also prioritized on the basis of their effectiveness against vulnerabilities. Thus, the study's primary hypothesis is to determine the rank of SCCs for oil supply chains of developing countries. For this purpose, a hybrid combination of two MCDM techniques has been used. Full Consistency Method (FUCOM), a rather recent technique, has been used to assign relative importance weights to supply chain vulnerabilities. Furthermore, Fuzzy Quality Function Deployment (QFD), has been used to prioritize supply chain capabilities as per their ability to combat the previously prioritized vulnerabilities and reinforce other capabilities.

The full consistency method has been employed because it is an improved method for the relative comparison of criteria. It embodies the advantages of qualitative decision making and non-linear programming, thus assigning a reasonably fair value for relative comparison of attributes. In this study, initially, SCVs have been compared relative to each other and assigned with numerical values with the aid of the FUCOM method. Moreover, the Fuzzy Quality Function Deployment tool was primarily developed to incorporate customer preferences into product design. It prioritises product design features that can ensure adherence to customer preferences. Lately, its scope has been diversified and has been widely adopted in research studies. In this study, it has been used to incorporate resilience against SCVs through SCCs.

The rest of this research study is structured as follows. The Introduction is followed by Literature Review, where research studies relevant to the topic and methodology have been discussed. Data Collection and Methodology elaborates the data collection process and the analysis. Subsequently, the Result and Discussions describe the results and policy recommendations. Finally, the Conclusion section concludes the study.

## 2. Literature Review

Crude oil is considered one of the key sources of energy. It plays a significant role in the day-to-day functioning of the world's economy. The Oil Supply Companies (OSCs) have multifarious structures with regards to the choice of products, consumer markets, and operations (Ahmad, de Brito M, Rezaei, & Tavasszy, 2017; Saad, Elsaghier, & Ezaga, 2018). Due to the complexity prevailing in the upstream, midstream, and downstream functions, the oil supply chains are quite vulnerable to disruptions. A research study emphasized and assessed safety risks and the overall vulnerability in the oil industry by establishing a risk matrix. The study analyzed the consequences of the indicators such as accidents' proportions, economic loss, reputation loss, and environmental pollution (Tian, et al., 2018). The most dangerous risk associated with OSCs is the financial risk. High price fluctuation within the global energy market is one of the key threats to the financial stability of the oil industry (Chikunov, et al., 2019). The recent shock due to the COVID-19 pandemic has also severely destabilized the energy sector, global economic growth, and geopolitics (McNally, 2020; Đukić et al. 2021).

Similarly, a study addressed vulnerabilities within remote operations of the oil industry including technical information and communications-based risks, organizational risks, and risks associated with human factors (Johnsen, et al., 2007). From the perspective of developing countries, the Nigerian oil industry was assessed with political risks (Frynas & Mellahi, 2003). The researchers concluded that it has varying effects on transnational firms. In some cases, firms underperform while in other cases, firms can get benefits under certain circumstances. In addition, (Bimha, et al., 2020) analyzed the Zimbabwean petroleum industry with respect to the uninterrupted flow of quality products at reasonable prices. The top fifteen oil-importing South Asian countries were assessed on the indicators like geopolitical risk, transportation risk, oil price unpredictability, and US dollar instability (Iqbal, et al., 2020). These risks result in poor performance and competitiveness at both micro and macro levels.

In past decades, supply chains have been challenged by vulnerabilities in the shape of disasters and have thus left an impact on society and ecosystems (Sodhi, et al., 2012). Resilient supply chains are required in order to tackle the frequently occurring and severe vulnerabilities. Numerous research studies have been conducted on resilient supply chains which focus on capabilities that help to confront such vulnerabilities. The pseudo-resilient supply chain concept was introduced in a study where the supply chain performs much better with the inclusion of risk management capabilities (Rajesh, 2018). A Decision Support System (DSS) was developed keeping in view the Indian petroleum supply chain. Managers can select a suitable risk management strategy and accelerate the execution of risk management enablers (Tarei, et al., 2020). SCCs sum up all such resilient measures to cope up with the vulnerabilities prevailing in any business. A study identified the problem of low visibility and integration in the supply chain and proposed three top resilient measures which include contingency plan, monitoring and maintenance, and the supply chain relationship management (Lam & Bai, 2016).

The complexity of oil supply chains requires effective supplier selection and close relationships to overcome the uncertainty. Researchers developed an integrated approach for supplier selection within Iran's oil industry to ensure a continuous supply stream (Kaviani, et al., 2019). The logistics network of OSCs is also exposed to vulnerabilities. A study discussed the uniform commercial code related to OSCs management issues and developed several strategies to improve the supply chain (Chima, 2007). Another research focused on European Union's oil supply chains and observed that there is a robust resiliencmechanismsm in place, however, it needs to be synchronized (Urciuoli, et al., 2014). (Hossain, et al., 2019) employed a Bayesianetwork-based approach to explore resilience in oil and gas supply chains. In addition, (Alfaqiri, et al., 2019) focused on Africa as a case study and investigated the existence and applicability of the complex system governance in the context of risks in oil supply chains. However, the demand side of oil supply chains, especially in the context of developing countries, has not been adequately addressed from the perspective of oil supply chains.

The adoption of blockchain in supply chains is a modern trend and has gained widespread popularity. Blockchain can enhance OSCs performance with unique features like real-time information sharing, cybersecurity, transparency, reliability, traceability, and visibility (Aslam, et al., 2021). The important and essential technologies of blockchain implementation in OSC has been discussed in a study with four features including trading, management and decision-making, supervision, and cybersecurity (Lu, et al., 2019). Traceability was ranked as the highest core innovation technology to exploit existing SCCs and resources (Hald & Kinra, 2019). Blockchain features including information transparency, information immutability, and effective contracts have a positive impact on partnership growth (Kim & Shin, 2019). A research study identified the disrupted vulnerabilities like piracy in OSCs by providing a holistic complex system of governance (Alfaqiri & Pinto, 2019). Furthermore, issues related to poor governance including weak regulatory system, poor policy regarding oil industry operations, logistics and communication challenges weaken the existing SCCs and industry competitiveness (Bimha, et al., 2020).

FUCOM is a Multi-Criteria Decision-Making (MCDM) technique, and it was developed by (Pamučar, et al., 2018). It has found several applications in determining the weight coefficients of the relative importance of attributes in consideration. (Pamucar & Ecer, 2020) presented the Fuzzy FUCOM approach and applied it to the evaluation of green suppliers. The authors compared the results of Fuzzy FUCOM with Fuzzy Analytical Hierarchy Process and Fuzzy Best Worst Method and thus confirmed its vitality. A research study combined FUCOM approach with D numbers and the Fuzzy RAFSI method for the development of a hybrid decision-making model (Božanić, et al., 2021). Similarly, (Durmić, et al., 2020) used FUCOM in addition with Rough SAW approach. Another research used FUCOM with the MABAC model in a decision making research scenario (Bozanic, et al., 2020). Thus, there is evidence from the literature that FUCOM has been used in addition with other decision-making techniques.

The Quality Function Deployment (QFD) technique was developed in the 1970s by Akao in Japan. QFD, being a comprehensive and extensively recognized quality management tool, was developed to translate customer requirements into characteristics of process or product (Akao & Mazur, 2003). This is achieved by building a House of Quality (HOQ). The needs can be identified through the help of past literature and questionnaire survey from managers and employees. QFD has proven to be a systematic process to resolve the key issues involved in any process. Lately, QFD has been widely used for the selection of strategies, risks, supplier selection while using the weight derived from decision-making tools (Lima-Junior & Carpinetti, 2016; Chen, Ko, & Yeh, 2017). Fuzzy set theory was developed for the mitigation of uncertainty in qualitative judgments (Zadeh, 1965). Fuzzy QFD has been used in a variety of studies. (Wang, et al., 2020) used Fuzzy QFD for developing a system collaborative framework for designing quality products. (Deveci, et al., 2019) employed Fuzzy QFD and developed a framework for quantitative assessment with regards to customer satisfaction in public transportation. Similarly, a study designed a safety methodology with the aid of Fuzzy QFD (Fargnoli, et al., 2018).

This research study contributes to the literature and addresses the research gap from two perspectives. Firstly, it focuses on mitigating vulnerabilities in oil supply chains in the context of developing countries. Oil supply chains in developing countries lie on the demand side in the supply chain spectrum have not been given adequate attention in the literature. Thus, the results of this study would be of considerable significance to developing countries and aid them in enhancing the resilience of oil supply chains. Secondly, this study has used a novel combination of research techniques for addressing supply chain vulnerabilities with supply chain capabilities. The proposed combination of research tools i.e., FUCOM in association with Fuzzy QFD has rarely been used to address the vulnerabilities and design a resilience framework. Thus, the results of this study would not only add a unique perspective to the existing literature regarding risks in oil supply chains but also propose a research framework that can be adopted for enhancing resilience in other sectors.

## 3. Data Collection & Methodology

This research study is focused on the evaluation of adequate supply chain resilience capabilities against the most important and common vulnerabilities, in the context of Pakistan's oil industry. The study utilizes a unique combination of FUCOM and Fuzzy QFD methods to conduct the analysis. The finalized vulnerabilities and capabilities are presented in Table 1 and 2, respectively.

*Table 1. Supply Chain Vulnerabilities*

| Categories | Vulnerabilities | References |
|---|---|---|
| Demand and Supply Vulnerabilities | Resource Unavailability | (Sovacool, et al., 2011); (Feygin & Satkin, 2004) |
| | Oil Dependence Risks | (Zhang, et al., 2013); (Yang, et al., 2014); (Li, et al., 2014) |
| | Supplier Disruptions | (Sun, et al., 2017); (Alfaqiri, et al., 2019) |
| Financial Vulnerabilities | Crude Prices Instability | (Kaufmann, 2016); (Alfaqiri, et al., 2019) |
| | Economic Recession | (Hanabusa, 2010); (Blos, et al., 2009) |
| | Refined Fuel Prices Shocks | (Blos, et al., 2009) |
| Social and Political Vulnerabilities | Geopolitical Risks | (Blos, et al., 2009); (Iqbal, et al., 2020) |
| | Transportation Risks | (Sun, et al., 2014); (Wu, et al., 2009) |
| | Pandemic/Epidemics | (Mhalla, 2020) |
| | Natural Hazards | (Badida, et al., 2019) |
| | Political Instability | (Blos, et al., 2009); (Block, et al., 2015) |
| Operational Vulnerabilities | Demand Fluctuations | (Davis, 2018); (Zhu, et al., 2020); (Berget, 2020) |
| | Information & Communication Disruptions | (Giri & Sarker, 2017); (Aslam, et al., 2021); (Kshetri, 2018) |
| | Lack of Research & Development | (Kraal, 2019) |
| | Inadequate Government Policies | (Imbun, 2019); (Aung, 2017); (Akrofi & Antwi, 2020) |

The proposed combination is novel as it integrates the two techniques, by utilizing the relative importance weights deducted from the FUCOM analysis in the Fuzzy QFD analysis. In the first step, an extensive literature review was conducted to identify supply chain vulnerabilities and capabilities. It resulted in the identification of several factors, and for maintaining relevancy and reduction of redundancy, a total of fifteen capabilities and vulnerabilities were shortlisted. In addition, a panel of experts was also consulted for shortlisting these factors.

*Table 2. Supply Chain Vulnerabilities*

| S. No. | SC Capabilities | References |
|---|---|---|
| 1. | Minimization of Shutdown Period | (Machado, et al., 2020) |
| 2. | Compliance with Regulatory Developments | (Myasnikova, et al., 2019); (Sanchez, et al., 2019) |
| 3. | Improved Reliability | (Aslam, et al., 2021); (Hasan, et al., 2020) |
| 4. | Real-time Information Sharing System | (Aslam, et al., 2021); (Hald & Kinra, 2019); (Queiroz, et al., 2019) |
| 5. | Transparency | (Aslam, et al., 2021); (Cole, et al., 2019); (Kim & Shin, 2019) |
| 6. | Traceability | (Aslam, et al., 2021); (Hasan, et al., 2020); (Kshetri, 2018); (Song, et al., 2019) |
| 7. | Visibility | (Aslam, et al., 2021); (Kim & Shin, 2019); (Kshetri, 2018) ; (Rogerson & Parry, 2020) |
| 8. | E-Procurement | (Aslam, et al., 2021); (Tie & Cheng, 2015) |
| 9. | Risk Management Culture | (Ahmad, et al., 2016); (Pagell & Wu, 2009) |
| 10. | Improved Forecast Reliability | (Chima, 2007); (Vonderembse, et al., 2006) |
| 11. | Timely and Effective Delivery | (Ako, 2012); (Ablo, 2015); (Chang, et al., 2011) |
| 12. | Continuous Supply Stream of Products | (Neiro & Pinto, 2003) |
| 13. | Product Quality in Compliance with Specifications | (Wei, et al., 2019) |
| 14. | Unbundling/Decentralization of Authority in Petroleum Industry | (Agrell & Bogetoft, 2017) |
| 15. | Managing Bullwhip | (Rajesh, 2018); (Mackelprang & Malhotra, 2015) |

The techniques used in this study are reliant on expert opinion for assigning importance and adequacy weights to attributes. Therefore, a questionnaire was developed which comprised of three major parts. In the first part, the experts were asked to gauge the relative importance of each attribute, and in the second part, the experts were asked to rate the effectiveness of each capability against vulnerabilities. The third part focused on the nature of bolstering or undermining the relationship between capabilities. The experts' panel was comprised of reputable managers in the oil industry. These experts, as shown in figure 1, were serving in refineries, exploratory firms, OMCs, and the Ministry of Petroleum. A total of eleven responses were gathered which are sufficient, considering the detailed nature of the questionnaire and the usual sample size used in MCDM techniques. The questionnaires were filled after a detailed briefing to experts and their queries regarding various aspects of questionnaires were addressed.

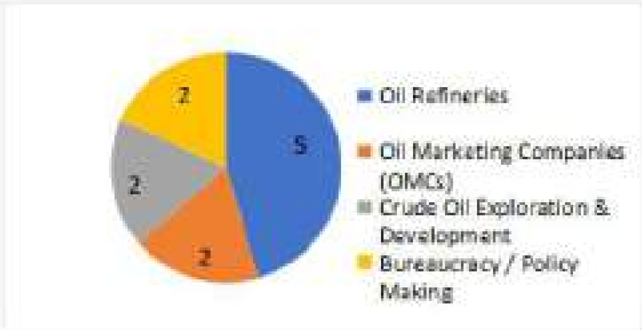


*Figure 1. Experts' Panel*

### 3.1. Fully Consistency Method (FUCOM)

Fully Consistency Method (FUCOM) is a Multi-Criteria Decision Making (MCDM) technique, developed by (Pamučar, et al., 2018). FUCOM has been employed to gauge the relative effectiveness of supply chain vulnerabilities, as each vulnerability has a different level of importance owing to its probability, severity, costs, and other aspects. The various steps involved in the FUCOM method are explained below.

**Step 1:** The set of factors, whose relative importance is to be gauged, is identified. A questionnaire is formed, and the experts are asked to respond on a Likert scale, determining the importance of each factor.

**Step 2:** The average importance weight for each factor is determined and the factors are ranked in the decreasing order of their weights.

$$SCV_{j(1)} > SCV_{j(2)} > SCV_{j(3)} > \ldots\ldots > SCV_{j(k)} \quad (1)$$

Where SCV represents the supply chain vulnerabilities, and j represents the ranks of criteria when arranged in an order.

**Step 3**: Comparative priorities of criteria, which represent the advantage of criteria over other criteria, are determined with the aid of equations 2 and 3.

$$\alpha_{j/_{j+1}} = \frac{SCV_j}{SCV_{j+1}} \quad (2)$$

$$\Phi = \alpha_{1/2}, \alpha_{2/3}, \ldots, \alpha_{k/k+1} \quad (3)$$

**Step 4:** A non-linear programming model is constructed, which essentially comprises of two conditions.

The ratio of final weight coefficients of criteria equals the respective comparative priority.

$$\frac{w_j}{w_{j+2}} = \frac{\alpha_j}{\alpha_{j+1}} \quad (4)$$

The condition of mathematical transitivity is fulfilled by the weight coefficients.

$$\frac{w_j}{w_{j+1}} = \frac{\alpha_j}{\alpha_{j+1}} * \frac{\alpha_{j+1}}{\alpha_{j+2}} \qquad (5)$$

**Step 5:** The final weight coefficients are determined by forming and solving a nonlinear programming model. The standard format of the model is given below.

These weight coefficients are later used in the Fuzzy QFD analysis, explained in the next section.

$$\min \chi$$

s.t.

$$\left| \frac{W_j}{W_{j+1}} - \phi_{j/_{j+1}} \right| \leq \chi, \forall j$$

$$\left| \frac{W_j}{W_{j+2}} - \phi_{j/_{j+1}} * \phi_{j+!/_{j+2}} \right| \leq \chi, \forall j$$

$$\sum_{j=1}^{n} w_j = 1,$$

$$w_j \geq 0, \forall j \qquad (6)$$

### 3.2. Fuzzy Quality Function Deployment (QFD)

Quality Function Deployment alternatively knows as, House of Quality is a tool developed by Akao, a Japanese researcher (Akao, 1990). Originally, it was designed to translate customer requirements into product design. However, its scope has lately been diversified and it's widely used in scenarios where there are sets of clearly defined challenges and solution strategies. The challenges and strategies are referred to as WHATs and HOWs respectively. In this study, the supply chain vulnerabilities and capabilities constitute WHATs and HOWs.

QFD analysis is also dependent upon the experts' response, which inherently contains vagueness or uncertainty up to a certain degree. In order to mitigate this uncertainty, Fuzzy Set Theory developed by (Zadeh, 1965) has been incorporated in the QFD. The Fuzzy set theory considers the relative importance of attributes instead of absolute judgments. The various steps involved in Fuzzy QFD analysis are explained below.

Step 1: The WHATs and HOWs for the QFD model are identified and expert opinion is gathered. Experts' panel is asked to respond on a Likert scale, regarding the effectiveness of each strategy against a challenge, and the supporting or diminishing role with respect to other strategies.

Step 2: The final weights derived from the FUCOM analysis for SCVs are used as the importance weights of strategies or WHATs in the QFD model. This step embodies the methodolgoial contribution of the study as it incorporates the relative importance weights derived from the FUCOM analysis, instead of absolute weightages given by experts. Thus, the relative importance weights increase the authencity of the weights and improve the overall analysis.

Step 3: The Relationship matrix is constructed, between WHATs and HOWs. The (i,j) entry in the matrix shows the strength of jth HOW in achieving ith WHAT. In this case, it represents the ability of jth capability to mitigate ith vulnerability. The matrix is developed, based on the average value of expert responses. The experts are asked to rate the effectiveness of each strategy against each challenge on the Likert scale given in Table 3.

*Table 3. Linguistic Scale for Relationship Matrix*

| Degree of Relationship | | | |
|---|---|---|---|
| Degree of Relationship | Fuzzy Number | | |
| Strong | 0.7 | 1 | 1 |
| Medium | 0.3 | 0.5 | 0.7 |
| Weak | 0 | 0 | 0.3 |

Step 4: The Correlation matrix is constructed between HOWs. It represents the nature of the relationship between various HOWS. The (i,j) entry in the matrix shows the relationship of ith HOW and jth HOW. In this case, it represents the relationship between supply chain capabilities. The matrix is developed, based on the average value of expert responses. The positive values show supporting relationships while negative values show a damaging relationship between strategies. The experts are asked to rate the effectiveness of each strategy against each challenge on the Likert scale given in Table 4.

*Table 4. Linguistic Scale for Relationship Matrix*

| Degree of Correlation | | | |
|---|---|---|---|
| Degree of Relationship | Fuzzy Number | | |
| Strong Positive | 0.3 | 0.5 | 0.7 |
| Positive | 0 | 0.3 | 0.5 |
| Negative | -0.5 | -0.3 | 0 |
| Strong Negative | -0.7 | -0.5 | -0.3 |

Step 5: The relative importance weights of each HOW are calculated from the relationship matrix, with the aid of equation 7.

$$RI_j = \sum_{i=1}^{n} W_i * R_{ij} \quad (7)$$

where j = 1,2,..,m and $(R_j = R_{jU}, R_{jM}, R_{jU})$

Here $W_i$ refers to the weight coefficients calculated from FUCOM analysis, while $R_{ij}$ represents the entries of the relationship matrix.

Step 6: The priority weights are calculated with equation 8.

$$RI_j^* = RI_j + \sum_{k=j} T_{kj} * RI_k \quad (8)$$

where j = 1,2,.., m and $(RI_j^* = RI_{jL}^*, RI_{jM}^*, RI_{jU}^*)$

Here, T refer to the entries of the correlation matrix.

Step 7: The priority weights are normalized by the division of each value by the maximum value of priority wights. Subsequently, the priority weights are de-fuzzified via geometric mean. The HOWs are then ranked in the descending order of the de-fuzzified weights.

## 4. Results and Discussion

The results and discussion section is divided into two parts. The first part focuses on the results of the FUCOM analysis while the second part elaborates on the results of the Fuzzy QFD analysis.

### 4.1. FUCOM Analysis – Supply Chain Vulnerabilities

The non-linear programming model of FUCOM analysis resulted in final weight coefficients given in Table 5.

*Table 5. Rankings of SCVs derived from FUCOM*

| Rankings | Supply Chain Vulnerabilities | | Weight |
|---|---|---|---|
| 1 | SCV 4 | Crude Prices Instability | 0.096 |
| 2 | SCV 6 | Refined Fuel Prices Shocks | 0.093 |
| 3 | SCV 12 | Demand Fluctuations | 0.083 |
| 4 | SCV 13 | Information & Communication Disruptions | 0.083 |
| 5 | SCV 15 | Inadequate Government Policies | 0.080 |
| 6 | SCV 3 | Supplier Disruptions | 0.069 |
| 7 | SCV 1 | Resource Unavailability | 0.067 |
| 8 | SCV 2 | Oil Dependence Risks | 0.065 |
| 9 | SCV 9 | Pandemic/Epidemics | 0.065 |
| 10 | SCV 14 | Lack of Research & Development | 0.065 |
| 11 | SCV 5 | Economic Recession | 0.056 |
| 12 | SCV 8 | Transportation Risks | 0.049 |
| 13 | SCV 11 | Political Instability | 0.048 |
| 14 | SCV 7 | Geopolitical Risks | 0.046 |
| 15 | SCV 10 | Natural Hazards | 0.035 |

The weights coloumn of the anlysis indicate the final relative weights assigned to SCVs. Each of the SCVs have been assigned with a weight between 0 and 1, and the sum of all these weights equal 1. These weights indicate the priority of each vulnerability with respect to other vulnerabilities, and the higher weights indicate increased priority.

The FUCOM analysis indicates that crude oil price instability is a top-ranked vulnerability, which can jeopardize the steady operations of oil supply chains. Crude oil price instability is directly associated with stock returns of oil companies, production costs, diminished profit margins, inability to meet consumer demand, inventory costs, and policy fluctuations (Apergis & Miller, 2009; Arouri & Nguyen, 2010). However, this vulnerability is inherently extrinsic in nature as crude oil prices are primarily determined by the Organization of Petroleum Exporting Countries (OPEC). Moreover, fuel price shock occupied second place in ranked vulnerabilities. In Pakistan, usually, fuel prices are revised on a fortnightly basis. Thus, there are constant speculations about expected trends or policy decisions, and OMCs respond respectively. In case of lower expected prices, these companies try to delay procurement and in case of higher prices, the ignominious practise of hoarding takes place.

Unpredictable demand proved to be yet another vital risk in the petroleum sector. The recent COVID-19 pandemic exhibited a strong and unpreceded fluctuation in consumer demands. OPEC asked its petroleum sector to cut oil production by a record of 10 million barrels per day in May 2020, which was still not sufficient to minimize the gap between demand and supply (IEA, 2020). Since the lockdowns are expected to happen routinely in a near future due to the ravaging nature of the pandemic, and other reasons, consumer demand would remain unpredictable and would thus adversely affect oil supply chains. Information and communication disruptions are also prevalent in the petroleum industry of Pakistan. These disruptions have severe disastrous impacts on the functioning and operations of oil supply chains. These disruptions cause supply-demand imbalance, financial mismanagement, and increased operational costs. Thus, the ranking derived from FUCOM analysis is justifiable and there is a need to design preemptive strategies which should help in overcoming these vulnerabilities.

### 4.2. Fuzzy QFD Analysis – Supply Chain Capabilities

The results of the Fuzzy QFD analysis are presented in the Table 6. The RI coloumn lists the relative importance weights of SCCs. These weights indicate the strength of each SCC with respect to combating SCVs as per their importance, and the capacity of each SCC to withhold/support other SCCs.

*Table 6. Rankings of SCCs derived from QFD*

| Rankings | | Supply Chain Capabilities | RI |
|---|---|---|---|
| 1 | SCC4 | Real-time Information Sharing System | 0.38 |
| 2 | SCC7 | Visibility | 0.37 |
| 3 | SCC8 | E-Procurement | 0.37 |
| 4 | SCC6 | Traceability | 0.36 |
| 5 | SCC5 | Transparency | 0.36 |
| 6 | SCC15 | Managing Bullwhip | 0.33 |
| 7 | SCC9 | Risk Management Culture | 0.30 |
| 8 | SCC3 | Improved Reliability | 0.29 |
| 9 | SCC11 | Timely and Effective Delivery | 0.28 |
| 10 | SCC12 | Continuous Supply Stream of Products | 0.28 |
| 11 | SCC10 | Improved Forecast Reliability | 0.27 |
| 12 | SCC1 | Minimization of Shutdown Period | 0.24 |
| 13 | SCC13 | Product Quality in Compliance with Specifications | 0.08 |
| 14 | SCC 2 | Compliance with Regulatory Developments | -0.06 |
| 15 | SCC14 | Unbundling/Decentralization of Authority in Petroleum Industry | -0.12 |

The results of the Fuzzy QFD analysis are presented in the table 6. The RI column lists the relative importance weights of SCCs. These weights indicate the strength of each SCC with respect to combating SCVs as per their importance, and the capacity of each SCC to withhold/support other SCCs.

The results of the Fuzzy QFD analysis present strong evidence for the need for the incorporation of blockchain features in Pakistan's petroleum supply chains. The top five capabilities, prioritized as a result of Fuzzy QFD analysis are associated with blockchain features and practices. The top-ranked strategy that would mitigate most vulnerabilities and play a supporting role with regards to other capabilities, is the real-time information sharing system. Its incorporation would lead to the smooth functioning of the business activities and effective communication within and between business entities (Wanga, et al., 2020). It would also aid in improved forecasts as the varying trend of demand and supply can be instantaneously accommodated in the forecasting mechanisms (Zhoua & Benton, 2007). The information system would provide accurate information regarding the status of availability of crude, demand at the downstream end, and the transportation associated with OSCs. Thus, its incorporation would lead to mitigation of vulnerabilities as respective authorities would be better able to track down instabilities and interruptions, conduct effective planning, design preemptive strategies.

Similarly, the adoption of visibility as a vulnerabilities mitigation mechanism would serve in a variety of ways. It would enhance focus, monitoring, and control of the entire operations of oil supply chains (Bartlett, et al., 2007). There are several products involved in the OSCs and each product has a distinct route, source, and destination. In addition, there are supporting roles for ensuring the smooth delivery of products. Visibility would maintain coordination between all these segments of operations.

Furthermore, E-procurement is another rapidly growing modern trend that enables purchasing via digital means. It reduces delivery time, provides better bargaining options, increases accountability and transparency, and minimizes communication disruptions (Jelassi & Martínez-López, 2020). E-Procurement can also reduce severity or impact in case of occurrence of disruptions. It also reduces significant costs through reduction of lead time, effective resource planning, and reduction of inventory levels.

Traceability has also proven to be a dominant feature with regard to resilience in supply chains. It helps in mapping down the processes and the complete journey of petroleum products in the oil industry. Petroleum products require adequate and well-designed safety and quality measures, which can be improved with traceability mechanisms as companies are in knowledge of where, when, and how their products are coming (Malik, et al., 2021). It also aids in protective mechanisms against physical thefts in vulnerable areas.

Supply chain transparency is another feature that increases acceptibilty and success of supply chains (Jabbar, et al., 2021). Transparancy refers to the practice of communicating information, functional status, operationa; standards, and impact within supply chains, to upstream and downstream linkages and customers (Gardnera, et al., 2019). Trasnparancy in supply chains assure customers and other associated entities that supply chain's practices align with their ethical, functional, and busuiness values. Thus, it increases confidence in supply chains and associated entities are able to positively engage with the supply chain. Ensuring transaparancy is also a blockchain feature, and with the use of digitial communication, artificial intelligence, and industry 4.0, the information can be gathered, analysed and broadcasted to respective audience (Saberi, et al., 2019).

In addition to the five discussed SCCs, all the other SCCs with positive RI values are viable strategies and should be incorporated in oil supply chains of Pakistan. However, in case of time, cost, or other constraints, priority should be given to the top five ranked strategies. The incorporation of top five SCCs would enable Pakistan's oil supply chains to track demand, disruptions, variations and respond proactively to these challanges. It would also aid in effective monitoring of market and operational status, effective planning, and optimized distribution of resources. These benefits would lead to stability in the overall oil industry and government authorities would be able to design and implement improved policies. Companies operating the in upstream and downstream of OSCs would also be able to gain functional insights. Thus, the supply chain data management support system, if integrated with the products, materials, suppliers, and governmental bodies, would provide numerous benefits.

## 5. Conclusion

The oil industry is one of the key determinants of the effective functioning of national economies. Its smooth, timely, and efficient supply reinforces other sectors of the economy while interruptions in its services lead to deleterious effects on the overall economy. Therefore, it is pertinent for government authorities and private sectors to design preemptive strategies that could identify and minimize the impact of vulnerabilities. This research study aimed to identify and prioritize various supply chain vulnerabilities that could occur within Pakistan's oil industry. Subsequently, it identified and prioritized supply chain capabilities that can improve the risk mitigation profile of Pakistan's oil industry.

This study employed a combination of FUCOM and Fuzzy QFD, MCDM techniques, for analysis. FUCOM was used to rank the supply chain vulnerabilities while Fuzzy QFD aided in prioritizing supply chain capabilities in order to preemptively deal with the vulnerabilities. A total of ten supply chain vulnerabilities and ten supply chain capabilities were identified from the literature and analyzed. Results indicated that crude price instability, fuel price shocks, unpredictable demand, and information and communication disruptions are amongst the most important vulnerabilities. In order to reduce the impact of these vulnerabilities, oil supply chains should incorporate real-time information sharing systems, visibility, e-procurement, traceability, and transparency practices in every aspect of their operations. These strategies are associated with the blockchain technologies, that are gaining popularity day by day.

Pakistan is a developing country whose oil industry and its intermediaries are lagging in terms of financial performance. The mitigation of vulnerabilities would lead to relative stability, increase the confidence of investors, boost economic activities and thus improve the quality of life of citizens besides bolstering economic activities.

This research study has few limitations as it relied only on qualitative judgements of experts and first hand numerical data was not incorporated. Moreover, the experts panel was limited in geographical context, as all the experts had professional experience in a common country. In future studies the analysis can be improved by feasibility analysis of the recommended features, pilot studies relying on firsthand data, geographical expansion of experts' panel, and the factors considered in this study can be further diversified. In addition, the comparative analysis with the established methodologies and proposed methodology can also be conducted.

***Acknowledgement:*** This research was supported by the Ministry of Petroleum, Oil & Gas Regulatory Authority (OGRA), Attock Refinery Ltd (ARL), National Refinery Ltd (NRL), Pakistan's State Oil (PSO), Oil & Gas Development Corporation Ltd (OGDCL).

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 90-106*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta180222016p*

# ESTIMATING RUBBER COVERED CONVEYOR BELTING CURE TIMES USING MULTIPLE SIMULTANEOUS OPTIMISATIONS ENSEMBLE

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Received: 15 July 2021
Accepted: 08 November 2021
First online: 18 February 2022

*Research paper*

**Abstract:** *Multiple response surface methodology (MRSM) has been the favorite method for optimizing multiple response processes though it has two weaknesses which challenge the credibility of its solutions. The first weakness is the use of experimentally generated small sample size datasets, and the second is the selection, using classical model selection criteria, of single best models for each response for use in simultaneous optimization to obtain the optimum or desired solution. Classical model selection criteria do not always agree on the best model resulting in model uncertainty. The selection of single best models for each response for simultaneous optimization loses information in rejected models. This work proposes the use of multiple simultaneous optimizations to estimate multiple solutions that are ensembled in solving a conveyor belting cure time problem. The solution is compared with one obtained by simultaneous optimization of single best models for each response. The two results were different. However, results show that it is possible to obtain a more credible solution through ensembling of solutions from multiple simultaneous optimizations.*

**Key words:** *Multiresponse surface methodology, ensembling, credibility of results, solution uncertainty, small sample size problems, simultaneous optimisation*

## 1. Introduction

The mining industry is at the heart of the Southern African Development Community (SADC) region's economic activities and development. Conveyor belts are critical for conveyance of bulk ore over distances and through various stages of processing. The regional product quality standard minimum requirements for general purpose rubber covered conveyor belts for the mining industry were amended. The component adhesion requirement was increased from 5N/mm to 7N/mm. However, key customers were insisting on a minimum of 10N/mm adhesion and $60^{0}$ Shore A rubber compound cover hardness. After redesigning of the specifications of rubber

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compounds, a client manufacturing company required optimum cure times ($T_c$), which would ensure a minimum of 12N/mm adhesion and $60^0$ Shore A hardness, to be determined for the vulcanisation of different conveyor belt thicknesses ($R_t$) for use in shop-floor work instructions.

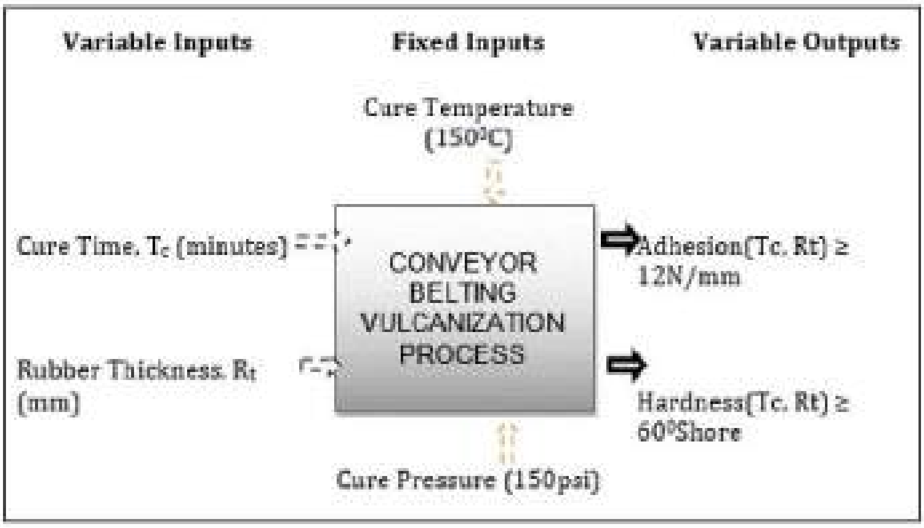


*Figure 1. Illustrating the conveyor belting vulcanization process problem*

Given the illustrated process in Figure 1, it was thus intended to estimate credible cure times ($T_c$) for given rubber thicknesses ($R_t$), as shown in Table 1 below.

*Table 1. Showing the expected solution*

| $R_t$(mm) | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_c$(min.) | $T_7$ | $T_8$ | $T_9$ | . | . | . | . | . | . | . | . | . | . | $T_{20}$ |

For manufacturers, optimum cure time ($T_c$) is critical for product quality and production process productivity. Good adhesion between conveyor belt components (covers, skims and reinforcement fabrics) ensures that they do not separate during heavy duty operations in the mines. The top and bottom rubber covers protect the reinforcement fabrics, therefore hardness is essential for wear resistance to the abrasive mining operational environments. The separation of belting components during heavy duty operation and excessive rubber cover wear are the two major failures of conveyor belting during mining operations. Increasing adhesion between belting components and cover hardness ensures more belting life and therefore lower mining operational costs. Beyond just providing a solution to the client company, the study sought to recommend to the conveyor belt manufacturing industry a credible and efficient tool for converting changes in product standard requirements to production process input parameters. Quality and productivity are critical manufacturing industry competitive factors and the speed of successfully implementing change is critical in any industry as it gives first mover advantages. This work is of interest, therefore, to operations researchers, industrial engineers and business management strategists in the conveyor belting manufacturing industry.

The authors could not find anywhere in literature were cure times per given conveyor belt thickness were estimated for the vulcanisation process of general purpose rubber covered conveyor belting. Literature only gives methodologies for estimating the cure times of different rubber compounds. A rubber covered conveyor belt is constructed from a rubber cover compound, a rubber skim compound (which provides the bonding strength between components) and reinforcement fabric. These components individually contribute to the overall vulcanization time due to different heat conductivities.

In this work, the sufficiency of the contemporary multiple response surface methodology (MRSM) framework in estimating a credible solution to the problem was critiqued and two major weaknesses identified. Firstly, it is statistically difficult to extract credible process information from small sample size MRSM datasets. Secondly, the selection of single best models for each response for simultaneous optimization is prone to (1) loss of information in the rejected response models and (2) model uncertainty as model selection criteria do not always agree on the best model. This work proposes the use of multiple simultaneous optimizations to estimate multiple solutions that are then ensembled, to account for the two weaknesses in the MRSM framework, in solving the conveyor belting cure time problem. Results suggest that the proposed ensemble system can provide a credible solution to the problem.

## 2. Literature Review

### 2.1. Rubber technology perspective

A number of techniques have been proposed in rubber technology literature to estimate the cure time of rubber products such as nuclear magnetic resonance spectroscopy, differential scanning calorimetry, dynamic mechanical analysis, adaptive neuro-fuzzy inference systems, equivalent cure concept, and artificial neural networks and finite element analysis (Gatos and Karger-Kocsis, 2004; Karaagâc et al., 2011; Gough, 2017). The accepted basic tool of cure time estimation is the rheograph (Appendix A) which shows how the shear strength of a sample of rubber changes with time during vulcanisation. The rheograph does not consider the case where there are different layers of constituent rubber compounds and other materials such as conveyor reinforcement fabric (nylon and/or polyester). The conveyor belting case requires a multiple factor and multiple response simultaneous optimisation solution methodology, hence the shift to multiple response surface methodology (MRSM).

### 2.2 Multiple response surface methodology (MRSM)

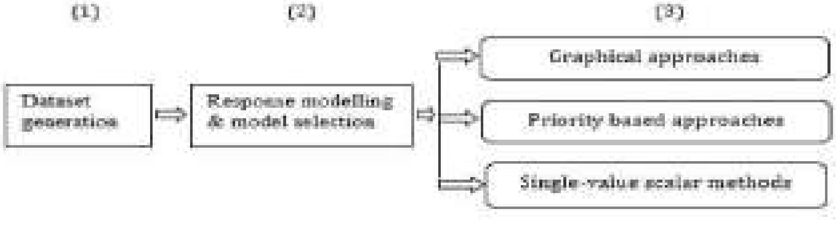


*Figure 2. Showing the contemporary MRSM framework*

MRSM is an important tool for optimising manufacturing processes in industry. It is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which multiple responses are influenced by several variables and the objective of the analysis is to optimize the responses by determining the best settings of the input variables (Myers et al., 2016; Hejazi et al., 2017; Khuri, 2017). In Figure 2, the MRSM dataset generation stage, stage (1), involves designing and running screening and MRSM experiments (Myers et al., 2016). The stage (3) are the solution methodologies for estimating the operating conditions that optimise all the responses or at least keep them in desired ranges.

MRSM experimental designs are constructed to eliminate or minimise correlations between chosen variables which allows independent estimation of variable effects and their potential interactions (Myers et al., 2016; Khuri, 2017; Mäkelä, 2017). Examples include central composite designs (CCD), Box-Behnken, Orthogonal Arrays, Placket-Burman, and computer-generated optimal designs (Myers et al., 2016; Khuri, 2017; Alhorn et al., 2019). The strength of MRSM is in efficient experimental designs (Khuri, 2017). However, statistically, it is difficult to extract credible population information from small sample size datasets (Rawlings et al., 1998; Yuan and Yang, 2005; Xu and Goodacre, 2018; Jenkins and Quintana-Ascencio, 2020). This is the first weakness that requires to be accounted for to obtain credible solutions.

Optimisation in MRSM is multi-objective in nature, and is performed after regression modelling and model selection of single "best" models for each response (Myers et al., 2016; Khuri, 2017). MRSM solution methodologies rely heavily on classical model selection criteria for choosing the best model for each response for simultaneous optimisation. This the second weakness of the contemporary MRSM framework. Problems associated with the contemporary MRSM contextual framework are presented in Figure 3 below.

| # | WEAKNESS | IMPLICATIONS |
|---|---|---|
| 1 | Small sample size dataset | MS criteria inefficiency (Hurvich & Tsai, 1989)<br>Model over-& underfitting (Burnham & Anderson, 2002)<br>Modelling credibility (Rawlings et al. 1998) |
| 2 | Selection of single best model for each response | Model selection bias (Miller, 2002; Lukacs et al. 2010)<br>Model & criteria uncertainty (Schomaker & Heumann, 2018)<br>Dataset uncertainty (Myers et al, 2016)<br>Loss of information (Burnham & Anderson, 2002)<br>Simultaneous optimisation compromise (Myers et al, 2016) |

*Figure 3. Problems related to the current MRSM contextual framework*

In this paper, the authors proposed and utilised a novel solution methodology that accounted for the two weaknesses to obtain a credible solution.

## 3. Solution Methodology

The MRSM dataset generation for the rubber covered conveyor belting problem is explained in detail in Pavolo and Chikobvu (2020). The dataset was adopted as is and is shown in Table 2.

*Table 2. The two-factor CCD experiment MRSM dataset*

| Run | T (min.) | $R_t$ (mm) | Ave. Hardness (°shore A) | Ave. Adhesion(N/mm) |
|---|---|---|---|---|
| 1 | 16 | 7.2 | 60 | 10.60 |
| 2 | 30 | 7.2 | 63 | 13.34 |
| 3 | 16 | 22.8 | 53 | 6.20 |
| 4 | 30 | 22.8 | 61 | 12.10 |
| 5 | 23 | 15 | 58 | 11.80 |
| 6 | 23 | 15 | 58 | 12.10 |
| 7 | 13 | 15 | 44 | 6.5 |
| 8 | 33 | 15 | 63 | 13.30 |
| 9 | 23 | 4 | 63 | 13.30 |
| 10 | 23 | 26 | 56 | 3.50 |
| 11 | 23 | 15 | 58 | 12.20 |
| 12 | 23 | 15 | 57 | 12.30 |
| 13 | 23 | 15 | 58 | 12.10 |

Ensemble-based systems have been recommended for small sample size situations in literature (Kittler, 1998; Burnham and Anderson, 2002; Polikar, 2006; Yang et al., 2016; Ahangi et al., 2019). An ensemble system was considered the best option for accounting for the weaknesses of the contemporary MRSM framework and delivering a credible solution. The solution methodology is summarised in Figure 4.

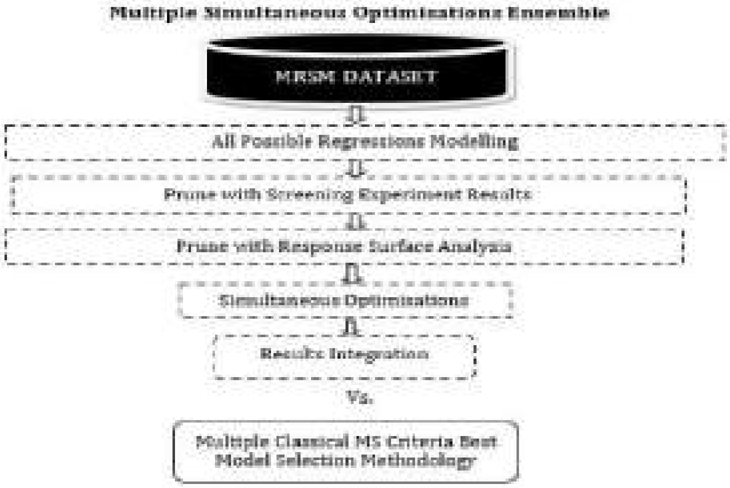


*Figure 4. Showing the solution methodology flow diagram*

At response surface analysis, the one hardness model with response surface conformity was adopted as is from Pavolo and Chikobvu (2020). However, in this work, all the adhesion response models were assumed to be response surface conforming.

The estimated cure time solution was compared with one from a methodology structured after the contemporary MRSM contextual framework. Figure 5 shows the strategies used in the solution methodology to deal with each problem listed in Figure 3.

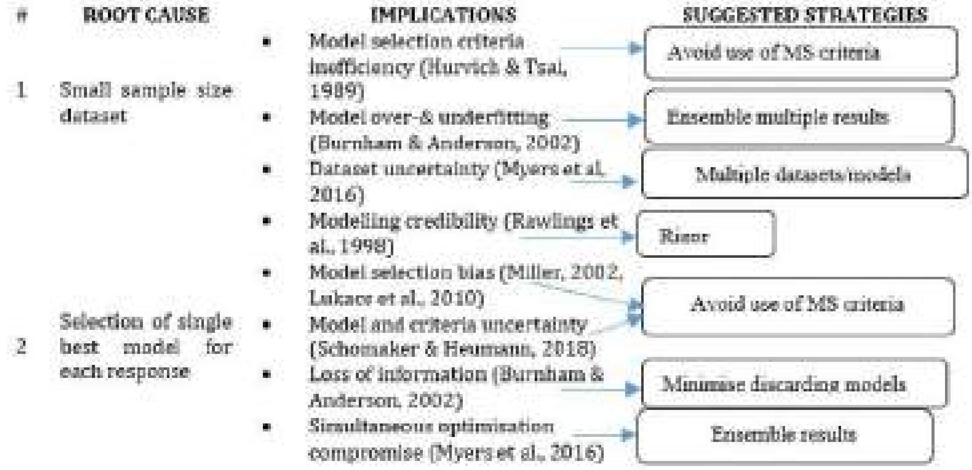


*Figure 5. Showing the strategies employed to deal with problems*

Figure 6 summarises the problems of the contemporary solution methodologies and presents the advantages of the ensembling methodology from literature.

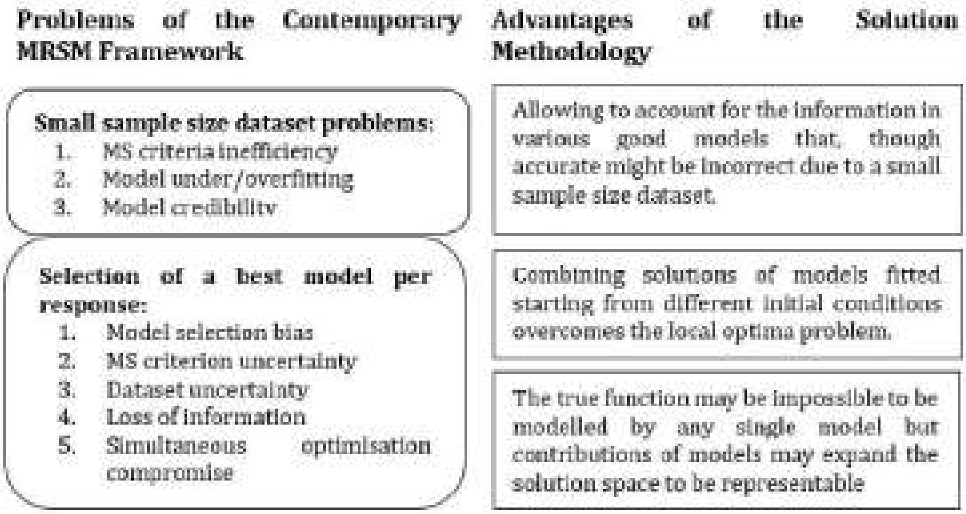


*Figure 6. The advantages of the solution methodology vs. problems of contemporary MRSM*

The formulae used for computation of theoretical accuracy are shown below. Validation was computed against the minimum targeted response values as the sample size was too small to be split into a fitting set and a validation set.

***$MSPE_{val(min.)}$:*** The validation minimum mean squared prediction error ($MSPE_{val(min.)}$) of a response model measures the minimum squared deviation of the model predictions from the targeted. $MSPE_{val(min.)}$ is given below for a sample size *n*.

$$MSPE_{val(min.)} = \frac{\sum_{i=1}^{n}(Y_i - Y_T)^2}{n}, \quad (1)$$

where $\boldsymbol{Y_i}$ is the $i^{th}$ estimated response, $\boldsymbol{Y_T}$ is the a response value.

***$MSPE_{simul}$:*** The mean squared prediction error at simultaneous optimisation ($MSPE_{simul}$) of a response model in an adhesion – hardness model pair indicates the mean squared deviation of the model predictions from the targeted and is given below for a sample size *n* as:

$$MSPE_{simul} = \frac{\sum_{i=1}^{n}(Y_i - Y_T)^2}{n}, \quad (2)$$

where $\boldsymbol{Y_i}$ is the $i^{th}$ estimated response value at simultaneous optimisation.

The $MSPE_{simul}$ bias-variance decomposition estimates were integrated by arithmetic averaging to estimate the bias-variance-covariance decomposition of the $MSPE_{simul}$ of the ensembled results (Geman et al., 1992; Ueda and Nakano, 1996).

$$\text{MSE}(f) = \text{bias}(f)^2 + \text{var}(f) \quad (3)$$

And the expected ensemble MSE is,

$$E\{\text{MSE}(fens.)\} = \text{Bias}^2 + \left(\frac{1}{k}\right) \times \text{Variance} + \left(1 - \frac{1}{k}\right) \times \text{Covariance} \quad (4)$$

Where *k* is the number of base models in the ensemble.

***Prediction Accuracy Compromise:*** Define Prediction Accuracy Compromise (PAC) as the difference between $MSPE_{simul}$ and the $MSPE_{val(min.)}$ of a response model. PAC gives a picture of how models compromise their accuracy in the process of simultaneous optimisation. Then % PAC will be the percentage change in $MSPE_{val(min.)}$ to achieve simultaneous optimisation.

$$\% \text{ PAC} = 100\% \times (MSPE_{simul} - MSPE_{val(min.)}) / MSPE_{val(min.)} \quad (5)$$

***Relative accuracy:*** The Relative Accuracy is computed for each base model in the ensemble relative to the ensemble result and is given by:

$$\text{Relative Accuracy} = \frac{\textit{Number of Base Model or Ensemble Correct Predictions}}{\textit{Total Number of Instances}} \quad (6)$$

## 4. Results

### 4.1 All possible regression modelling results

Tables 3 and 4 below show the all possible ordinary least squares (OLS) regression models for both responses after removal of response models that did not conform to the recommendations of the screening experiment at dataset generation.

*Table 3. The twenty-five OLS adhesion all possible regression response models*

| MODEL | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_{12}$ | $\beta_{11}$ | $\beta_{22}$ |
|---|---|---|---|---|---|---|
| $T_c.R_t$ | 12.2600 | | | -0.0039 | | |
| $T_c, R_t$ | 7.9500 | 0.3244 | -0.3127 | | | |
| $T_c, T_c.R_t$ | 3.2600 | 0.5100 | | -0.0124 | | |
| $T_c, Rt^2$ | 6.1800 | 0.3244 | | | | -0.0111 |
| $R, T_c.R_t$ | 15.4100 | | -0.7910 | 0.0208 | | |
| $R_t, T_c^2$ | 11.6700 | | -0.3127 | | 0.0067 | |
| $T_c.R_t, T_c^2$ | 8.9600 | | | -0.0119 | 0.0105 | |
| $T_c.R_t, R_t^2$ | 10.4970 | | | 0.0203 | | -0.0258 |
| $T_c^2, R_t^2$ | 9.9100 | | | | 0.0066 | -0.0111 |
| $T_c, R_t, T_c.R_t$ | 12.9400 | 0.1070 | -0.6460 | 0.0145 | | |
| $T_c, R_t, T_c^2$ | 2.4100 | 0.8350 | -0.3127 | | -0.0111 | |
| $T_c, R_t, R_t^2$ | 3.6100 | 0.3244 | 0.3800 | | | -0.0231 |
| $T_c, T_c.R_t, T_c^2$ | -2.2800 | 1.0200 | | -0.0124 | -0.0111 | |
| $T_c, T_c.R_t, R_t^2$ | 9.1400 | 0.0910 | | 0.0156 | | -0.0224 |
| $T_c, T_c^2, R_t^2$ | -0.2500 | 0.9190 | | | -0.0129 | -0.0112 |
| $R_t, T_c.R_t, T_c^2$ | 15.2400 | | -0.7710 | 0.0199 | 0.0003 | |
| $R_t, T_c.R_t, R_t^2$ | 11.0800 | | -0.0980 | 0.0208 | | -0.0231 |
| $R_t, T_c^2, R_t^2$ | 7.5200 | | 0.3580 | | 0.0066 | -0.0224 |
| $T_c.R_t, T_c^2, R_t^2$ | 10.3900 | | | 0.0189 | 0.0005 | -0.0249 |
| $T_c, R_t, T_c.R_t, T_c^2$ | 7.4000 | 0.6180 | -0.6460 | 0.0145 | -0.0111 | |
| $T_c, R_t, T_c.R_t, R_t^2$ | 8.6100 | 0.1070 | 0.0470 | 0.0145 | | -0.0231 |
| $T_c, R_t, T_c^2, R_t^2$ | -4.2500 | 1.0210 | 0.4300 | | -0.0151 | -0.0248 |
| $T_c, T_c.R_t, T_c^2, R_t^2$ | 1.9500 | 0.7590 | | 0.0168 | -0.0149 | -0.0234 |
| $R_t, T_c.R_t, T_c^2, R_t^2$ | 11.2100 | | -0.1130 | 0.0215 | -0.0003 | -0.0232 |
| $T_c, R_t, T_c.R_t, T_c^2, R_t^2$ | 0.7400 | 0.8040 | 0.0970 | 0.0145 | -0.0151 | -0.0248 |

*Table 4. The twenty-five OLS hardness all possible regression response models*

| MODEL | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_{12}$ | $\beta_{11}$ | $\beta_{22}$ |
|---|---|---|---|---|---|---|
| $T_c.R_t$ | 56.1800 | | | 0.0040 | | |
| $T_c, R_t$ | 48.4600 | 0.5130 | -0.1800 | | | |
| $T_c, T_c.R_t$ | 45.7500 | 0.6040 | | 0.0061 | | |
| $T_c, Rt^2$ | 46.5300 | 0.5130 | | | | -0.0030 |
| $R, T_c.R_t$ | 60.2500 | | -0.9610 | 0.0339 | | |
| $R_t, T_c^2$ | 54.8400 | | -0.1800 | | -0.0097 | |
| $T_c.R_t, T_c^2$ | 52.8900 | | | 0.0045 | -0.0111 | |
| $T_c.R_t, R_t^2$ | 55.0800 | | | 0.0209 | | -0.0181 |
| $T_c^2, R_t^2$ | 52.9000 | | | | 0.0097 | -0.0030 |
| $T_c, R_t, T_c.R_t$ | 57.5000 | 0.0320 | -0.7180 | 0.0321 | | |
| $T_c, R_t, T_c^2$ | 18.0000 | 3.3200 | -0.1800 | | -0.0610 | |
| $T_c, R_t, R_t^2$ | 57.5100 | 0.5130 | -1.6290 | | | 0.0483 |
| $T_c, T_c.R_t, T_c^2$ | 15.3000 | 3.4100 | | -0.0061 | -0.0610 | |
| $T_c, T_c.R_t, R_t^2$ | 41.9300 | 0.8760 | | -0.0242 | | 0.0146 |
| $T_c, T_c^2, R_t^2$ | 15.9000 | 3.3400 | | | -0.06160 | -0.0034 |
| $R_t, T_c.R_t, T_c^2$ | 65.0600 | | -1.4960 | 0.0572 | -0.00860 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| $R_t$, $T_c.R_t$, $R_t{}^2$ | 69.3100 | | -2.4090 | 0.0339 | | 0.0483 |
| $R_t$, $T_c{}^2$, $R_t{}^2$ | 64.0100 | | -1.6610 | | 0.0098 | 0.0494 |
| $T_c.R_t$, $T_c{}^2$, $R_t{}^2$ | 52.6600 | | | -0.0094 | 0.0127 | 0.0039 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c{}^2$ | 29.1000 | 2.8400 | -0.9180 | 0.0321 | -0.0610 | |
| $T_c$, $R_t$, $T_c.R_t$, $R_t{}^2$ | 68.6000 | 0.0320 | -2.3660 | 0.0321 | | 0.0483 |
| $T_c$, $R_t$, $T_c{}^2$, $R_t{}^2$ | 13.4000 | 3.5300 | | -0.0196 | -0.0592 | 0.0108 |
| $T_c$, $T_c.R_t$, $T_c{}^2$, $R_t{}^2$ | 29.4200 | 3.0020 | -1.4500 | | -0.0541 | 0.0423 |
| $R_t$, $T_c.R_t$, $T_c{}^2$, $R_t{}^2$ | 73.31000 | | -2.8470 | 0.0540 | -0.0074 | 0.0048 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c{}^2$, $R_t{}^2$ | 40.5000 | 2.5210 | -2.1870 | 0.0321 | -0.0541 | 0.0423 |

Hardness response model [$T_c$, $R_t$, $T_c.R_t$, $T_c{}^2$] was the only hardness model with a conforming response surface.

### 4.2. Simultaneous optimisation results

Table 5 shows the simultaneous optimisation of the adhesion-hardness model pair [$T_c.R_t$, $R_t{}^2$] - [$T_c$, $R_t$, $T_c.R_t$, $T_c{}^2$] using an Excel spreadsheet tool. The rest of the adhesion response models were similarly optimised with the same hardness model.

*Table 5. Showing simultaneous optimisation on an Excel spreadsheet*

| $T_c$ | $R_t$ | | Adhesion | | | Hardness | |
|---|---|---|---|---|---|---|---|
| (min.) | (mm) | | [T*$R_t$, $R_t{}^2$] | $e^2$ | | [T, $R_t$, T* $R_t$, $T^2$ ] | $e^2$ |
| 21 | 7 | 12 | 12.2169 | 0.0470 | 60 | 60.1317 | 0.0173 |
| 22 | 8 | 12 | 12.4186 | 0.1752 | 60 | 60.3616 | 0.1308 |
| 22 | 9 | 12 | 12.4266 | 0.1820 | 60 | 60.1498 | 0.0224 |
| 23 | 10 | 12 | 12.5860 | 0.3434 | 60 | 60.3540 | 0.1253 |
| 23 | 11 | 12 | 12.5111 | 0.2612 | 60 | 60.1743 | 0.0304 |
| 24 | 12 | 12 | 12.6282 | 0.3946 | 60 | 60.3528 | 0.1245 |
| 24 | 13 | 12 | 12.4704 | 0.2213 | 60 | 60.2052 | 0.0421 |
| 24 | 14 | 12 | 12.2610 | 0.0681 | 60 | 60.0576 | 0.0033 |
| 25 | 15 | 12 | 12.3045 | 0.0927 | 60 | 60.2425 | 0.0588 |
| 25 | 16 | 12 | 12.0122 | 0.0001 | 60 | 60.1270 | 0.0161 |
| 26 | 17 | 12 | 12.0134 | 0.0002 | 60 | 60.2862 | 0.0819 |
| 27 | 18 | 12 | 12.0036 | 0.0000 | 60 | 60.3876 | 0.1502 |
| 29 | 19 | 12 | 12.3685 | 0.1358 | 60 | 60.4041 | 0.1633 |
| 30 | 20 | 12 | 12.3570 | 0.1274 | 60 | 60.3000 | 0.0900 |
| | | | **Ave**. 12.3270 | **MPSE**:0.1464 | | **Ave.**: 60.2525 | **MPSE**: 0.0755 |
| | | | **Bias**: 0.3270 | **Var.**: 0.0394 | | **Bias**: 0.2525 | **Var.**: 0.0117 |

Table 6 shows cure time estimates which each adhesion response model gave at simultaneous optimisation.

*Table 6. Showing the cure time estimate results for each adhesion response model*

| $R_t$ (mm) | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 26 | 27 | 28 | 29 | 30 | | |
| $T_c$, $T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| $T_c$, $R_t{}^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | | |
| $R_t$ ,$T_c.R_t$, | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 |
| $T_c$, $R_t{}^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 30 | | |
| $T_c.R_t$, $T_c{}^2$ | 22 | 23 | 23 | 24 | 25 | 26 | 26 | 27 | 28 | 29 | 30 | | | |
| $T_c.R_t$, $R_t{}^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 |
| $T_c{}^2$, $R_t{}^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 30 | | |
| $T_c$, $R_t$, $T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 |
| $T_c$ ,$R_t$, $T_c{}^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| $T_c$, $R_t$, $R_t{}^2$ | 22 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | 31 |
| $T_c$, $T_c.R_t$, $T_c{}^2$, | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| $T_c$, $T_c.R_t$, $R_t{}^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_c$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 23 | 24 | 24 | 25 | 26 | 28 | 30 | | |
| $R_t$, $T_c.R_t$, $T_c^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 |
| $R_t$, $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 26 | 28 | 29 | 30 |
| $R_t$, $T_c^2$, $R_t^2$ | 22 | 22 | 22 | 22 | 23 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | |
| $T_c$, $R_t$, $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 |
| $T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 23 | 24 | 24 | 25 | 25 | 26 | 27 | 30 | |
| $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 25 | 27 | 28 | 31 |

Table 7 shows the remaining thirteen adhesion response models with their cure time estimates after dropping those results that did not give estimates for the full rubber thickness range.

*Table 7. Showing the adhesion response models with simultaneous optimisation cure time estimates for the full rubber thickness range*

| Rt(mm) | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODEL | | | | | | | | | | | | | | |
| $R_t$, $T_c.R_t$, | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 |
| $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 |
| $T_c$, $R_t$, $T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 |
| $T_c$, $R_t$, $R_t^2$ | 22 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | 31 |
| $T_c$, $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $R_t$, $T_c.R_t$, $T_c^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 |
| $R_t$, $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 26 | 28 | 29 | 30 |
| $R_t$, $T_c^2$, $R_t^2$ | 22 | 22 | 22 | 22 | 23 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $R_t$, $T_c.R_t$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 |
| $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 25 | 27 | 28 | 31 |

A frequency analysis of the occurrence of the different cure time results is given in Table 8. There were only seven possible cure time estimate solutions in Table 7. The solution with the highest occurrence had a frequency of five.

*Table 8. Showing frequency of occurrence of cure time estimates results*

| $R_t$ | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Frequency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 | 1 |
| 2 | 22 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | 31 | 1 |
| 3 | 22 | 22 | 22 | 22 | 23 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 1 |
| 4 | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 25 | 27 | 28 | 31 | 1 |
| 5 | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 | 2 |
| 6 | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 2 |
| 7 | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 5 |

### 4.3 Integration results

Table 9 shows the results of integrating the cure time estimates of Table 6 using arithmetic averaging (A. Ave.) and majority vote (M. Vote).

*Table 9. Showing the integration of the thirteen cure time estimate results*

| MODEL | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Rel. Acc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_t, T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 | 36% |
| $T_c.R_t, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 79% |
| $T_c, R_t, T_c.R_t$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 | 29% |
| $T_c, R_t, R_t^2$ | 22 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | 31 | 86% |
| $T_c, T_c.R_t, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| $R_t, T_c.R_t, T_c^2$ | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 29 | 30 | 30 | 36% |
| $R_t, T_c.R_t, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 26 | 28 | 29 | 30 | 100% |
| $R_t, T_c^2, R_t^2$ | 22 | 22 | 22 | 22 | 23 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 29% |
| $T_c.R_t, T_c^2, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| $T_c, R_t, T_c.R_t, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| $T_c, T_c.R_t, T_c^2, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 79% |
| $R_t, T_c.R_t, T_c^2, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| $T_c, R_t, T_c.R_t, T_c^2, R_t^2$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 25 | 27 | 28 | 31 | 64% |
| **AVE** | **21** | **22** | **22** | **23** | **23** | **24** | **24** | **25** | **26** | **26** | **27** | **28** | **29** | **30** | |
| **M. Vote** | **21** | **22** | **22** | **23** | **23** | **24** | **24** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | |

Three observations to note: (1)The two integration methods did not agree on two cure time estimates for rubber thicknesses 14 and 15 mm; (2) Some adhesion-hardness pairs had relative accuracy less than 50%; and (3) The majority vote result was equivalent to the result with the highest frequency in Table 8.

Table 10 shows the bias-variance-covariance decomposition of the $MSPE_{simul}$ of the ensemble of results.

*Table 10. Showing the bias-variance-covariance decomposition of the $MSPE_{simul}$*

| MODEL | MSPE | Bias | Var. | Covar | MSPE | Bias | Var. | Covar. |
|---|---|---|---|---|---|---|---|---|
| $R_t, T_c.R_t$ | 0.1430 | 0.3849 | 0.0609 | | 0.1841 | 0.4015 | 0.0229 | |
| $T_c.R_t, R_t^2$ | 0.1464 | 0.3270 | 0.0394 | | 0.0755 | 0.2500 | 0.0117 | |
| $T_c, R_t, T_c.R_t$ | 0.1298 | 0.2980 | 0.0410 | | 0.1726 | 0.3738 | 0.0329 | |
| $T_c, R_t, R_t^2$ | 0.1121 | 0.2878 | 0.0292 | | 0.1048 | 0.2890 | 0.0202 | |
| $T_c, T_c.R_t, R_t^2$ | 0.1417 | 0.3543 | 0.0162 | | 0.0957 | 0.2852 | 0.0144 | |
| $R_t, T_c.R_t, T_c^2$ | 0.1297 | 0.2636 | 0.0602 | | 0.1841 | 0.4015 | 0.0229 | |
| $R_t, T_c.R_t, R_t^2$ | 0.1513 | 0.3699 | 0.0144 | | 0.0957 | 0.2852 | 0.0144 | |
| $R_t, T_c^2, R_t^2$ | 0.5463 | 0.3323 | 0.0161 | | 0.0957 | 0.2852 | 0.0144 | |
| $T_c.R_t, T_c^2, R_t^2$ | 0.1051 | 0.3006 | 0.0147 | | 0.0957 | 0.2852 | 0.0144 | |
| $T_c, R_t, T_c.R_t, R_t^2$ | 0.0992 | 0.2774 | 0.0223 | | 0.0957 | 0.2852 | 0.0144 | |
| $T_c, T_c.R_t, T_c^2, R_t^2$ | 0.4951 | 0.6186 | 0.1125 | | 0.0755 | 0.2500 | 0.0117 | |
| $R_t, T_c.R_t, T_c^2, R_t^2$ | 0.1265 | 0.3323 | 0.0161 | | 0.0957 | 0.2852 | 0.0144 | |
| $T_c, R_t, T_c.R_t, T_c^2, R_t^2$ | 0.1561 | 0.6155 | 0.1373 | | 0.0651 | 0.2200 | 0.0117 | |
| **AVE** | **0.21864** | **0.3586** | **0.0446** | **0.0937** | **0.1105** | **0.2998** | **0.0174** | **0.0209** |

There were six adhesion-hardness model pairs that have the same accuracy values on the hardness side. Generally, for a high adhesion side $MSPE_{simul}$, there was a low $MSPE_{simul}$ on the hardness side. This pattern, however, did not seem to have any significant relationship with the accuracy of the cure time estimates.

Table 11 gives the percentage accuracy compromise of the base model pairs of the ensemble at simultaneous optimisation.

*Table 11. Showing the PAC results at simultaneous optimisation*

| $R_t$ Adhesion Model | $MSPE_{valmin}$ | MSE | PAC(H) % | PAC(A) % |
|---|---|---|---|---|
| $R_t$, $T_c.R_t$ | 0.0242 | 2.3855 | 310 | 487 |
| $T_c.R_t$, $R_t^2$ | 0.0321 | 1.3382 | 69 | 357 |
| $T_c$, $R_t$, $T_c.R_t$ | 0.0405 | 2.3441 | 285 | 221 |
| $T_c$, $R_t$, $R_t^2$ | 0.0458 | 1.4710 | 145 | 134 |
| $T_c$, $T_c.R_t$, $R_t^2$ | 0.0456 | 1.2815 | 114 | 211 |
| $R_t$, $T_c.R_t$, $T_c^2$ | 0.0194 | 2.5300 | 114 | 569 |
| $R_t$, $T_c.R_t$, $R_t^2$ | 0.0226 | 1.3200 | 114 | 220 |
| $R_t$, $T_c^2$, $R_t^2$ | 0.0445 | 1.8069 | 114 | 1128 |
| $T_c.R_t$, $T_c^2$, $R_t^2$ | 0.0474 | 1.3377 | 114 | 219 |
| $T_c$, $R_t$, $T_c.R_t$, $R_t^2$ | 0.0407 | 1.2789 | 113 | 144 |
| $T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 0.0348 | 0.9842 | 33 | 1323 |
| $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 0.0345 | 1.3689 | 114 | 267 |
| $T_c$, $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$ | 0.0366 | 0.9762 | 69 | 1323 |

Table 11 shows that it's very difficult, were simultaneous optimisation is concerned, to find a model pair that has all the model accuracy criteria aligning.

- The response model pair with best $MSPE_{valmin}$ (0.0194) had the worst MSE (2.53).
- The adhesion response model with the best MSE (0.9762) compromised the worst (% accuracy compromise, PAC(A) = 1323%) to achieve simultaneous optimisation.
- The response model pair with the best PAC on the hardness side (33%), had the worst PAC on the adhesion side (1323%).
- There were six adhesion-hardness model response pairs with the same PAC(H) value. These six were not necessarily the same ones with similar $MSPE_{simul}$ values on the hardness side.

The average PAC(H) was lower compared to the PAC(A). This suggests that response models do not necessary compromise the same to achieve simultaneous optimisation.

### 4.4 Ensemble review results

Elimination of model pairs with relative accuracy less than 50% left nine adhesion-hardness pairs in the ensemble. The arithmetic average and majority vote results of the reviewed ensemble were equal throughout the whole rubber thickness range as shown in Table 12.

*Table 12. Showing the result of eliminating response models with relative accuracy<50%*

| Rt (mm) Model | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Rel. Acc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$T_c.R_t$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 79% |
| **$T_c$, $R_t$, $R_t^2$** | 22 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 30 | 31 | 86% |
| **$T_c$, $T_c.R_t$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| **$R_t$, $T_c.R_t$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| **$T_c.R_t$, $T_c^2$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| **$T_c$, $R_t$, $T_c.R_t$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 100% |
| **$T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 79% |
| **$R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 28 | 30 | 100% |
| **$T_c$, $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 25 | 27 | 28 | 31 | 64% |
| AVE | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
| **M. Vote** | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |

Table 13 shows that the accuracy results at simultaneous optimisation significantly improved, but more on the hardness side than the adhesion side.

*Table 13. Showing the accuracy results of the reviewed ensemble*

| MODEL | MSPE | Bias | Var. | Covar | MSPE | Bias | Var. | Covar. |
|---|---|---|---|---|---|---|---|---|
| **$T_c.R_t$, $R_t^2$** | 0.1464 | 0.3270 | 0.0394 | | 0.0755 | 0.2500 | 0.0117 | |
| **$T_c$, $R_t$, $R_t^2$** | 0.1121 | 0.2878 | 0.0292 | | 0.1048 | 0.2890 | 0.0202 | |
| **$T_c$, $T_c.R_t$, $R_t^2$** | 0.1417 | 0.3543 | 0.0162 | | 0.0957 | 0.2852 | 0.0144 | |
| **$R_t$, $T_c.R_t$, $R_t^2$** | 0.1513 | 0.3699 | 0.0144 | | 0.0957 | 0.2852 | 0.0144 | |
| **$T_c.R_t$, $T_c^2$, $R_t^2$** | 0.1051 | 0.3006 | 0.0147 | | 0.0957 | 0.2852 | 0.0144 | |
| **$T_c$, $R_t$, $T_c.R_t$, $R_t^2$** | 0.0992 | 0.2774 | 0.0223 | | 0.0957 | 0.2852 | 0.0144 | |
| **$T_c$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 0.4951 | 0.6186 | 0.1125 | | 0.0755 | 0.2500 | 0.0117 | |
| **$R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 0.1265 | 0.3323 | 0.0161 | | 0.0957 | 0.2852 | 0.0144 | |
| **$T_c$, $R_t$, $T_c.R_t$, $T_c^2$, $R_t^2$** | 0.1561 | 0.6155 | 0.1373 | | 0.0651 | 0.2200 | 0.0117 | |
| Arithmetic Ave | 0.2104 | 0.3870 | 0.0447 | 0.0619 | 0.0888 | 0.2706 | 0.0148 | 0.0157 |

If the base models were the five adhesion response models with the same cure time estimates the theoretical accuracy of the ensemble would be as shown in Table 14. It appeared, for this problem, that when the cure time estimates for different adhesion-hardness pairs were the same, the theoretical accuracy on the hardness response side was the same.

*Table 14. Accuracy results of the ensemble with five base models with similar $T_c$ estimates*

| MODEL | MSPE | Bias | Var. | Covar | MSPE | Bias | Var. | Covar. |
|---|---|---|---|---|---|---|---|---|
| $T_c, T_cR_t, R_t^2$ | 0.1417 | 0.3543 | 0.0162 | | 0.0937 | 0.2852 | 0.0144 | |
| $R_t, T_cR_t, R_t^2$ | 0.1513 | 0.3699 | 0.0144 | | 0.0937 | 0.2852 | 0.0144 | |
| $T_cR_t, T_c^2, R_t^2$ | 0.1051 | 0.3066 | 0.0147 | | 0.0937 | 0.2852 | 0.0144 | |
| $T_c, R_t, T_cR_t, R_t^2$ | 0.0992 | 0.2774 | 0.0223 | | 0.0937 | 0.2852 | 0.0144 | |
| $R_t, T_cR_t, T_c^2, R_t^2$ | 0.1265 | 0.3323 | 0.0161 | | 0.0937 | 0.2852 | 0.0144 | |
| Arithmetic Ave | 0.1248 | 0.3263 | 0.0167 | 0.0182 | 0.0937 | 0.2852 | 0.0144 | 0.0144 |

### 4.5 Multiple MS criteria best model selection methodology results

The first result was for the selection of the best model using majority vote of fifteen different model selection criteria. The formulae used to compute the criteria values are shown in the Appendix. Table 15 shows the model selection criteria values and their votes.

Adhesion response model [$T_cR_t, R_t^2$] is the obvious best with a vote of 10. This minimises uncertainty. Model [$T_c, T_cR_t, T_c^2, R_t^2$] follows behind with a vote of 6.

*Table 15. Showing multiple MS criteria selections*

| MODEL | $T_c, R_t, T_cR_t, T_c^2, R_t^2$ | $T_c, T_cR_t, T_c^2, R_t^2$ | $R_t, T_cR_t, R_t^2$ | $T_cR_t, R_t^2$ | $T_c, R_t, R_t^2$ | $T_c, T_cR_t$ |
|---|---|---|---|---|---|---|
| $R^2$ (pr.) | 26.5 | 51.5 | 49.9 | 65.4 | 49.4 | 52 |
| Adeq. pr. | 10.4 | 4.1 | 5.7 | 1.8 | 11.9 | 5.4 |
| Cp-k | 1.0 | 0.1 | 0 | 0 | 2.1 | 0 |
| PRESS | 88.1 | 59.3 | 81.3 | 42.1 | 62.2 | 53.6 |
| AIC | 11.7 | 9.8 | 11.6 | 9.0 | 13 | 17.3 |
| BIC | 15.1 | 12.6 | 13.9 | 11.5 | 15.3 | 19 |
| AICc | 20.2 | 14.8 | 14.3 | 11 | 15.7 | 18.5 |
| APCp | 2.9 | 2.4 | 2.6 | 2.9 | 2.6 | 4.0 |
| SBC | 1.9 | 1.7 | 4.9 | 4.8 | 6.1 | 11.9 |
| HQc | 1.1 | 1.1 | 4.3 | 4.5 | 5.6 | 11.5 |
| KICc | 87.3 | 64.4 | 51.2 | 38.1 | 52.6 | 45.6 |
| HQ | 0.5 | 0.5 | 4.2 | 4.2 | 5.6 | 11.7 |
| KIC | 20.7 | 17.8 | 18.6 | 15.8 | 20 | 23.3 |
| MKIC | 18.2 | 12 | 9.1 | 5.4 | 9.8 | 19.7 |
| TIC | 13.7 | 11.8 | 13.6 | 11.8 | [illegible] | 19.3 |
| VOTE | **2** | 6 | 1 | **10** | **1** | 1 |

The simultaneous optimisation results of both response models [$T_cR_t, R_t^2$] and [$T_c, T_cR_t, T_c^2, R_t^2$] are shown in Tables 12 and 13. The two have the same cure time estimate and theoretical accuracy results on the hardness side. The cure time estimate result, however, was different from the multiple simultaneous optimisations ensemble one.

## 5. Conclusion

The dilemma of choosing from two different solutions, see Table 16, both of which standing on strong positions makes the problem at hand challenging. However, an objective analysis and critic of each position helps in separating the two.

*Table 16. Multiple MS criteria solution ($S_6$) vs. Ensemble solution ($S_7$)*

| Rt | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Vote |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_6$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 25 | 26 | 27 | 29 | 30 | 2 |
| $S_7$ | 21 | 22 | 22 | 23 | 23 | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 5 |

The multiple simultaneous optimisations ensemble cure time estimate solution ($S_7$) shows credibility in that (i) it is the most frequent solution from the adhesion-hardness model pairs, (ii) there is agreement between the two integration methodologies used, and (iii) by design, it fairly accounts for all the listed problems of the contemporary MRSM contextual framework. It accounts for dataset uncertainty, loss of information, model over-/underfitting, and model parameter bias by utilising multiple models and minimising discarded models. It minimises model uncertainty and small sample size inefficiency by totally avoiding the use of classical model selection criteria.

On the other hand, seven of the ten model selection criteria that voted for the best single adhesion response model [$T_c.R_t$, $R_t^2$] are information criteria and three are prediction model selection criteria. This implies that the response model has the best parsimonious fit to the MRSM dataset, of all the 25 OLS adhesion response models, and has good prediction capability. However, the cure time estimate solution ($S_6$) is not considered the best in credibility because (i) model selection criteria have a small sample size inefficiency problem, (ii) they do not deal with the problem of model parameter bias, (iii) dataset uncertainty and (iv) since the methodology is structured as the contemporary MRSM framework, it loses information in discarded models by the selection and use of one model per response in simultaneous optimisation. It should be emphasised that where the model with the best parsimonious fit to the dataset is required, response model [$T_c.R_t$, $R_t^2$] is the model.

The arguments above clearly separate the most credible cure time solution ($S_7$) from the model with the best parsimonious fit to the MRSM dataset ($S_6$]. The multiple simultaneous optimisations ensemble, therefore, is both logically and empirically a better way of obtaining credible results compared to the current MRSM contextual framework which must first select a best model for each response before simultaneous optimisation. The multiple simultaneous optimisations ensemble is thus recommended to the rubber covered conveyor belting manufacturing industry for use in reviewing cure times when adhesion and cover hardness minimum quality standard requirements change.

The use of targeted values in validation is worth mentioning here, as well, since the size of the MRSM dataset is small and it would be senseless to split it. The other option would have been to use cross validation which would have taken back the solution methodology to the weakness of the contemporary MRSM framework. In itself, the practice is worth considering where targeted quality values have to be effectively converted to production process parameters.

Noting the fact that the multiple simultaneous optimisations ensemble worked well on a two factors and two responses problem, it then makes it imperative to investigate its generalisability to other more complex MRSM problems. As the number of factors and responses increase, the number of models to deal with quickly multiplies. This will definitely require software and intelligent algorithms to manage complexity and still achieve credible results.

**Acknowledgements:** We would like to thank the editor and anonymous referees for their valuable contributions that helped us to improve the quality and presentation of this paper.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 107-120*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta240322121n*

# APPLICATION OF WOODEN MODULAR CONSTRUCTION FOR THE NEEDS OF THE ELDERLY

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Received: 08 November 2021
Accepted: 25 February 2022
First online: 24 March 2022

*Research paper*

**Abstract:** *In recent years, changes in demographic structure have been observed worldwide. To sustain the growing population of elderly people with special needs, homes need a radical rethink both in designing new houses and in retrofitting new solutions to existing houses. Designs that facilitate aging in place, designs that maintain thermal comfort, and designs that have net-zero energy demands and low to zero to negative carbon footprints are needed. The article discusses the issues of construction for the elderly. The trends in the demographic development of society in selected countries are presented. Additionally, information on the housing stock for elderly people in Poland is provided. The carbon dioxide emission limits to mitigate climate change make it necessary to find an alternative to concrete and steel, traditional construction materials. In this context, Cross Laminated Timber (CLT) fulfills the sustainability requirements. However, to select the suitable panel a detailed analysis of timber characteristics is required. It is necessary to evaluate mechanical properties in bending, tension, compression, and shear. Since the mechanical properties of certain types of wood differ, their proper selection is challenging. The multi-criteria analysis could address this. In this article, four wood species, spruce, oak, ash, and beech, were evaluated using the Analytic Hierarchy Process (AHP) analysis. Based on the type of construction elements and their functions, analyses were using six mechanical properties as criteria. The optimal type of wood was indicated.*

**Key words**: *Cross Laminated Timber, modular construction, elderly people, optimization, AHP.*

## 1. Introduction

The studies on demographic change (Pašalić et. al. 2020) reveal a relatively rapid increase in the growth of the elderly population. It is expected that in the next 30 years the ratio of elderly people (aged 65 and above) to the whole population will increase from 7% in the first decade of the 21st century to 16% in 2050 (Cohen,

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2003; WHO, 2021). This trend is observed especially in the developed countries and results in a high reduction of the percentage of the population of working age. The life expectancy has increased in recent decades (Roser et al., 2013). The reason for that is mainly related to the improvement of living and social conditions (Nicał, 2016). Although demographic changes occur worldwide, their extent and timing differ significantly in the developing countries in Latin America and Africa from the western European countries and Japan (Krueger & Ludwig, 2007; Bloom & Williamson, 1998; United Nations, 2002). Due to health issues, the majority of elderly people spend most of their time at home and very often depend on other's people with housework. The solution for these people can be robotic support systems in everyday activities at home (ADLs - Activities of Daily Living) (Bock et al., 2012; Nicał, 2017). These systems are part of a research and development program AAL (Active and Assisted Living Programme) supporting projects that use information and communication technologies (ICT) to improve the quality of life of older people. The implementation of the AAL program usually entails the need to reconstruct the apartments where elderly people live. In many European countries (e.g. Poland), elderly people live in buildings erected in the 1960s, 1970s, and 1980s. A large proportion of these buildings are made in standardized large-block and large-panel systems. Figure 1. presents the share of each of these technologies in residential buildings in Poland in the period between 1970-1985 (Nicał, 2017; Dzierżewicz & Starosolski, 2010).

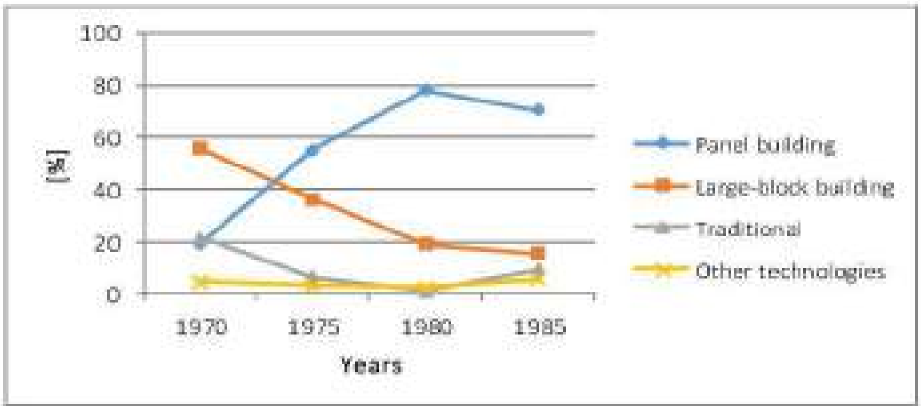


*Figure 1. Share of the various technologies in residential buildings in Poland in the period between 1970-1985 (Nicał, 2017; Dzierżewicz & Starosolski, 2010).*

Depending on the system, these buildings were erected in spatial arrangements in which most of the walls serve as load-bearing. Therefore, it is not possible to move or demolish such walls. This circumstance causes many inconveniences in terms of adapting apartments for elderly people such as widening corridors or door openings (Nicał et al., 2019). Therefore, it is necessary to build facilities adapted to the needs of the elderly. Moreover, these buildings should be erected as quickly as possible by the implementation of advanced technologies (Xing et al., 2020). Panel buildings, usually made in concrete technology, are not environmentally friendly. Research in this area has been carried out, inter alia, by (Pierobon et al., 2019). Results showed that an average of 26.5% reduction in the global warming potential is achieved in the hybrid CLT building compared to the concrete building. CLT compared to other wood-based materials such as glued laminated timber (GLT), has lower: emissions in Global warming potential (GWP), Terrestrial Ecotoxicity (TE), Land Use (LUP), and Ozone layer depletion (OLD) (Balasbaneh & Sher, 2021). In addition, taking into account the trends in the field of environmental protection and reduction of $CO_2$ emissions, it is necessary to use the material with the lowest carbon footprint. The material that meets these criteria is cross-laminated timber (CLT). When choosing wood for CLT, the decision-makers are faced with the dilemma of choosing the wood species that compose it. Thus, a research gap exists at the interface between timber engineering and the decision-making process of selecting the leading parameters when selecting it. The purpose of this paper and its contribution to the field of construction for the elderly is to establish a methodology for selecting the most optimal timber spieces taking into account their six main mechanical criteria.

## 2. Cross Laminated Timber (CLT)

### 2.1. General information

CLT constitutes a plate-like engineered timber product, optimized for bearing loads in and out of plane and is composed of an uneven number of layers. As defined in the Standard PN-EN 16351 (PN-EN 16351:2015), CLT is structural construction timber consisting of at least three layers of wood or wood-based materials, of which at least three layers are perpendicular to each other. Figure 2. below presents an example of a CLT 160 L5s (40L-20W-40L-20W-40L). A detailed explanation of the individual symbols is provided below (Fig. 3).

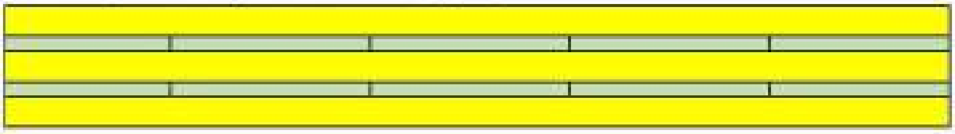

*Figure 2. An example of CLT 160 L5s (40l-20w-40l-20w-40l).*

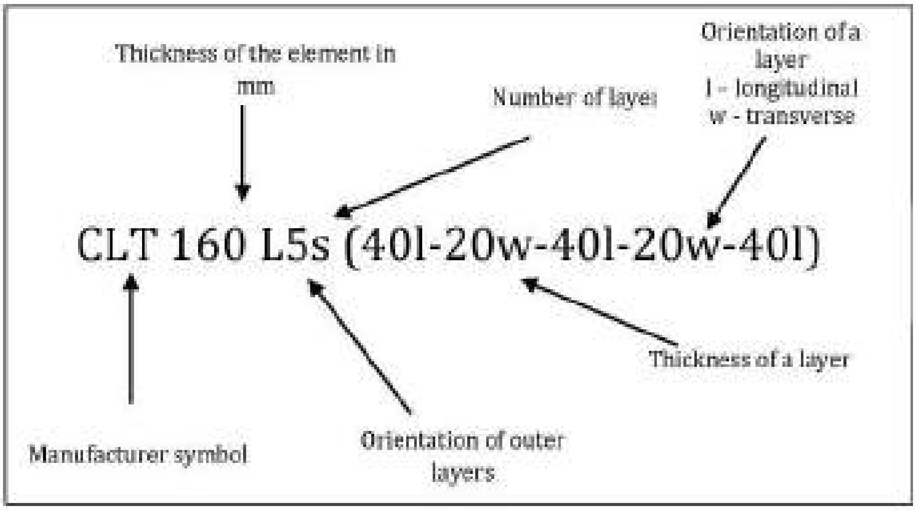


*Figure 3. A detailed explanation of the individual symbols in the CLT labeling.*

Layers are quasi rigidly connected by adhesive bonding (Brandner, 2013). Thanks to the multilayer, alternating arrangement of layers, the significance of the natural imperfections like knots of a single wooden board are reduced and a rigid wall or a floor slab is obtained (Kotarski & Przepiórka, 2020).

The advantages of CLT as a large-sized and panel-like solid timber construction element for the construction are mostly related to its outstanding degree of prefabrication, the dry and clean construction technique, and the short erection times on site (e.g. roughly one to two days per family house) (Brandner, 2013). CLT is characterized by high dimensional accuracy and easy adjustment. It can also transfer loads in two dimensions. Together with its low self-weight, it is particularly suitable for the conversion and modernization of existing buildings, but also for resisting exceptional loads (e.g. earthquakes). CLT offers, in contrast to the lightweight timber structures (e.g. framing, post, and beam system), a clear separation of load-bearing from insulation and installation layers. Additionally, CLT is characterized by the low air permeability, the distinctive specific storage capacity for humidity and temperature, the independence of modular dimensions in arranging window and door openings as well as in fastening of furniture.

### 2.2. Production and processing of CLT

The first stage of CLT production is not much different from the production process of glued laminated timber and consists of the following activities (Figure 4) (Brandner, 2013):

- strength or stiffness grading of already (kiln) dried boards;
- cutting out of local growth characteristics which do not meet the requirements of the strength class and finger jointing of the residual board segments to endless lamellas;
- division and cutting of lamellas for later use in longitudinal and transverse layers of CLT.

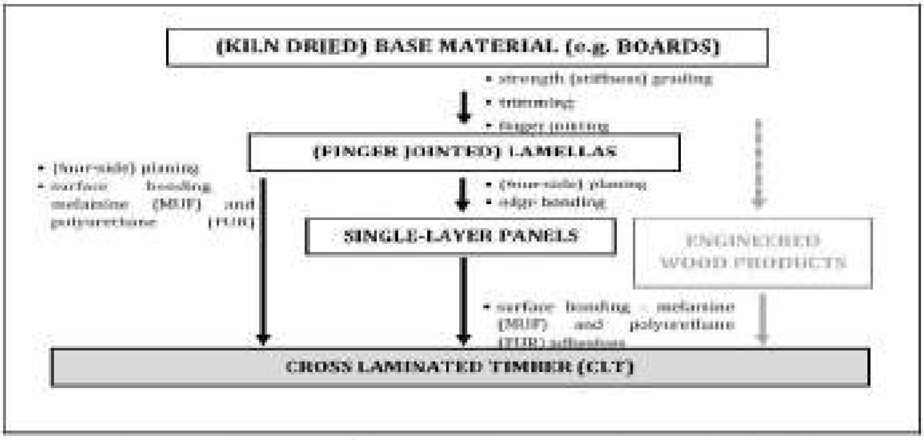


*Figure 4. Overview of CLT production process (Brandner, 2013).*

Usually, CLT is composed of boards with thickness $t_B$ = (12 ÷ 45) mm (PN-EN 16351:2015). There is no upper limit for the board width but due to rolling shear stresses in-between the CLT layers a minimum width of $w_B \geq 4 \cdot tB$ (Brandner, 2013). The reference board width is proposed with $w_{B,ref}$ = 150 mm, as given in PN-EN 338 (PN-EN 338:2016-06) and PN-EN 384 (PN-EN 384+A1:2018-12). Currently, mainly softwood species are used for CLT. Material moisture tolerance is 12 +/- 2% (Kotarski & Przepiórka, 2020). Each of the CLT layers must be made of sawn timber of the same strength class determined in accordance with PN-EN 14081-1 (PN-EN 14081-1+A1:2019-11), however, it is allowed to use different types of wood provided that the same technical parameters are maintained, especially swelling and shrinkage. It is also possible to use bent cross-laminated timber elements, the thickness of which depends primarily on the bend radius of the elements. The demand for bent CLTs is very small on the market, and the cost of setting up the production is incomparably higher than for simple elements, hence few manufacturers decided to offer this type of product. However, it is a future-proof product, offering an even greater range of design options for architects (Brandner, 2013). The second stage of CLT production consists of the following activities (PN-EN 16351:2015) (Figure 4):

- adhesive bonding of lamellas to single-layer panels (optional);
- assembling and adhesive bonding of lamellas or single-layer panels to CLT;
- cutting and joining to structural elements (customizing).

Melamine (MUF) and polyurethane (PUR) adhesives are most often used to connect the individual layers. They meet stringent standards in terms of formaldehyde emissions and are safe for health during production, use, and also during fire. The application of the adhesive to surface bonding is usually carried out mechanically and without contact on single lamellas in a continuous through-feed device or on CLT layers already pre-positioned in a positioning or press bed. A line-wise discrete application of adhesive is preferred (Brandner, 2013). The lamellas do not have to be glued on the side surfaces and it is allowed to arrange them with a spacing of up to 6 mm. Cross-glued timber is glued in hydraulic or vacuum presses (Kotarski & Przepiórka, 2020). In both cases, under the gluing technology, adequate pressure of the joined elements is required, which enables a permanent adhesive bond. In the case of hydraulic presses, it is from 0.1 to 1.0 $N/mm^2$, and in the case of vacuum gluing, from 0.05 to 0.1 $N/mm^2$ (Kotarski & Przepiórka, 2020), with 0.4 $N/mm^2$ being already sufficient for most typical configurations (Sikora et al., 2015). Clamps, pins, and nails are very rarely used in the production of CLT, this is acceptable (Kotarski & Przepiórka, 2020). After pressing, standard CLT elements are normally trimmed on their edges. The surface of the elements after pressing is treated differently, without further processing by planning or sanding (Brandner, 2013). Application of additional non-load-bearing layers like OSB, acoustic panels, gypsum plasterboards, or three-layered solid wood panels is possible. The additional layers are primarily connected by surface bonding (Brandner, 2013).

To ensure the appropriate quality of products, it is necessary to maintain the following parameters during production (Brandner, 2013):

- during bonding: temperature ≥ 15°C and relative humidity (40 ÷ 75) %;
- during curing: temperature ≥ 18°C and relative humidity ≥ 30 %;

- moisture content of adherents u = (6 ÷ 15) % (≤ 18 % in case of preservative treatment);
- the maximum difference in moisture content between two parallel layers Δu ≤ 5 %.

### 2.3. Selected properties of CLT

Mechanical properties of CLT panels are determined mainly by destructive testing i.a. bending, rolling shear, compression, tension (He et al., 2020). Among the conducted research, it is necessary to mention the i.a. bending and compressive properties of CLT panels made from Canadian hemlock that calibrated the theoretical bending stiffness using the experimental values (He, 2018), and the bending and shear properties of three- and five-layer CLT panels fabricated with Irish Sitka spruce (Sikora et al., 2016, O'Ceallaigh et al., 2018). Moreover, testing of rolling shear properties of CLT fabricated with New Zealand Radiata pine and correlation between lamination thickness and its influence on rolling shear strength has been developed (Li, 2017). The test results for the properties of the 3-layer and the 5-layer CLT (He et al., 2020) panels show, inter alia, that 3-layer panels have about 11.3% higher stiffness parallel-to-grain direction and over 15.8% higher stiffness perpendicular-to-grain direction. In addition, the average global modulus of elasticity of 3-layer panels is over 19.2% higher than 5-layer panels. 5-layer panels are characterized by, among others 11.4% higher strength parallel-to-grain direction and 9.7% higher strength perpendicular-to-grain direction. The average local bending stiffness by the 5-layer panel is 243.9% larger than for the 3-layer panel, and the average global bending stiffness by 252.5%, respectively. The average shear strength by the 5-layer panel is 3.8% higher than for the 3-layer panel, while the bending strength is 4.3% higher than for the 3-layer panel. Both the 3-layer and the 5-layer CLT panels were manufactured with a width of 310 mm, using the Canadian black spruce lumber (No 2-grade) with the following material properties (NLGA, 2010):

- stiffness parallel-to-grain direction ($E_{l,0}$) = 10925.0 MPa;
- stiffness perpendicular-to-grain direction ($E_{l,90}$) = 993.2 MPa;
- strength parallel-to-grain direction ($f_{lc,0}$) = 28.7 MPa;
- strength parallel-to-grain direction ($f_{lc,90}$) = 5.8 MPa.

Based on the presented results, it can be concluded that both the 3-layer and the 5-layer CLT panels fabricated with the No.2-grade black spruce can provide ideal bending or shear properties. The properties can be comparable to those of the CLT fabricated with other commonly used wood species (He et al., 2018).

## 3. Housing for the elderly

### 3.1. General assumptions

Buildings intended for the stay of elderly people should meet several criteria, such as:

- the building and its surroundings must not have architectural barriers;

- a multi-storey building must have a lift adapted to the needs of disabled and elderly people;
- the building must be equipped with a call and alarm system and a fire alarm system.

Other requirements include the need to construct wide corridors, larger areas of rooms, dining rooms, guest rooms, and other technical rooms to meet the sanitary needs of residents. It is also important to remember to provide adequate conditions in the bathrooms. These are the place where a lot of accidents happen. While designing it is important to take into account the necessity of ensuring an adequate maneuver space for a wheelchair that should not be smaller than 150x150 cm (Nicał, 2016), (Budny, 2009). Providing large living and communication areas entails the necessity to construct facilities with the use of construction elements with significant spans. Additionally, the construction elements should be light and slender to ensure the largest possible cubic capacity. Buildings intended for the stay of elderly people should also be made of prefabricated elements, to ensure a short construction time. In this respect, the use of CLT seems to perfectly meet the expectations.

### 3.2. Selection of wood for construction

Hardwood shows a higher natural strength potential than softwood, see Figure 5 (Franke, 2013). Additionally, hardwood, with its good mechanical properties, perfectly fits for long-spanned and high stressed timber constructions.

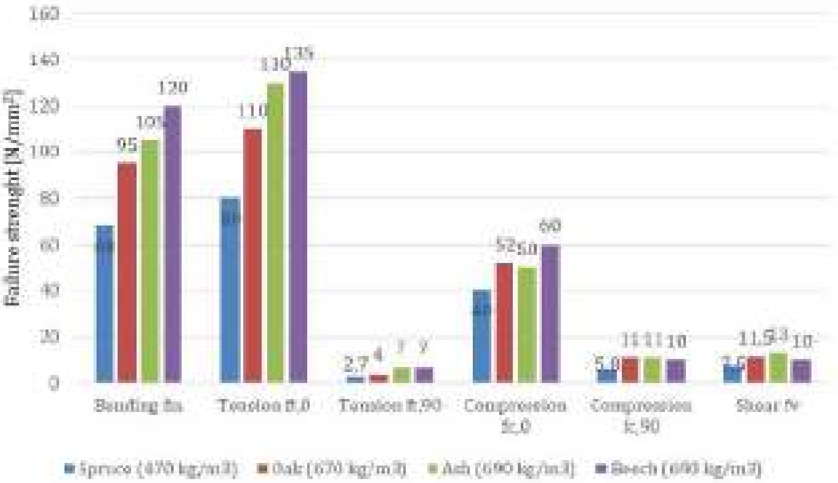


*Figure 5. Comparison of mechanical properties of hardwood and softwood species (Franke, 2016).*

The tensile strength perpendicular to the grain for hardwood can reach up to 260% of the softwood strength values (Franke, 2016). Regarding bending and compression parallel to the grain, the strength values are up to 175% and 150% higher, respectively (Franke, 2016). As a result, the use of hardwood allows larger spans and smaller cross-sections. These numbers indicate that structural elements for buildings intended for the stay of elderly people could be erected of hardwood.

# 4. Methodology

## 4.1. AHP multicriteria assessment method for the selection of wood for construction materials

One of the most difficult problems in construction, as well as, in CLT material selection is to take objective decisions, especially for the selection of technology and material solutions (Książek et al., 2014). Construction projects planning requires a proper materials selection process that should be assessed in terms of their long-term cost (Rosłon et al., 2020), durability, quality (Nicał & Anysz, 2020), expected construction time (Ibadov, 2019), and mechanical properties. The utilization of AHP (Analytic Hierarchy Process) multicriteria assessment method (Hwang & Yoon, 1981), (Alosta, et al. 2021) can be beneficial. Among many proven and recognized methods of multi-criteria evaluation, such as e.g. FUCOM (Bozanic et al, 2021) or Decision Making Trial and Evaluation Laboratory Model (DEMATEL) technique, integrated with Analytic Network Process (ANP) (Osintsev et al. 2021), as well as, Fuzzy AHP and Fuzzy MARCOS Approach (Bakir et al. 2021), it was decided to use the AHP method. It is broadly spread in engineering and is very usable method that separates the problem into litter steps.

The AHP is a four-step method with the following steps (Saaty, 1980), (Saaty, 2008), (Trzaskalik, 2006). The steps are the following:

- Step I – hierarchy of the problem;
- Step II – definition of preferences by the decision-maker;
- Step III – preference matrix consistency testing;
- Step IV – creating a summary ranking.

In step I, it is necessary to define: the problem faced by the decision-maker, available options of a solution, criteria against which the available options will be assessed, and possibly further sub-criteria. The hierarchical structure results from the decomposition of the problem into the main goal, main factors, and side factors (Anysz et al., 2021). In step II the decision-maker using numerical values from 1 to 9 (less often from 1 to 7) has to define the preferences. Table 1. shows the values of the comparative assessment against each other. Values not listed in Table 2 (2, 4, 6, 8) characterize intermediate values (Anysz et al., 2021).

*Table 1. Comparative assessment in the AHP method (Anysz et al., 2021).*

| COMPARATIVE, PAIRWISE ASSESSMENT OF A AGAINST B | VALUE |
|---|---|
| Just as good or important | 1 |
| A little better or more important | 3 |
| Definitely better or more important | 5 |
| Much better or more important | 7 |
| Extremely better or more important | 9 |

Preferences are specified for each level within the defined hierarchical structure (Anysz et al., 2021). Objects that are only at one level of the hierarchy can be assessed against each other. The comparative assessment is subjective and is made by the decision-maker (Grzegorzewski, 2019). The result of step II is a square matrix A in which the terms $a_{ij}$ concerns the preferences of the decision-maker. The digits 1 are on the diagonal of the matrix A, there is also the reciprocal of the adopted preferences, i.e.:

$$a_{ij} = \frac{1}{a_{ji}} \tag{1}$$

The following sub-step is to normalize matrix A to matrix B using the dependence below:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

The value $b_{ij}$ is expressed as the quotient of the term $a_{ij}$ to the sum of the terms in the j-th column of matrix A (Anysz et al., 2021). Weights of the examined elements ($w_i$) are the arithmetic means of the rows of the matrix B according to the following formula (Saaty, 1980; Anysz et al., 2021; Książek et al., 2014; Tułecki & Król, 2007).

$$w_i = \frac{1}{n}\sum_{j=1}^{n} b_{ij} \tag{3}$$

In step III only one pair of criteria is assessed by the decision-maker each time. The preference relationship between the criteria is asymmetric (Anysz et al., 2021). Potential inconsistencies in the assessments of the decision-maker can be avoided, with the introduction of the following control coefficients: Consistency Index (CI) and Consistency Ratio (CR).

$$CI = \frac{\lambda_{max} - n}{(n-1)} \tag{4}$$

$$CR = \frac{\lambda_{max} - n}{RI \cdot (n-1)} \tag{5}$$

where:

$\lambda_{max}$ - the maximum eigenvalue of the matrix,

*RI* - the value of the average random consistency index *CI* according to the table below (Table 2).

*Table 2. The values of the average random index of RI.*

| Matrix dimension n | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

If $CR \leq 0.10$, then the preference matrix is considered consistent. When $CR > 0.150$, the assumptions from step II should be changed (Saaty, 1980; Saaty, 2008).

In the last step IV, a ranking of the available solutions in terms of their suitability to meet the main goal is created. The order from the best to the worst needs to be kept. The total score of a single variant can be calculated according to the following formula (Anysz et al., 2021):

$$P = \sum_{i=1}^{n} w_i \cdot k_i \tag{6}$$

where:

$P$ - final score for a given solution variant,

$w_i$ - criterion weight according to the formula (3),

$k_i$ - evaluation of a given criterion.

### 4.2. Application of AHP for the selection of wood

The decision problem lies in the selection of the most advantageous type of wood for the structural elements from which the buildings intended for the stay of the elderly will be erected. For this purpose, the study of the data contained in Figure 5, concerning the mechanical characteristics of wood, will be applied. The evaluation criteria, in this case, are the results obtained in the following tests:

- Criterion 1: bending, $f_m$;
- Criterion 2: tension, $f_{t,0}$;
- Criterion 3: tension, $f_{t,90}$;
- Criterion 4: compression, $f_{c,0}$;
- Criterion 5: compression, $f_{c,90}$;
- Criterion 6: shear, $f_v$.

The variants are assigned as follows:

- Variant 1: spruce;
- Variant 2: oak;
- Variant 3: ash;
- Variant 4: beech.

### 4.3. Results

Currently, the natural higher strength can potentially be mostly used for partial reinforcements in timber structures, e.g. for strengthening the lateral compression capacity at supports or loading plates or the tension capacity perpendicular to grain at notches and holes or in tapered and curved beams (Franke, 2013).

According to the calculations in the AHP assessment method, the following criteria weights are obtained (Figure 6).

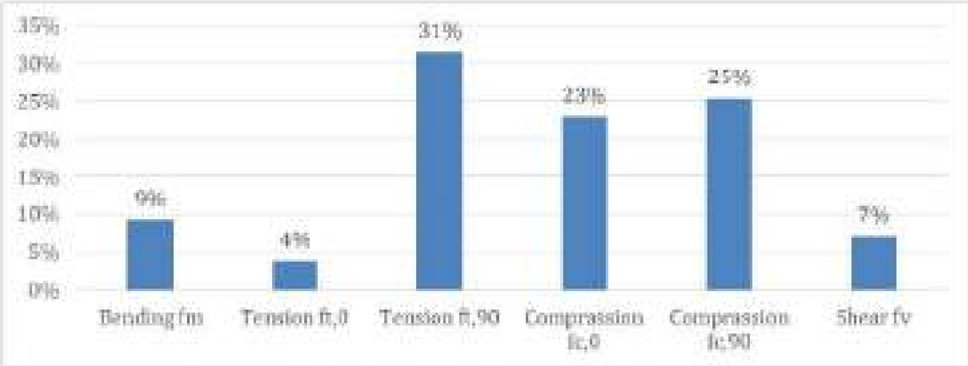


*Figure 6. Criteria weights obtained in the AHP method.*

Using the criteria weights from Figure 6, the final result and order are as follows (Table 3).

*Table 3. Final results and order in the AHP method.*

| | bending, $f_m$ | tension, $f_{t,0}$ | tension, $f_{t,90}$ | compression, $f_{c,0}$ | compression, $f_{c,90}$ | shear, $f_v$ | priority vector | solutions vector | order |
|---|---|---|---|---|---|---|---|---|---|
| Spruce | 0.049 | 0.049 | 0.124 | 0.095 | 0.066 | 0.064 | 0.092 | 0.088 | 4 |
| Oak | 0.131 | 0.140 | 0.096 | 0.258 | 0.364 | 0.423 | 0.038 | 0.229 | 3 |
| Ash | 0.300 | 0.308 | 0.390 | 0.181 | 0.364 | 0.329 | 0.315 | 0.320 | 2 |
| Beech | 0.520 | 0.503 | 0.390 | 0.466 | 0.207 | 0.185 | 0.229 | **0.363** | **1** |
| | | | | | | | 0.254 | | |
| | | | | | | | 0.071 | | |

The highest score of 0.363 was obtained for beech. It is followed by ash, oak, and spruce, respectively.

## 5. Conclusion

AHP analyses ranked timber species taking into account the main mechanical and criteria of main concerns for the elderly population. Results indicated that the most optimum was Beech, followed by Ash, Oak Spruce. However, to provide the selection guidelines that will be generally accepted by the industry further studies should concern aspects of the CLTdurability of the erected facilities and the costs of their long-term operation. It is important to take into account potential limitations in the development of CLT technology, related to, inter alia, access to wood resources with the required strength parameters, and regulations for the silviculture and timber design and utilization as construction material. The aspects of the availability and cost of obtaining wood raw material, which may differ significantly from country to country, are also important. Further studies on CLT optimization should focus on adhesives and bonding parameters, strength, and durability, as well as, on novel fully robotized and highly efficient production technology.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 121-138*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta250322151a*

# A COMPARATIVE STUDY OF USING MCDM METHODS INTEGRATED WITH ENTROPY WEIGHT METHOD FOR EVALUATING FACILITY LOCATION PROBLEM

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Received: 26 November 2021
Accepted: 14 February 2022
First online: 25 March 2022

*Research Paper*

**Abstract:** *The location selection of facilities became a major interest for the organizations to establish their planned business for a long period of time. The choice of the best location among a set of candidate locations is a complex process. Although the multiple criteria decision making (MCDM) methods are applicable for location selection problems, different solutions can be obtained using different MCDM methods. Thus, a comparative study between four different MCDM methods was applied within numerical example to show the deviations in ranking of the alternatives that occurs when different methods are used. The weights of attributes are assigned using objective method namely Entropy weight method. The rank disagreements are expressed using spearman`s correlation coefficients.*

**Keywords:** *Multiple-criteria decision making (MCDM); Facility location problem (FLP); Comparative study; Rank disagreement.*

## 1. Introduction

Locating a facility is a common problem generally called facility location problem (FLP). The study of facilities location was mainly as a result of Weber`s book "Theory of the Locations of the Industries" as Weber and Friedrich (1929) stated how to determine the location of a single warehouse to minimize the distance function. The location theory gained the researchers' interest as Hakimi (1964) mentioned how to find the optimum location of a switching center in a communication network and the best location for police station in a highway system. Facility location models can vary according to their objective function, number and sizes of the facilities and several other decisions (Farahani, 2009).

Traditionally, the objective of FLP could be minimizing either the costs of transportation or the distance from the demand areas. The FLP was analysed by a lot of researchers (Toregas et al., 1971; Voogd, 1983; Francis et al., 1992; Marianov et al.,

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2002; Drezner & Hamacher, 2004) and throughout the analyzation, it was developed to be a MCDM problem where several criteria are taken into account. This type of problems is called multiple criteria facility location problem where it is required to assign suitable location for a facility relative to a set of criteria. These criteria could be transportation costs, the land costs, safety and security, etc. Several alternatives are evaluated, data are collected and decisions are made relative to the defined set of criteria. The decision maker (DM) is responsible for making the right decision through various MCDM methods. The main steps in MCDM may be illustrated as follows:

(1) Establishing the criteria relating to a set of goals.

(2) Generation of the alternatives.

(3) Measuring the Performance of the alternatives.

(4) Applying a MCDM technique.

(5) Ranking of the alternatives.

(6) Accepting the solution obtained from the MCDM technique(s).

Steps (1) and (6) are mainly dependent on the decision makers while the other steps are likely an engineering tasks. A lot of potential is exerted in generating and evaluating the alternatives (steps (2) and (3)), and it can be even more harder to evaluate the alternative in some cases such as in the dynamic environment where the performance can be changed as a function of time. The generation of alternatives is a complicated process where there is no exact method or mathematical model to help in such process. Nothing can replace the human creativity in generating the alternatives.

For step (4), the decision maker must show his preference in applying a certain technique for obtaining the weights of criteria and the ranking of alternatives. Many MCDM approaches are available nowadays, most of them are following the same steps of making a decision. The only doubt is that each MCDM techniques produces a diverse ranking from the other techniques (Voogd, 1983). The differences in the mathematical models of MCDM methods leads to inconsistency of ranking. Afterwards, leads to several possible solutions.

Several MCDM methods can be applied to FLPs such as technique for order of preference by similarity to ideal solution (TOPSIS) method, grey relational analysis (GRA) method, weighted sum method (WSM), analytical hierarchical process (AHP) (Alosta et al. 2021), evaluation based on distance from average solution (EDAS) method and combined compromise solution (CoCoSo) method. The pre-mentioned methods require a method for assigning the weights for criteria except for AHP as criteria weights are calculated using pairwise comparisons between the criteria.

Most of MCDM methods requires a technique for assigning the weights of criteria as each criterion must have its importance compared to other criteria. The assigned weights can be calculated through subjective or objective methods. In subjective methods, the weights are determined through the experience of judgements while the objective methods depend on mathematical computations that neglects the decision maker preference towards some criteria. One of the most common objective weighting methods is entropy weight method (EWM). The EWM is used widely by decision makers for determining criteria weights. However, it sometimes fails to express the importance of certain criterion within a set of decision criteria.

In this research, the classical methods namely TOPSIS and GRA are compared with some newly developed methods namely EDAS and CoCoSo for evaluating the facility location problem. The focus will be on the deviation of ranking for the four different methods and whether they will agree the best and worst alternative or not. The procedures of each method will be illustrated and the methods will be compared through a numerical example concerning a facility location problem.

## 2. Literature Review

In this section, the past studies that evaluated FLPs using MCDM is presented while there is a lot of focus on the studies that used more than one MCDM method for the evaluation of location problems as decision makers seek for optimal and consistent solutions. However, no solution will be considered to be the optimum one in the existence of conflicting criteria (Shokri et al., 2013).

Some studies used only one method to evaluate location problems as Athawale et al. (2012) applied PROMETHEE II method for FLP under linguistic expressions. The method was proved to be effective tool for location selection problems. Żak and Węgliński (2014) applied ELECTRE III/IV method for location selection of logistics center in Poland. Stević et al. (2015) applied AHP method for location selection of logistics center with three candidate locations.

Many studies headed for using more than one MCDM method to ensure the consistency of results as Chakraborty et al. (2013) applied four MCDM methods for location selection of distribution centers, the four methods are GRA, multi-objective optimization on the basis of ratio analysis (MOORA), operational competitive rating analysis (OCRA) and ELECTRE II. The four methods agreed the best location while there was a deviation in ranking for the remaining locations. They concluded that the deviation that occurred in ranking of the locations within each method is due to the difference in the mathematical model of each method. Niyazi and Tavakkoli (2014) used three MCDM methods for the same problem, the methods are TOPSIS, additive ratio assessment (ARAS) and complex proportional assessment (COPRAS). The three methods produced different ranking even for the best location.

Parhizgarsharif et al. (2019) ranked forty locations in a construction site to choose the top twenty locations for establishing twenty facilities within them. The criteria weights were determined using best-worst method (BWM), GRA and VIKOR methods were used for ranking the sites. They concluded that GRA method is reliable and its ranking can be considered as a final solution for their case study.

Mihajlović et al. (2019) applied two MCDM methods for location selection of logistics center in Serbia. They used AHP and hybrid AHP-WASPAS methods, AHP method for criteria weights, moreover, the ranking of alternatives and WASPAS for ranking of alternatives using weights from AHP method. The two methods agreed the choice of best and worst alternative, furthermore, the ranking was almost identical.

Adalı and Tuş (2021) ranked four candidate hospital site locations by TOPSIS, EDAS and combinative distance-based assessment (CODAS) methods. The three methods produced the same ranking and the authors pointed out to the simplicity of both TOPSIS and EDAS methods. Chen et al. (2018) used EDAS and modified WASPAS methods for a teahouse location selection in Lithuania. The results showed that using random weighting techniques leads to inconsistent ranking of applied MCDM methods.

The integration of fuzzy theory with MCDM methods was mostly used to overcome the problem of dealing with linguistic variables in most of MCDM methods. As a result, Chauhan and Singh (2016) applied fuzzy AHP and fuzzy TOPSIS to determine a location for throwing away the healthcare waste. Suman et al. (2021) compared between AHP and fuzzy AHP methods for location selection of furniture industry in Bangladesh. The two methods agreed the ranking of alternatives. However, there was a variation in the priority of weights developed by the two methods. Kieu et al. (2021) used hybrid spherical fuzzy AHP and CoCoSo method for location selection of distribution center in Vietnam. They proved the stability of CoCoSo method as the ranking was consistent regardless the value of parameter $\lambda$.

## 3. Methodology

In this study, the EWM is used to determine the criteria weights and the final ranking of alternatives will be done using TOPSIS, GRA, EDAS and CoCoSo methods. TOPSIS and GRA methods are well known to most of decision makers. However, the recently developed methods namely EDAS and CoCoSo require further analysis and preview. The beginning of the solution of any of the proposed methods must be the construction of the decision making matrix which represent the performance evaluation of alternatives with respect to criteria chosen by the decision makers.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & x_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & x_{mn} \end{bmatrix}_{m\times n}$$

The rows stand for alternatives and the columns stand for criteria, $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$.

### 3.1 Entropy Weight Method

The entropy concept was developed by Shannon (1948) in theory of the communication to deal with uncertain information and missing data. However, the entropy concept was used to describe the irreversible motion that occurs in thermodynamics science. Later, entropy concept was found to be effective dealing with decision making problems (Zeleny, 2012). The method depends on the numerical data collected by decision makers to determine the relative importance of each criterion. In other words, the Shannon`s entropy was extended to entropy weight method which is an objective method for determining the weights of criteria. The steps of entropy weight method can be illustrated as follows:

(1) The normalization of numerical data using Weitendorf`s linear normalization (Aytekin, 2021),

$$\bar{r}_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{1}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (2)$$

Eq. (1) for benefit criterion and Eq. (2) for cost criterion.

(2) Calculate the intensity of the attributes using.

$$y_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (3)$$

(3) Calculate the entropy measure using.

$$E_j = -\frac{1}{\ln(m)} \times \sum_{i=1}^{m} y_{ij} \cdot ln(y_{ij}) ; \ \{if\ (y_{ij} = 0) \rightarrow (y_{ij} \cdot ln(y_{ij})) = 0\} \quad (4)$$

(4) Determine the weight of each criterion using.

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \quad (5)$$

### 3.2 TOPSIS Method

The classical TOPSIS procedures was developed by Hwang and Yoon (1981) in their book "Multiple-Attribute Decision Making" that was considered to be one of the most efficient MCDM methods. The basic algorithm of TOPSIS method is that the most preferred alternative having the minimum distance from the positive ideal solution (PIS) and the maximum distance from the negative ideal solution (NIS). The steps of classical TOPSIS method can be illustrated as follows:

(1) Normalize the numerical data using vector normalization represented by the formula.

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} x_{ij}^2} \quad (6)$$

Where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$ from the decision matrix [D].

(2) Calculate the weighted normalized matrix using.

$$v_{ij} = w_j r_{ij} \quad (7)$$

Where $i = 1, 2, \ldots, m$ , $j = 1, 2, \ldots, n$ and $w_j$ is weight of each criterion as $\sum_{j=1}^{n} w_j = 1$

(3) Determine the PIS and the NIS for each alternative using.

$$PIS = \{v_1^+, \dots, v_n^+\} = \left\{\left(\max_i v_{ij} \mid j \in I'\right), \left(\min_i v_{ij} \mid j \in I''\right)\right\} \quad (8)$$

$$NIS = \{v_1^-, \dots, v_n^-\} = \left\{\left(\min_i v_{ij} \mid j \in I'\right), \left(\max_i v_{ij} \mid j \in I''\right)\right\} \quad (9)$$

Where $I'$ represents benefit criteria and $I''$ represents cost criteria.

(4) Calculate the distances from the PIS and NIS for each alternative dependent on the Euclidean distance. The distance from the PIS is calculated as,

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (10)$$

And similarly the distance from the NIS is calculated as,

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (11)$$

(5) Calculation of the closeness coefficient for each alternative using,

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (12)$$

(6) Ranking of the alternatives on basis of the closeness coefficient values. The higher the value of the closeness coefficient the more preferred the alternative.

### 3.3 GRA Method

Grey relational analysis (GRA) is derived from the grey theory that was developed by Ju-Long (1982). The grey theory proved to be efficient dealing with incomplete information. The word "grey" refers to the mixture of black and white, the colour black for unavailable information and white for the available information. Kuo et al. (2008) tested GRA method as a decision making method by comparing it with three different methods. They proved that GRA method is applicable as MCDM method for real-world problems. The steps of the GRA method can be illustrated as follows:

(1) The normalization of the decision making matrix using Weitendorf's linear normalization represented by equations (1) and (2).

(2) Compute the deviation from reference sequences matrix using,

$$\Delta_{ij} = \left|x_{0j} - x_{ij}\right| \quad (13)$$

Where $x_{0j} = Max\{x_{ij}, \ j = 1, 2, \dots, n\}$

(3) Calculation of the grey relational coefficients.

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}} \quad (14)$$

Where,

The distinguishing coefficient $\xi \in [0,1]$,

$\Delta_{min} = Min\{\Delta_{ij}, i = 1,2, \ldots, m\ ;\ j = 1,2, \ldots, n\}$,

$\Delta_{max} = Max\{\Delta_{ij}, i = 1,2, \ldots, m\ ;\ j = 1,2, \ldots, n\}$.

(4) Calculation of the grey relational grade (GRG) for each alternative.

$$\Gamma(X_0, X_i) = \sum_{j=1}^{n} w_j\ \gamma(x_{0j}, x_{ij}) \quad (15)$$

$w_j$ is weight of each criterion as $\sum_{j=1}^{n} w_j = 1$.

(5) Ranking of the alternatives on basis of GRG values. The best alternative has the highest value of GRG.

### 3.4 EDAS Method

The EDAS method developed by Keshavarz et al. (2015), is claimed to be useful dealing with conflicting set of criteria in decision making problems. In EDAS method the evaluation is based only on one measure which is the distance from the average solution in positive and negative directions. The steps of EDAS method can be illustrated as below:

(1) The average solution (AV) according to a set of criteria is calculated using.

$$\overline{AV_j} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \quad (16)$$

(2) The positive and negative distances from the average solution matrices are calculated using.

If $i \in I^{+}$ then use equations,

$$PDA_{ij} = \frac{\max\left(0, \left(x_{ij} - \overline{AV_j}\right)\right)}{\overline{AV_j}} \quad (17)$$

$$NDA_{ij} = \frac{\max\left(0, \left(\overline{AV_j} - x_{ij}\right)\right)}{\overline{AV_j}} \quad (18)$$

If $i \in I^{-}$ then use equations,

$$PDA_{ij} = \frac{\max\left(0, \left(\overline{AV_j} - x_{ij}\right)\right)}{\overline{AV_j}} \tag{19}$$

$$NDA_{ij} = \frac{\max\left(0, \left(x_{ij} - \overline{AV_j}\right)\right)}{\overline{AV_j}} \tag{20}$$

(3) Calculation of the weighted sum of $PDA$ and $NDA$ for each alternative using,

$$SP_i = \sum_{j=1}^{n} w_j PDA_{ij} \tag{21}$$

$$SN_i = \sum_{j=1}^{n} w_j NDA_{ij} \tag{22}$$

(4) Normalization of $SP$ and $SN$ values for each alternative using,

$$NSP_i = \frac{SP_i}{\max_i SP_i} \tag{23}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i SN_i} \tag{24}$$

(5) Calculate the appraisal score for each alternative using,

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{25}$$

Where $0 \leq AS_i \leq 1$

(6) Ranking the alternative based on the values of $AS$, where the best alternative has the highest value of average score.

### 3.5 CoCoSo Method

This method was developed recently by Yazdani et al. (2019) which is based on two common approaches namely weighted sum model (WSM) and exponentially weighted product model. This method develops three different appraisal scores to evaluate the alternatives. Thus, a final coefficient combining these scores is calculated to obtain more robust results. The steps of the CoCoSo method is shown as follows:

(1) The normalization of the decision making matrix using equations (1) and (2).

(2) The calculation of the comparability sequences using,

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \tag{26}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{27}$$

$S_i$ is the sum of the weighted comparabilty sequences and $P_i$ is the sum of the power weighted comparability sequences.

(3) Three appraisal scores are calculated using,

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} (S_i + P_i)} \tag{28}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{29}$$

$$k_{ic} = \frac{\lambda S_i + (1 - \lambda) P_i}{\lambda \max_i S_i + (1 - \lambda) \max_i P_i}, \qquad \lambda \in [0,1] \tag{30}$$

(4) Final Ranking of the alternatives based on the values of coefficient $k_i$ as the higher the value the more preferred the alternative.

$$k_i = (k_{ia} k_{ib} k_{ic})^{1/3} + \frac{1}{3} (k_{ia} + k_{ib} + k_{ic}) \tag{31}$$

## 4. Numerical Example

In this section, the location problem presented by Zak and Węgliński (2014) is adopted. The aim of the problem is to select the most suitable region for placing logistics center (LC) in Poland. Ten different locations are nominated for placing the LC on their region, each location covers an area of 12 – 44 thousands $km^2$ and has a specific characteristic than the others. The performance of nominated locations is measured relative to nine criteria represented by C1, C2, … C9 are considered to meet the stakeholders' interest and requirements. The set of criteria considered in this example are, Condition of transportation infrastructure (C1), Economic development (C2); Investment cost (C3); Level of transportation and logistics competitiveness (C4); Investment attraction (C5), Transportation and logistics attraction (C6), Social attraction (C7); Environmental affability (C8), Safety and security (C9). The attentive reader can refer to Zak and Węgliński (2014) for more details about the case study. The performance of alternatives within the set of criteria is shown in table (1). The outranking ELECTRE III/IV method was used to solve this problem. However, the proposed MCDM methods (Section 3) are used in this study which gives a clear ranking of the alternatives.

*Table 1. The Performance of the Alternatives Respect to Criteria*

| Criterion | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Preference | MAX | MAX | MIN | MIN | MAX | MAX | MAX | MAX | MAX |
| A1 | 90.3 | 11350 | 392 | 9 | 1110 | 9709 | 4.5 | 7.5 | 7.5 |
| A2 | 132.2 | 11558 | 421 | 12 | 1019 | 13379 | 7.17 | 6.5 | 4.5 |
| A3 | 98 | 9416 | 395 | 6 | 1176 | 6991 | 4.33 | 6.5 | 8 |
| A4 | 101.3 | 13275 | 443 | 9 | 312 | 11904 | 4.17 | 6.5 | 6 |
| A5 | 138.5 | 11939 | 402 | 6 | 606 | 7958 | 7 | 8 | 7.5 |
| A6 | 146.8 | 20049 | 424 | 18 | 284 | 15669 | 4 | 6.5 | 3.75 |
| A7 | 133.1 | 9396 | 393 | 7 | 900 | 10425 | 7 | 6 | 7.5 |
| A8 | 121.7 | 12989 | 395 | 10 | 2789 | 13275 | 8 | 7.5 | 5.25 |
| A9 | 222.7 | 13822 | 406 | 12 | 1733 | 14382 | 4.17 | 4 | 3.75 |
| A10 | 146.9 | 10131 | 397 | 13 | 2355 | 11653 | 7 | 4.5 | 4.75 |

## 5. Results and Analysis

In this section, the weights of each criterion are computed, the results of the four methods will be discussed and presented within tables. A comparative analysis between the four methods including spearman`s rank correlation analysis will be discussed.

### 5.1 EW Method

The weight of each criterion is calculated as shown in table (2). The weights of criterion C2 and C7 are the highest among the set of criteria which is realistic as the economic development (C2) and the social attractiveness (C7) are important factors for the success of the logistics center. The level of transportation and logistics competitiveness (C4) has the least value of weight which is confusing as the transportation is one of the most factors affecting the logistics centers. However, the weights obtained by the entropy method is satisfying for an objective weighting method.

*Table 2. The Entropy Weights of Each Criterion*

| **Criteria** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** | **C9** |
|---|---|---|---|---|---|---|---|---|---|
| $E_j$ | 0.851 | 0.799 | 0.934 | 0.935 | 0.833 | 0.903 | 0.794 | 0.918 | 0.841 |
| $w_j$ | **0.125** | **0.168** | **0.055** | **0.054** | **0.141** | **0.081** | **0.173** | **0.069** | **0.133** |

### 5.2 TOPSIS Method

The ranking of each alternative on basis of the closeness coefficient values is shown in table (3). The ranked one alternative (A8) has the shortest distance from the ideal solution and the longest distance from the worst solution. Thus, it has the highest value of closeness coefficient.

*Table 3. The Final Ranking of TOPSIS Method*

| Alternative | $D_i^+$ | $D_i^-$ | $CC_i$ | Rank |
|---|---|---|---|---|
| **A1** | 0.08149 | 0.04220 | 0.34117 | **9** |
| **A2** | 0.07506 | 0.04434 | 0.37136 | **6** |
| **A3** | 0.08488 | 0.04538 | 0.34837 | **8** |
| **A4** | 0.09632 | 0.03011 | 0.23820 | **10** |
| **A5** | 0.08081 | 0.04898 | 0.37739 | **5** |
| **A6** | 0.09445 | 0.05166 | 0.35360 | **7** |
| **A7** | 0.07892 | 0.04857 | 0.38097 | **4** |
| **A8** | 0.04640 | 0.08992 | 0.65963 | **1** |
| **A9** | 0.06414 | 0.06401 | 0.49948 | **3** |
| **A10** | 0.05745 | 0.07238 | 0.55746 | **2** |

### 5.3 GRA Method

The results of GRA method are presented in table (4). The value of the distinguishing coefficient ($\xi$) was set initially at 0.5 as per past researches (Tosun, 2006; Kuo et al., 2008; Abhang et al., 2021). The ranked one alternative (A8) has the highest value of GRG. In other words, A8 has the most similarity to reference sequence that makes it the best possible choice among the set of alternatives.

*Table 4. The Final Ranking of GRA Method*

| Alternative | GRG | Rank |
|---|---|---|
| **A1** | 0.51695 | **8** |
| **A2** | 0.49420 | **9** |
| **A3** | 0.52507 | **7** |
| **A4** | 0.43080 | **10** |
| **A5** | 0.58826 | **2** |
| **A6** | 0.53862 | **4** |
| **A7** | 0.55923 | **3** |
| **A8** | 0.68309 | **1** |
| **A9** | 0.53136 | **5** |
| **A10** | 0.52805 | **6** |

The value of distinguishing coefficient is analyzed to study its effect on the results of GRA method for this example. The distinguishing coefficient was set at 0.25, 0.5, 0.75 and 1 respectively. The results are shown in Fig (1). It is important to mention that the ranking of the of alternatives A8, A5, A9 and A4 are always ranked 1, 2, 7 and 10 respectively regardless the value of the distinguishing coefficient.

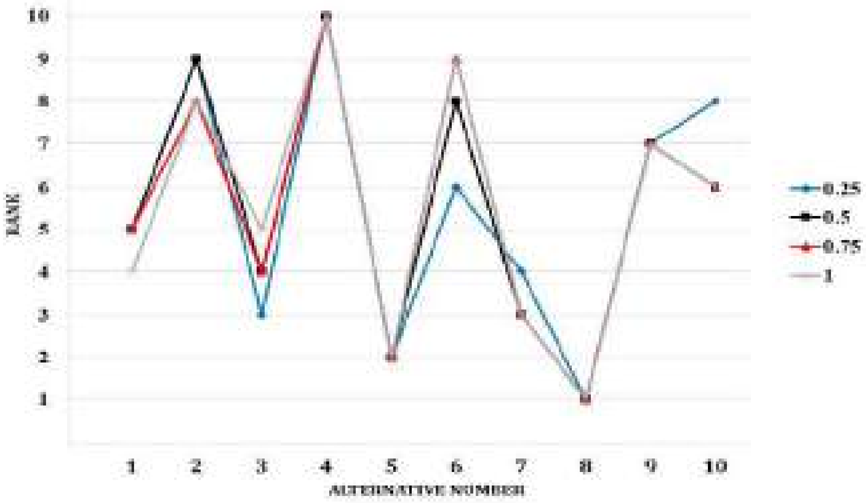


*Figure 1. The Ranking of GRA Method for Different Values of Distinguishing Coefficient*

### 5.4 EDAS Method

The results of EDAS method are presented in table (5). The best alternative (A8) has the highest positive distance from average solution and the shortest negative distance from average solution (after normalization using Eq. 24, the value of $NSN_i$ increases as the value of $SN_i$ decreases). As a result, the appraisal score of alternative (A8) is the highest among the set of alternatives. It is valuable to note the gap in the appraisal score between A8 (rank one) and A10 (rank two).

*Table 5. The Final Ranking of EDAS Method*

| Alternative | $NSP_i$ | $NSN_i$ | $AS_i$ | Rank |
|---|---|---|---|---|
| **A1** | 0.20661 | 0.53047 | 0.36854 | 7 |
| **A2** | 0.20521 | 0.68894 | 0.44708 | 6 |
| **A3** | 0.26318 | 0.38895 | 0.32606 | 8 |
| **A4** | 0.09187 | 0.25713 | 0.17450 | 10 |
| **A5** | 0.43053 | 0.59305 | 0.51179 | 4 |
| **A6** | 0.52181 | 0 | 0.26090 | 9 |
| **A7** | 0.33481 | 0.64312 | 0.48896 | 5 |
| **A8** | 1 | 0.90288 | 0.95714 | 1 |
| **A9** | 0.64331 | 0.48344 | 0.56338 | 3 |
| **A10** | 0.64531 | 0.64019 | 0.64275 | 2 |

### 5.5 CoCoSo Method

The coefficient ($\lambda$) in Eq. 30 is usually given the value of 0.5 by the decision makers. Hence, the results of this method when $\lambda = 0.5$ are presented in table (6).

*Table 6. The Final Ranking of CoCoSo Method*

| Alternative | $K_{ia}$ | $K_{ib}$ | $K_{ic}$ | $K_i$ | Rank |
|---|---|---|---|---|---|
| **A1** | 0.09961 | 2.9070 | 0.82907 | 1.9001 | **6** |
| **A2** | 0.11205 | 3.2108 | 0.93264 | 2.1134 | **4** |
| **A3** | 0.09051 | 2.6170 | 0.75332 | 1.7166 | **8** |
| **A4** | 0.08936 | 2.3526 | 0.74374 | 1.6006 | **9** |
| **A5** | 0.11451 | 3.5790 | 0.95307 | 2.2798 | **2** |
| **A6** | 0.06815 | 2.3060 | 0.56724 | 1.4272 | **10** |
| **A7** | 0.10513 | 3.3134 | 0.87505 | 2.1042 | **5** |
| **A8** | 0.12015 | 4.0929 | 1 | 2.5270 | **1** |
| **A9** | 0.08841 | 2.8061 | 0.73584 | 1.7774 | **7** |
| **A10** | 0.11208 | 3.3375 | 0.93282 | 2.1648 | **3** |

The values for coefficient ($\lambda$) must be checked to measure the effect of ($\lambda$) on the ranking of the alternatives. The test values are 0.25, 0.5, 0.75, 1 respectively. The results of the analysis are shown in figure (2). The only change occurred due to the variation of ($\lambda$) is the ranking of alternatives A1 and A2 as they switched the ranks when the value of ($\lambda$) equal to one. The remaining alternatives had the same ranking regardless the value of ($\lambda$) coefficient.

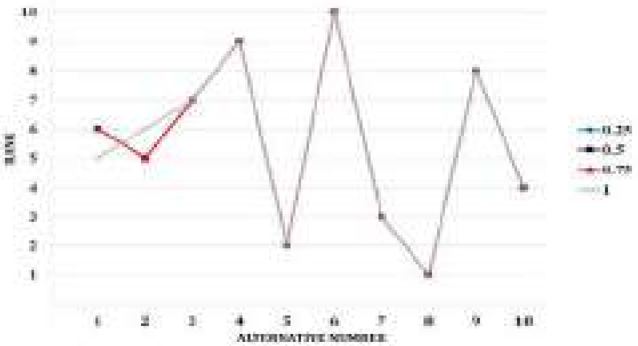


*Figure 2 The Ranking of CoCoSo Method for Different Values of ($\lambda$) Coefficient.*

### 5.6 Comparative Analysis

The final ranking of TOPSIS, GRA, EDAS, CoCoSo and reference method is shown in table (7). The results show that there is an agreement on the rank one alternative (A8). A disagreement occurred between the methods for the second choice alternative as EDAS and TOPSIS methods stand for A10 while GRA and CoCoSo methods stand for A5.

*Table 7. The Comparative Ranking between the Four Methods and Reference Method*

| Alternative | TOPSIS | GRA | EDAS | CoCoSo | Reference Method |
|---|---|---|---|---|---|
| A1 | 9 | 8 | 7 | 6 | 7 |
| A2 | 6 | 9 | 6 | 4 | 6 |
| A3 | 8 | 7 | 8 | 8 | 10 |
| A4 | 10 | 10 | 10 | 9 | 9 |
| A5 | 5 | 2 | 4 | 2 | 3 |
| A6 | 7 | 4 | 9 | 10 | 4 |
| A7 | 4 | 3 | 5 | 5 | 4 |
| A8 | 1 | 1 | 1 | 1 | 1 |
| A9 | 3 | 5 | 3 | 7 | 1 |
| A10 | 2 | 6 | 2 | 3 | 7 |

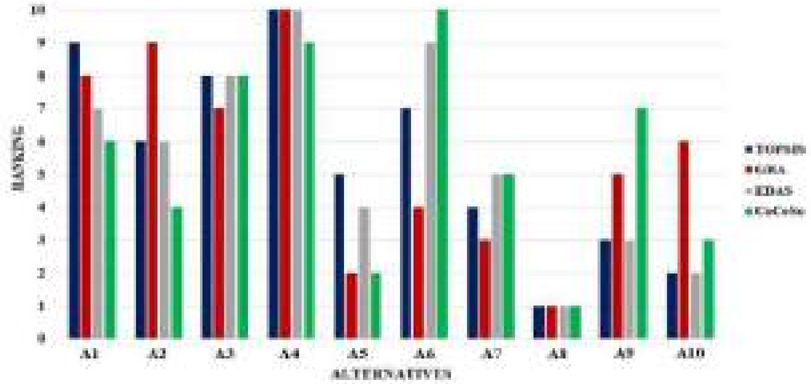


*Figure 3. Graphical Representation of the Ranking Order for Each Method*

A spearman's rank correlation coefficient ($r_s$) is calculated to express the deviation between the rankings of different methods in numerical numbers. The value of ($r_s$) always lies between +1 and -1 where the value of (+1) indicates a perfect coincidence between the two methods and the value of (-1) indicated that there is no coincidence between the two methods. The closer the value of ($r_s$) to zero, the weaker the association of the ranking between the two methods. The value of spearman's rank correlation coefficient can be calculated using.

$$r_s = 1 - \frac{6\sum d_i^2}{m \times (m^2 - 1)} \tag{32}$$

Where $d_i$ is the difference in ranking of the alternative by the two methods and $m$ is the number of alternatives.

*Table 8. Rank Correlation Coefficients Between the Four MCDM Methods*

| MCDM Method | GRA | EDAS | CoCoSo |
|---|---|---|---|
| TOPSIS | 0.69697 | 0.93939 | 0.69697 |
| GRA | - | 0.61212 | 0.49090 |
| EDAS | - | - | 0.8303 |

As shown in table (8), there is almost a perfect match between TOPSIS and EDAS methods as the two methods are similar to each other in the concept of solution while the smallest value of ($r_S$) was between GRA and CoCoSo methods. In general, the GRA method has a moderate correlation coefficient when compared to the other three methods

## 6. Conclusions

In this study, four MCDM methods namely TOPSIS, GRA, EDAS and CoCoSo were compared to show the deviation in the ranking of alternatives that occurs when using different MCDM methods. The four methods were applied to solve FLP regarding LC location selection and the weights of the criteria were assigned using EWM. The subsequent observations are:

1. The weights obtained by EWM is unreasonable regarding two criteria namely level of transportation and logistics competitiveness (C4) and transportation and logistics attraction (C6) as the transportation criterion is one the most important criterion for LC location selection problem. The decision maker`s preference must be present for such cases when the objective methods fail to express the importance of a certain criterion. However, the two criteria namely economic development (C2) and social attraction (C7) has reasonable weights.
2. Although the presence of two conflicting criteria namely investment cost (C3) and investment attraction (C5), the four different MCDM methods proved to be efficient dealing with such case. The alternative (A8) was selected as the best alternative by the four methods while the ranking of the other alternatives has some deviations from a method to others.
3. TOPSIS and EDAS methods has a very strong relation on basis of the spearman`s correlation value. The result was expected due to the similarity on concept of solution between TOPSIS and EDAS method.
4. Among the four methods, GRA method has the lowest correlation coefficient especially with CoCoSo method. The value of distinguishing coefficient is still confusing as it is based on the decision maker preference without a reasonable explanation. However, the choice of the best alternative has not changed when changing the value of distinguishing coefficient.
5. CoCoSo method is one of the newly developed methods that proved to be efficient as a MCDM tool. In this study, the value of the coefficient ($\lambda$) almost had no effect on the ranking of the alternatives. For further researches, the effect of changing the coefficient ($\lambda$) must be analyzed for different numerical examples.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 139-151*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta070422211v*

# A NOVEL IMF SWARA-FDWGA-PESTEL ANALYSIS FOR ASSESSMENT OF HEALTHCARE SYSTEM

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Received: 16 January 2022
Accepted: 04 April 2022
First online: 07 April 2022

*Research paper*

**Abstract:** *Decision-making represents a very popular field with many developed approaches. However, still exists the need for the creation of novel integrated models such as well is the case in this paper. The novel integrated Improved Fuzzy Stepwise Weight Assessment Ratio Analysis (IMF SWARA) method, Fuzzy Dombi weighted geometric averaging (FDWGA) operator and PESTEL (P-Political, E-Economic, S-Social, T-Technological, E-Environmental, L-Legal) model has been developed. Five decision-makers (DMs) have evaluated six main elements of the PESTEL analysis and 30 elements more (five for each group). In total, we have created 35 models based on the developed model. Results of PESTEL analysis based on IMF SWARA method and FDWGA shows that legal and economic factors represent the most significant parameters, while last placed belong environmental group. Also, the usefulness of the developed integrated model has been demonstrated.*

**Key words**: *IMF SWARA, Fuzzy Dombi operator, PESTEL, decision-making, FDWGA operator*

## 1. Introduction

Consideration of the problem of decision-making in the presence of a number of influential factors has become an extremely important area. Methods, techniques, approaches that belong to the field of multicriteria decision making (MCDM) (Alosta et al. 2021; Yildirim et al. 2022; Pamučar and Savin, 2020) become very popular and applicable in all fields of both science and profession (Mahmutagić et al. 2021; Karagoz et al. 2021; Stanujkić et al. 2021; Švadlenka et al. 2020; Shekhovtsov et al. 2021; Özdağoğlu et al. 2021). They have practically become an indispensable tool for

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efficient management of any system, thanks to their very flexible performance If we add to that the possibility of making decisions in different conditions of uncertainty (Ali et. al. 2021; Mishra et al. 2021; Bausys et al. 2021; Stanujkić et al. 2021) then it is clear why this is one of the most developed areas of operational research in the last 10-15 years. In addition to a large number of newly developed MCDM methods, the development of different aggregators is being pursued in parallel (Yang et al. 2020; Vojinović et al. 2021; Debnath, 2021) which contribute to decision-making in more precise way. Another very flexible feature of MCDM methods is the easy way to integrate with other approaches (Blagojević et al. 2020; Ali et al. 2021; Khan, 2018; Wang et. al. 2020Another very flexible feature of MCDM methods is the easy way to integrate with other approaches in order to overcome potential difficulties and make more precise decisions.

The aim of this paper is to create an original integrated IMF SWARA-FDWGA-PESTEL model in order to enable accurate quantification of PESTEL analysis. In this way, soft analysis becomes precise with clear quantified values that make decision-making easier.

The IMF SWARA method was developed last year and has been successfully applied in several studies so far. Stević et. al. (2022) have created an objective critique of the application of the fuzzy SWARA method by proving the applicability and advantages of the IMF SWARA methodSeven different studies have been investigated to prove the validity of the IMF SWARA method. Damjanović et. al. (2022) have created the original DEA (Data Envelopment Analysis) – IMF SWARA – MARCOS (Measurement of alternatives and ranking according to COmpromise solution) model for determination level of traffic safety in Montenegro in interval of 23 years. IMF SWARA was applied in all six scenarios for determining the weighting coefficients of the criteria. Zolfani et al. (2021) have applied an integrated MCDM model in which they used IMF SWARA method for computing criteria weights for the evaluation of logistics villages in Turkey. Vojinović and Stević, (2021) have just applied the combination of IMF SWARA and PESTEL for health system analysis. They defined six main elements of PESTEL analysis and five sub-criteria for each of the main groups. Vojinović et al. (2021) have also applied the IMF SWARA method to determine the importance of criteria in the evaluation of companies engaged in the transport of dangerous goods. Part of the criteria has been referred to the legal aspect, which is extremely important for the proper functioning of this area. When it comes to Dombi operator, a number of approaches have been developed including various fuzzy forms: picture fuzzy Dombi (Jana et al. 2019), spherical fuzzy Dombi (Ashraf et al. 2020), pythagorean fuzzy Dombi (Khan et al. 2019), intuitionistic fuzzy Dombi (Seikh and Mandal, 2021) etc. The combination of PESTEL analysis and MCDM methodology is rare. (Tsangas et al. 2019) have combined SWOT (Strengths, Weakness, Opportunities, Threats) with PESTEL and AHP (Analytic Hierarchy Process) for assessment hydrocarbons sector in Cyprus.

Throughout the rest of the paper, the algorithms of the applied methodology are presented, the PESTEL analysis is set, and the results are presented, along with the presentation of the calculation of individual steps. A discussion of the results and concluding remarks were presented.

## 2. Methods

### 2.1. IMF SWARA method

IMF SWARA method has been represented first time by Vrtagić et al. (2021). Algorithm of IMF SWARA method can be represented through the next steps:

Step 1: Arrangement of criteria in descending order based on their expected significance.

Step 2: Starting from the previously determined rank, the relatively smaller significance of the criterion (criterion $C_j$) was determined in relation $\overline{\kappa_j}$ to the previous one ($C_{j-1}$), and this was repeated for each subsequent criterion. TFN scale for assessment of criteria using IMF SWARA is shown in Table 1.

*Table 1. Linguistics and the TFN scale for application of IMF SWARA method*

| Linguistic Variable | Abbreviation | TFN Scale |
|---|---|---|
| Absolutely less significant | ALS | (1,1,1) |
| Dominantly less significant | DLS | (0.5,0.667,1) |
| Much less significant | MLS | (0.4,0.5,0.667) |
| Really less significant | RLS | (0.333,0.4,0.5) |
| Less significant | LS | (0.286,0.333,0.4) |
| Moderately less significant | MDLS | (0.25,0.286,0.333) |
| Weakly less significant | WLS | (0.222,0.25,0.286) |
| Equally significant | ES | (0,0,0) |

Step 3: Calculation the fuzzy coefficient $\overline{\partial_j}$ (1):

$$\overline{\partial_j} = \begin{cases} \overline{1} & j = 1 \\ \overline{\kappa_j} & j > 1 \end{cases} \tag{1}$$

Step 4: Calculation the weights $\overline{c_j}$ (2):

$$\overline{c_j} = \begin{cases} \overline{1} & j = 1 \\ \dfrac{\overline{c_{j-1}}}{\overline{\partial_j}} & j > 1 \end{cases} \tag{2}$$

Step 5: Calculation of the fuzzy weight coefficients (3):

$$\overline{w_j} = \frac{\overline{c_j}}{\sum_{j=1}^{m} \overline{c_j}} \tag{3}$$

where $w_j$ is the fuzzy relative weight of the criteria $j$, and $m$ denotes the total number of criteria.

### 2.2. Fuzzy Dombi operator

FDWGA is represented by equations (4) and (5) based on changing and modification of the previously developed approach RNDWGA (Sremac et al. 2018), which implies the application of fuzzy instead rough numbers.

$$FDWGA(\wp)=\left(\wp_j^l,\wp_j^m,\wp_j^u\right)=\begin{cases}\wp_j^l=\dfrac{\sum_{j=1}^{n}(\wp_j^l)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f(\wp_j^l)}{f(\wp_j^l)}\right)^p\right\}^{1/p}}\\[2ex]\wp_j^m=\dfrac{\sum_{j=1}^{n}(\wp_j^m)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f(\wp_j^m)}{f(\wp_j^m)}\right)^p\right\}^{1/p}}\\[2ex]\wp_j^u=\dfrac{\sum_{j=1}^{n}(\wp_j^u)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f(\wp_j^u)}{f(\wp_j^u)}\right)^p\right\}^{1/p}}\end{cases}\tag{4}$$

where $w_j$ denotes weights of $s$ decision makers participating in the research, while $p\geq 0$ is non-negative number. $\wp_j^l$ - low value of TFN, $\wp_j^m$ - middle value of TFN and $\wp_j^u$ - upper values of TFN.

$$f\left(\wp_j^l,\wp_j^m,\wp_j^u\right)=\begin{cases}f\left(\wp_j^l\right)=\dfrac{\left(\wp_j^l\right)}{\sum_{j=1}^{n}\left(\wp_j^l\right)}\\[2ex]f\left(\wp_j^m\right)=\dfrac{\left(\wp_j^m\right)}{\sum_{j=1}^{n}\left(\wp_j^m\right)}\\[2ex]f\left(\wp_j^u\right)=\dfrac{\left(\wp_j^u\right)}{\sum_{j=1}^{n}\left(\wp_j^u\right)}\end{cases}\tag{5}$$

## 3. PESTEL analysis

In this study has been reproduced PESTEL (political, economic, socio-cultural, technological, environmental and legal factors) analysis from the paper (Vojinović and Stević, 2021). PESTEL analysis of the healthcare system of the local community of Pale with reference to the emergency situation caused by the COVID-19 pandemic consist of 30 parameters and has been shown as follow. Performing such analysis is very important because according to Dukić. (2020) pandemic impact of coronavirus (COVID-19) on human health can shutter international investment and the business environment. In addition to the economic crisis, a pandemic has influence on crisis of health systems, which requires huge economic investments (Bukač et al. 2021).

*Political factors – P*

*P1 – Political instability*

*P2 – Corruption and political influence in the healthcare system*

*P3 – Organization, insurance and comprehensiveness of health care*

*P4 – Social and healthcare policy of the economy*

*P5 – Healthcare quality and safety policy*

*Economic factors – E*

*E1 – Healthcare financing system*

*E2 – Population living standard*

*E3 – Investing in healthcare improvement*

*E4 – Economic crises (national and international)*

*E5 – Healthcare service prices*

*Social factors – S*

*S1 – Education, healthcare habits and lifestyle of the population*

*S2 – Age of the population*

*S3 – Demographic changes and migrations*

*S4 – Social health care*

*S5 – Public opinion and the media in health promotion*

*Technological factors – T*

*T1 – Application of technology in the diagnosis and treatment of diseases*

*T2 – Negative impact of technology on health (mobile telephony, Internet, social networks)*

*T3 – Development and application of new medicines and methods in the treatment of diseases*

*T4 – Informatization of records of healthcare users and diseases*

*T5 – Electronic communication in accessing health care and providing information about health hazards and measures taken*

*Environmental factors – EN*

*EN1 – Healthy environment*

*EN2 – Competitiveness of the public and private health sector*

*EN3 – Education, training and expertise of healthcare professionals*

*EN4 – Population awareness of the importance of health and self – care*

*EN5 – Population healthcare and health improvement projects*

*Legal factors – L*

*L1 – Legal and institutional framework of health care*

*L2 – Healthcare quality control*

*L3 – Legal protection of users of healthcare services*

*L4 – Implementation and application of international legal norms*

*L5 – The role and activity of national and international regulatory bodies*

## 4. Application of novel IMF SWARA-FDWGA-PESTEL MODEL

In this part of the paper has been demonstrated the application of a novel IMF SWARA-FDWGA-PESTEL model based on the preferences of five decision-makers (DMs). As the first we have created five various IMF SWARA models for the main factors of the PESTEL analysis. After that has been formed five similar models for each main parameter, so in total have been created 35 IMF SWARA models. IMF SWARA models with all elements calculated using equations (1) – (3) for five DMs for the main parameters of the PESTEL analysis have shown in Tables 2, 3, 4, 5, and 6.

*Table 2. IMF SWARA of the main factors of PESTEL analysis (DM1)*

| | DM1 | $\overline{\kappa_j}$ | $\overline{\partial_j}$ | $\overline{1_j}$ | $\overline{w_j}$ |
|---|---|---|---|---|---|
| C2 | E | | (1,1,1) | (1,1,1) | (0.234,0.243,0.255) |
| C3 | D | (0,0,0) | (1,1,1) | (1,1,1) | (0.234,0.243,0.255) |
| C1 | PO | (0.222,0.25,0.286) | (1.222,1.25,1.286) | (0.778,0.8,0.818) | (0.182,0.194,0.208) |
| C6 | PR | (0.286,0.333,0.4) | (1.286,1.333,1.4) | (0.556,0.6,0.636) | (0.13,0.146,0.162) |
| C5 | O | (0.333,0.4,0.5) | (1.333,1.4,1.5) | (0.37,0.429,0.477) | (0.087,0.104,0.122) |
| C4 | T | (0.4,0.5,0.667) | (1.4,1.5,1.667) | (0.222,0.286,0.341) | (0.052,0.069,0.087) |
| | | | SUM | (3.926,4.114,4.273) | |

*Table 3. IMF SWARA of the main factors of PESTEL analysis (DM2)*

| | DM2 | $\overline{\kappa_j}$ | $\overline{\partial_j}$ | $\overline{1_j}$ | $\overline{w_j}$ |
|---|---|---|---|---|---|
| C6 | PR | | (1,1,1) | (1,1,1) | (0.233,0.242,0.254) |
| C4 | T | (0,0,0) | (1,1,1) | (1,1,1) | (0.233,0.242,0.254) |
| C2 | E | (0.222,0.25,0.286) | (1.222,1.25,1.286) | (0.778,0.8,0.818) | (0.181,0.194,0.207) |
| C1 | PO | (0.25,0.286,0.333) | (1.25,1.286,1.333) | (0.583,0.622,0.655) | (0.136,0.151,0.166) |
| C3 | D | (0.333,0.4,0.5) | (1.333,1.4,1.5) | (0.389,0.444,0.491) | (0.091,0.108,0.124) |
| C5 | O | (0.5,0.667,1) | (1.5,1.667,2) | (0.194,0.267,0.327) | (0.045,0.065,0.083) |
| | | | | (3.944,4.133,4.291) | |

*Table 4. IMF SWARA of the main factors of PESTEL analysis (DM3)*

| | DM3 | $\overline{\kappa_j}$ | $\overline{\partial_j}$ | $\overline{1_j}$ | $\overline{w_j}$ |
|---|---|---|---|---|---|
| C6 | PR | | (1,1,1) | (1,1,1) | (0.251,0.265,0.284) |
| C1 | PO | (0.222,0.25,0.286) | (1.222,1.25,1.286) | (0.778,0.8,0.818) | (0.196,0.212,0.233) |
| C2 | E | (0,0,0) | (1,1,1) | (0.778,0.8,0.818) | (0.196,0.212,0.233) |
| C3 | D | (0.333,0.4,0.5) | (1.333,1.4,1.5) | (0.519,0.571,0.614) | (0.13,0.152,0.174) |
| C5 | O | (0.5,0.667,1) | (1.5,1.667,2) | (0.259,0.343,0.409) | (0.065,0.091,0.116) |
| C4 | T | (0.286,0.333,0.4) | (1.286,1.333,1.4) | (0.185,0.257,0.318) | (0.047,0.068,0.09) |
| | | | | (3.519,3.771,3.977) | |

*Table 5. IMF SWARA of the main factors of PESTEL analysis (DM4)*

| | DM4 | $\overline{\kappa_j}$ | $\overline{\partial_j}$ | $\overline{1_j}$ | $\overline{w_j}$ |
|---|---|---|---|---|---|
| C3 | D | (0,0,0) | (1,1,1) | (1,1,1) | (0.23,0.238,0.248) |
| C6 | PR | (0,0,0) | (1,1,1) | (1,1,1) | (0.23,0.238,0.248) |
| C4 | T | (0.222,0.25,0.286) | (1.222,1.25,1.286) | (0.778,0.8,0.818) | (0.179,0.19,0.203) |
| C5 | O | (0.286,0.333,0.4) | (1.286,1.333,1.4) | (0.556,0.6,0.636) | (0.128,0.143,0.158) |
| C2 | E | (0.25,0.286,0.333) | (1.25,1.286,1.333) | (0.417,0.467,0.509) | (0.096,0.111,0.126) |
| C1 | PO | (0.333,0.4,0.5) | (1.333,1.4,1.5) | (0.278,0.333,0.382) | (0.064,0.079,0.095) |
| | | | | (4.028,4.2,4.345) | |

*Table 6. IMF SWARA of the main factors of PESTEL analysis (DM5)*

| | DM5 | $\overline{\kappa_j}$ | $\overline{\partial_j}$ | $\overline{1_j}$ | $\overline{w_j}$ |
|---|---|---|---|---|---|
| C1 | PO | (0,0,0) | (1,1,1) | (1,1,1) | (0.236,0.243,0.251) |
| C2 | E | (0,0,0) | (1,1,1) | (1,1,1) | (0.236,0.243,0.251) |
| C6 | PR | (0.222,0.25,0.286) | (1.222,1.25,1.286) | (0.778,0.8,0.818) | (0.184,0.194,0.205) |
| C4 | T | (0.25,0.286,0.333) | (1.25,1.286,1.333) | (0.583,0.622,0.655) | (0.138,0.151,0.164) |
| C5 | O | (0.286,0.333,0.4) | (1.286,1.333,1.4) | (0.417,0.467,0.509) | (0.098,0.113,0.128) |
| C3 | D | (1,1,1) | (2,2,2) | (0.208,0.233,0.255) | (0.049,0.057,0.064) |
| | | | | (3.986,4.122,4.236) | |

The next step represents the application of FDWGA operator using equations (4) and (5) in order to aggregate previously obtained criteria weights by IMF SWARA method. It is important to note that the weight $w_j$ of each DMs is equal i.e 0.200.

Example of the application of FDWGA operstor for the first PESTEL main parameter is as follows.

$$FDWGA(\overline{\wp})=\left(\wp_j^l,\wp_j^m,\wp_j^u\right)=\begin{cases}\wp_j^l=\dfrac{\sum_{j=1}^{n}\left(\wp_j^l\right)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f\left(\wp_j^l\right)}{f\left(\wp_j^l\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{0.812}{1+\left(0.2\times\frac{1-0.224}{0.224}\right)+\left(0.2\times\frac{1-0.167}{0.167}\right)+\left(0.2\times\frac{1-0.241}{0.241}\right)+\left(0.2\times\frac{1-0.079}{0.079}\right)+\left(0.2\times\frac{1-0.256}{0.256}\right)}=0.132\\ \wp_j^m=\dfrac{\sum_{j=1}^{n}\left(\wp_j^m\right)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f\left(\wp_j^m\right)}{f\left(\wp_j^m\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{0.872}{1+\left(0.2\times\frac{1-0.221}{0.221}\right)+\left(0.2\times\frac{1-0.172}{0.172}\right)+\left(0.2\times\frac{1-0.241}{0.241}\right)+\left(0.2\times\frac{1-0.096}{0.096}\right)+\left(0.2\times\frac{1-0.276}{0.276}\right)}=0.151\\ \wp_j^u=\dfrac{\sum_{j=1}^{n}\left(\wp_j^u\right)}{1+\left\{\sum_{j=1}^{n}w_j\left(\dfrac{1-f\left(\wp_j^u\right)}{f\left(\wp_j^u\right)}\right)^{\rho}\right\}^{1/\rho}}=\dfrac{0.955}{1+\left(0.2\times\frac{1-0.218}{0.218}\right)+\left(0.2\times\frac{1-0.174}{0.174}\right)+\left(0.2\times\frac{1-0.244}{0.244}\right)+\left(0.2\times\frac{1-0.166}{0.166}\right)+\left(0.2\times\frac{1-0.263}{0.263}\right)}=0.169\end{cases}$$

In the same way have been obtained the other main parameters of the PESTEL analysis and consequently all subparameters. After applying IMF SWARA – FDWGA – PESTEL model fuzzy weights for the main parameters is shown in Figure 1.


*Figure 1. Weights of the main parameters of PESTEL analysis*

Figure 1 shows fuzzy weights of the main parameters of PESTEL analysis. Red color denotes low value of TFN, blue middle and green upper value of TFN. The most important parameter is the legal group with value of:

$$w_1 = (0.085, 0.102, 0.118), \quad w_6 = (0.194, 0.207, 0.222)$$

The results obtained according to previously described steps of IMF SWARA – FDWGA – PESTEL model that denotes fuzzy values of subelements have been shown in Table 7.

*Table 7. Overall results of importance of PESTEL analysis for each group after application of IMF SWARA – FDWGA model*

| $w_j$ | TFN | $w_j$ | TFN | $w_j$ | TFN |
|---|---|---|---|---|---|
| $w_{11}$ | (0.085,0.102,0.118) | $w_{21}$ | (0.215,0.227,0.239) | $w_{31}$ | (0.23,0.245,0.261) |
| $w_{12}$ | (0.203,0.217,0.232) | $w_{22}$ | (0.184,0.207,0.226) | $w_{32}$ | (0.15,0.171,0.192) |
| $w_{13}$ | (0.181,0.201,0.221) | $w_{23}$ | (0.192,0.207,0.222) | $w_{33}$ | (0.089,0.108,0.126) |
| $w_{14}$ | (0.162,0.185,0.205) | $w_{24}$ | (0.092,0.11,0.127) | $w_{34}$ | (0.275,0.285,0.297) |
| $w_{15}$ | (0.195,0.21,0.226) | $w_{25}$ | (0.16,0.178,0.195) | $w_{35}$ | (0.134,0.153,0.172) |
| $w_j$ | TFN | $w_j$ | TFN | $w_j$ | TFN |
| $w_{41}$ | (0.273,0.282,0.294) | $w_{51}$ | (0.193,0.206,0.22) | $w_{61}$ | (0.245,0.253,0.264) |
| $w_{42}$ | (0.089,0.115,0.138) | $w_{52}$ | (0.087,0.101,0.113) | $w_{62}$ | (0.259,0.266,0.276) |
| $w_{43}$ | (0.204,0.219,0.234) | $w_{53}$ | (0.263,0.269,0.278) | $w_{63}$ | (0.206,0.218,0.232) |
| $w_{44}$ | (0.117,0.138,0.156) | $w_{54}$ | (0.212,0.225,0.238) | $w_{64}$ | (0.114,0.134,0.152) |
| $w_{45}$ | (0.138,0.158,0.177) | $w_{55}$ | (0.122,0.141,0.158) | $w_{65}$ | (0.09,0.109,0.126) |

Final results have been obtained multiplication of values represented in Figure 1 (the main parameters of PESTEL analysis) and values of subcriteria represented in Table 7. These final results have been shown in Table 8.

*Table 8. Final results of importance of PESTEL analysis after application of IMF SWARA – FDWGA model*

| $w_j$ | TFN | $w_j$ | TFN | $w_j$ | TFN |
|---|---|---|---|---|---|
| $w_{11}$ | (0.011,0.015,0.02) | $w_{21}$ | (0.036,0.042,0.048) | $w_{31}$ | (0.024,0.029,0.035) |
| $w_{12}$ | (0.027,0.033,0.039) | $w_{22}$ | (0.031,0.038,0.045) | $w_{32}$ | (0.016,0.02,0.026) |
| $w_{13}$ | (0.024,0.03,0.037) | $w_{23}$ | (0.033,0.038,0.045) | $w_{33}$ | (0.009,0.013,0.017) |
| $w_{14}$ | (0.021,0.028,0.035) | $w_{24}$ | (0.015,0.02,0.025) | $w_{34}$ | (0.029,0.034,0.04) |
| $w_{15}$ | (0.026,0.032,0.038) | $w_{25}$ | (0.027,0.033,0.039) | $w_{35}$ | (0.014,0.018,0.023) |
| $w_j$ | TFN | $w_j$ | TFN | $w_j$ | TFN |
| $w_{41}$ | (0.024,0.031,0.039) | $w_{51}$ | (0.014,0.02,0.026) | $w_{61}$ | (0.048,0.053,0.059) |
| $w_{42}$ | (0.008,0.013,0.018) | $w_{52}$ | (0.006,0.01,0.013) | $w_{62}$ | (0.05,0.055,0.061) |
| $w_{43}$ | (0.018,0.024,0.031) | $w_{53}$ | (0.02,0.026,0.032) | $w_{63}$ | (0.04,0.045,0.051) |
| $w_{44}$ | (0.01,0.015,0.021) | $w_{54}$ | (0.016,0.022,0.028) | $w_{64}$ | (0.022,0.028,0.034) |
| $w_{45}$ | (0.012,0.018,0.024) | $w_{55}$ | (0.009,0.014,0.018) | $w_{65}$ | (0.017,0.023,0.028) |

According to calculated results shown in Table 8, it can be concluded that legal ($w_{62}$, $w_{61}$, and $w_{63}$) and economic factors ($w_{21}$, $w_{23}$, and $w_{22}$) are the most significant within the PESTEL analysis with values of (0.05,0.055,0.061), (0.048,0.053,0.059), (0.04,0.045,0.051), (0.036,0.042,0.048), (0.033,0.038,0.045), and (0.033,0.038,0.045), respectively. Least significant factors are , $w_{33}$, $w_{42}$, and $w_{52}$ with values (0.009,0.013,0.017), (0.008,0.013,0.018), and (0.006,0.01,0.013) respectively.

## Conclusion

Quality and adequate functioning of healthcare systems are not only medical question, because depends on economic factors, environment, legal factors, political events, organization of the healthcare system, and others. For that reason we have implemented a novel integrated IMF SWARA-FDWGA-PESTEL model in this important field to can observe the real and current state of healthcare system taking into account political, economic, socio-cultural, technological, environmental, and legal factors. Strengths of the developed integrated model can be manifested through the possibility of its application in any area which considers various parameters and various solutions.

Results of PESTEL analysis based on IMF SWARA method and FDWGA shows that legal and economic factors represent the most significant parameters, while last placed belong environmental group. The contribution of the performed study can be observed from the following aspects: quantification of the PESTEL analysis, it is possible to find out how important and influential these factors are in the current situation in the healthcare system. Also, integration of PESTEL analysis with the IMF SWARA – FDWGA with PESTEL has been performed for the first time in the literature. Future research can be related to defining appropriate strategies for management of this healthcare system and developing a novel MCDM model for their evaluation.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 152-168*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta240322136m*

# NIGHT TRAFFIC FLOW PREDICTION USING K-NEAREST NEIGHBORS ALGORITHM

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Received: 31 December 2021
Accepted: 14 February 2022
First online: 24 March 2022

*Original scientific paper*

**Abstract:** *The aim of this research is to predict the total and average monthly night traffic on state roads in Serbia, using the technique of supervised machine learning. A set of data on total and average monthly night traffic has been used for training and testing of predictive models. The data set was obtained by counting the traffic on the roads in Serbia, in the period from 2011 to 2020. Various classification and regression prediction models have been tested using the Weka software tool on the available data set and the models based on the K-Nearest Neighbors algorithm, as well as models based on regression trees, have shown the best results. Furthermore, the best model has been chosen by comparing the performances of models. According to all the mentioned criteria, the model based on the K-Nearest Neighbors algorithm has shown the best results. Using this model, the prediction of the total and average nightly traffic per month for the following year at the selected traffic counting locations has been made.*

**Keywords**: *machine learning, traffic flow, prediction, K-Nearest Neighbors, Weka.*

## 1. Introduction

The accelerated urban development is faced with mobility challenges caused by increased transport of passengers and goods. The development of smart cities is based on the analysis of traffic data. They are used in dimensioning of road sections, connections and intersections, as well as dimensioning of road structures, environmental protection measures, economic and financial evaluation of projects, planning of management and maintenance of road infrastructure (Public Enterprise "Roads of Serbia", 2012). Monitoring the road network is one way to collect real-time traffic data. Various sensor technologies prevail in this type of data collection, such as technologies based on inductive loop detectors, laser radar sensors, etc. (Magalhaes et al., 2021).

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The monitoring of traffic flows is important, both because of monitoring of the traffic conditions in real time, and because of predicting the characteristics of traffic flows in the future (Janković et al., 2020). Time determinants, such as: a day of the week, an hour of the day, the dates of state and religious holidays, holiday vacations, and so on, are some of the factors that permanently influence the formation of the usual intensity of traffic flows. Some other factors, such as: weather conditions, road conditions, maintenance of road infrastructure (Sénquiz-Díaz, 2021), use of alternative routes and traffic accidents can influence the characteristics of traffic flows to change for the observed time interval. In the situation where the flow of vehicles exceeds the capacity of the road congestion occurs. Traffic congestion leads to: prolongation of time spent in transport, increase in transport costs, increase in emissions of harmful gases, passenger delays, as well as delays in the delivery of goods. Therefore, the prevention of traffic congestion is one of the most important goals of predicting the characteristics of traffic flows.

Supervised machine learning is a method of predictive analysis that enables prediction of future values of a target variable for independent attributes in the future, based on known values of the same target variable and known values of the same attributes in the past. Collection of traffic data provides opportunities for the development of supervised machine learning models which are going to be used to predict the characteristics of future traffic flows (Zhang et al., 2020; Park et al., 2018; Xu et al., 2013).

The forecasting of traffic flows has been the subject of numerous studies over the last two decades. The second section of this paper contains an overview of the most significant studies related to this subject. The authors of this paper have limited their research to detection of night traffic patterns and the prediction of night traffic (i.e. traffic in the time period from 22.00 hours to 06.00 hours). The purpose of this research is to examine the possibilities of short - term prediction of night traffic volume using the technique of supervised machine learning. The methodology according to which this research has been performed and the basic characteristics of the algorithm that has shown the best results in prediction (K-Nearest Neighbors, K-NN) are presented in the third section of this paper. The fourth section of the paper describes a case study realized within this research. In the case study predictive models have been created and the prediction of the total and average amounts of night traffic per month has been performed on selected road sections in Serbia. The data collected by automatic traffic counters (ATC) have been used in training and testing of machine learning models. The most significant results of the case study and discussion on the results are presented in the fifth section of the paper, while the last sixth section concludes the paper.

## 2. Literature Review

All models developed for traffic prediction can be broadly classified into three categories: parametric, nonparametric and hybrid types of models. Parametric models are e.g. historical average (Williams et al., 1998) time series models and Kalman filter (Guo & Williams, 2010). Seasonal autoregressive integrated moving average (ARIMA) is a classic parametric time series model used in the study (Williams & Hoel, 2003). In contrast, nonparametric models are mostly data-driven and use empirical prediction methods, including primarily Neural Networks models (Vlahogianni et al., 2005; Yasin

Çodur & Tortum, 2015), nonparametric regression (Marković et al., 2010; Cai et al., 2016), and Support Vector Machine (Zhang & Xie, 2008; Peng & Tang, 2015). In addition, the hybrid approach combines two or more models to generate predictions, e.g. non-linear chaotic prediction model (Wang & Shi, 2013), multiagent prediction model (Ma et al., 2001), modular network model (Vlahogianni et al., 2007), etc. The Karlaftis & Vlahogianni study (2011) compares traffic forecasting models based on parametric (statistical) methods and neural network-based models. Boukerche & Wang (2020) provide a classification and an overview of machine learning models used in traffic flow prediction. According to these authors, the mentioned models are divided into regression models, instance-based models (such as K-NN), kernel-based models (such as Support Vector Machine - SVM and Radial Basis Function - RBF), neural network models (such as Feed Forward Neural Network - FFNN, Recurrent Neural Network - RNN, Convolutional Neural Network - CNN) and hybrid models (combinations of two or more different models).

Shamshad & Sarwr (2020) developed a model for predicting traffic volume at an hourly level, using two machine learning algorithms: Artificial Neural Network (ANN) and SVM. Traffic data obtained with the help of road sensors, as well as data on meteorological conditions have been used to train and later test different machine learning models. This study shows that ANN-based machine learning models show good results in long-term predictions, while SVM-based models show good results in short-term predictions.

Zhang et al. (2013) have developed a nonparametric regression model, based on the K-NN algorithm on the MATLAB platform. The experimental results of this study show that the prediction accuracy of the highway traffic volume, using the K-NN method, is over 90 percent accurate. In the study (Zou et al., 2015) the authors show that, when applying K-NN methods in short-term traffic prediction, a much more accurate prediction is achieved if, in addition to temporal attributes, spatial attributes are included in independent attributes as well. In some studies, the basic K-NN method for short-term traffic prediction has been improved, in some way. For example "Specifically, two screening layers based on shape similarity were introduced in the K-nearest Neighbor non-parametric regression method, and the forecasting results were output using the weighted averaging on the reciprocal values of the shape similarity distances and the most-similar-point distance adjustment method. "(Pang et al., 2016). Zheng & Su (2014) have introduced a time limit when selecting the nearest Neighbors.

In the study (Liu et al., 2018), a short-term prediction of traffic volume has been performed using a hybrid model, based on the ANN and K-NN algorithms. Four types of ANN have been used: back-propagation (BP) neural network, radial basis function (RBF) neural network, generalized regression (GR) neural network, and Elman neural network. The K-NN method has been used to reconstruct a data set on which artificial neural networks have been trained, combining similar traffic flow patterns. By applying these ANNs to real traffic data two important conclusions have been reached: BP and GR neural networks show better prediction performance than the other two types of networks, but are sensitive to changing the scope of the training data set. On the other hand, the RBF and Elman neural networks show prediction results that are fairly stable when increasing the data set for training. The study (Toan & Truong, 2020) shows that applying K-NN methods to a training data set can significantly reduce the size of this data set, thus achieving faster model training using SVM methods, without affecting prediction performance.

In the research (Filipovska & Mahmassani, 2020) different models of machine learning for predicting traffic interruption have been developed and tested and their results have been compared to the results of traditional probabilistic approach.

Stojčić (2018) has given an overview of research in which the ANFIS (Adaptive Neuro-Fuzzy Inference System) model has been used in the prediction of traffic congestion. Zaki et al. (2016), as well as Shankar et al. (2012) take velocity and density as independent attributes and congestion level as a dependent variable in the prediction of congestion using the ANFIS model. Kukadapwar & Parbat (2015), among others, use traffic volume to roadway capacity ratio as an independent variable, while the target variable in their study is congestion index.

Recent research includes the application of deep learning methods in the prediction of traffic flow intensity (Wang et al., 2018). In the study (Lv et al., 2015) the application of a deep learning approach is demonstrated with stacked autoencoders (SAEs) to traffic data sets that have Big Data features. Alshaykha & Shaban (2021) combine the K-NN method and the Broad Learning System (KNN-BLS). "The basic structure of BLS is built on the traditional RVFLNN (Random Vector Functional-Link Neural Network), but unlike RVFLNN that directly uses the original input data to build an enhanced node, BLS first maps the input into a series of mapping nodes, and then uses the mapping node to build an enhanced node, and the mapping node and the enhanced node form joint Nodes, and finally combine the nodes and the output layer to establish a linear connection." (Alshaykha & Shaban, 2021). Mohammed & Kianfar (2018) have investigated the application of four categories of predictive methods in traffic flow prediction. The results obtained using distributed random forest method slightly exceed the results obtained using other methods.

## 3. Methodology

The machine learning process takes place in the following stages: data preparation, model training, model validation, model testing and prediction. It is an iterative process in which all of the above mentioned phases are repeated as many times as necessary. The repetition of these phases ends when all attribute combinations, all available algorithms and algorithm parameter values are exhausted, or when a satisfactory model performance is reached. Once the model testing shows that the model is successful, the use of the model in the prediction of the selected variable can begin.

The data preparation consists of: cleaning raw data from incomplete records or records with incorrect values, converting data into the appropriate format, etc.

The construction of the prediction models consists of:

1. Selection of the target variable, i.e. an attribute whose value should be projected using a machine learning model;
2. Selection of an algorithm, in accordance with the nature of the target variable and attributes;
3. Selection of relevant attributes of the data set;
4. Preparation of data sets for learning and testing of models, according to the requirements of the selected algorithm;

5. Model adjustment, i.e. values of hyperparameters specific to each type of machine learning algorithm;
6. Model learning – implies obtaining model's hyper-parameters through applying a training data set algorithm on the training data set.

Since the target variables of the data set used in this study are continuous, machine learning models based on the most popular regression algorithms have been built: Linear Regression, K-Nearest Neighbors, Decision Tree, Support Vector Machines for Regression (SMOreg), Neural Network.

In addition to model training and testing, a model validation has been performed in order to select the best type of model among multiple candidates, determine the optimal configuration of model parameters, and avoid problems known as overfitting and underfitting. Excessive matching refers to a situation in which prediction for instances from the training set has been perfectly learned through the model, but there is a very weak ability to predict instances that are slightly different from those learned. Insufficient matching refers to a case when there is failure to approximate training data through the model, so it shows poor performance even on a training data set.

An approach known as cross-validation has been used to validate a model. This approach to model performance evaluation uses only training data and consists of the following phases:

1. The available data set for model training is divided into K equal parts - folds. It is usually divided into 10 subsets (10-fold cross-validation).
2. The model is trained on K-1 subsets of data (e.g. on the first of K-1 subsets).
3. The model is evaluated on the only remaining (K-th) subset of data.
4. Steps 2 and 3 are repeated K times. In each iteration one part of the data is taken for the purpose of model validation, while the rest (K-1 parts) is used for learning. A different subset is always selected to be used for model validation.
5. Model performances are calculated as the arithmetic mean of the performances obtained in K iteration.

Success of the numerical prediction can be evaluated using different metrics (Witten et al., 2017). The projected values of the target variable, obtained for the set of instances for model validation are: $p_1, p_2, \ldots, p_n$; while the actual values of the target variables are: $a_1, a_2, \ldots, a_n$.

Mean-squared error - Eq. (1), is the average error.

$$Mean - squared\ error = \frac{(p_1-a_1)^2+\cdots+(p_n-a_n)^2}{n} \quad (1)$$

Mean-absolute error – Eq. (2), is the mean of the absolute value of the errors.

$$Mean - absolute\ error = \frac{|p_1-a_1|+\cdots+|p_n-a_n|}{n} \quad (2)$$

Root mean-squared error – Eq. (3), is calculated in an obvious way.

$$Root\ mean - squared\ error = \sqrt{\frac{(p_1-a_1)^2+\cdots+(p_n-a_n)^2}{n}} \quad (3)$$

Relative-squared error – Eq. (4) is the square root of the mean of the squared errors.

$$Relative - squared\ error = \frac{(p_1-a_1)^2+\cdots+(p_n-a_n)^2}{(a_1-\bar{a})^2+\cdots+(a_n-\bar{a})^2} \quad (4)$$

Root relative-squared error – Eq. (5), is calculated in an expected way.

$$Root\ relative - squared\ error = \sqrt{\frac{(p_1-a_1)^2+\cdots+(p_n-a_n)^2}{(a_1-\bar{a})^2+\cdots+(a_n-\bar{a})^2}} \quad (5)$$

Relative-absolute error – Eq. (6), is the total absolute error, with the same type of normalization.

$$Relative - absolute\ error = \frac{|p_1-a_1|+\cdots+|p_n-a_n|}{|a_1-\bar{a}|+\cdots+|a_n-\bar{a}|} \quad (6)$$

The last measure of prediction accuracy is the correlation coefficient - Eq. (7), which measures the statistical correlation between the values of $a$ and $p$. The correlation coefficient takes values from 1 for results that are completely correlated, over 0 when there is no correlation, to -1 when the results are in perfect negative correlation.

$$Correlation\ coefficient\ = \frac{S_{PA}}{\sqrt{S_P S_A}} \quad (7)$$

where $S_{PA}$, $S_P$ and $S_A$ are calculated as shown in (8):

$$S_{PA}\ = \frac{\sum_{i=1}^{n}(p_i-\bar{p})(a_i-\bar{a})}{n-1}, \quad S_P\ = \frac{\sum_{i=1}^{n}(p_i-\bar{p})^2}{n-1}, \quad S_A\ = \frac{\sum_{i=1}^{n}(a_i-\bar{a})^2}{n-1} \quad (8)$$

In the great number of empirical examples, the predictive model which is the best according to one measure is also the best in all other measures of error.

In order to predict the performances of models using unknown data, it is necessary to determine measures of their performance on a data set that did not play any role in model training. This previously uknown data set is entitled as the test data set.

The next phase is comparing the performances of models obtained on the test data set with the performances obtained on the training data set. This type of comparison enables to avoid a problem known as overfitting. If the performance of a model is good on training data but bad on the test data, then there is overfitting.

In order to predict the values of the selected target variables in the future, it is necessary to prepare an appropriate set of data and apply to it the machine learning model chosen as the best. In this research, the best results have been shown by machine learning models based on the K-NN algorithm.

The K-NN algorithm belongs to a class of supervised machine learning algorithms in model learning based on instances (Instance-Based Learning). In this class of algorithms, the classification of a new instance is done by comparing it with the most similar (the closest) instances in the training set (Aha et al., 1991). K is a parameter that indicates the number of most similar instances in the training set, with which the new instance is being compared. The K-NN algorithm belongs to the group of so-called lazy methods, because the decision on classification is postponed until the moment a new instance appears.

The main advantage of lazy methods is that they construct a different approximation of the objective function for each new instance that needs to be classified. Such local assessment of the objective function is suitable for complex objective functions. Because their models are slower to train than some other classes of algorithms, this algorithm is suitable for relatively "small" data sets. This feature of the K-NN algorithm has made it a good candidate for prediction in a case study conducted as part of this research.

In the Weka (Waikato Environment for Knowledge Analysis) software tool used in this study, the K-Nearest Neighbors algorithm has been implemented under the name IBk. Target variable (class), as well as attributes, with this algorithm can be: nominal, numerical, date or binary and missing values of class, as well as missing values of attributes are allowed. Thus, the K-NN algorithm is applicable both in solving classification problems and regression prediction problems. In this research, it has been applied to regression predictive analysis.

## 4. Case study

A Total of 391 automatic traffic counters have been installed on the network of state roads of the 1st category in the Republic of Serbia. Through automatic traffic counters vehicles are detected and classified in real-time, using inductive loops that are placed in the asphalt layer of the road structure. One such traffic counter is shown in Figure 1.

*Figure 1. Automatic traffic counter based on inductive loops*

The QLTC-10C counters continuously count and classify vehicles into ten categories, while QLTC-8C counters classify vehicles into eight categories. The QLTC-10C counters, classify vehicles into the following categories: A0 - Motorcycles, A1 - Passenger cars and Passenger cars with trailer, A2 - Combined vehicles and Combined vehicles with trailer, B1 - Light trucks and Light trucks with trailer, B2 – Medium heavy trucks, B3 - Heavy goods vehicles, B4 - Heavy goods vehicles with trailer, B5 - Semi-trailer trucks, C1 - Buses, C2 - Articulated buses, X - Uncategorized (other) vehicles.

For each vehicle it detects, the counter records: date, time, direction of vehicle movement, ordinal number of the vehicle on that day for the observed direction, traffic lane, vehicle category and vehicle speed. The obtained data is stored on SD (Secure Digital) memory cards.

In this case study data used have been obtained by automatic counting of traffic on state roads in Serbia at 21 counting points (Figure 2), in the period from 1.1.2011 to 31.12.2020. The research was done on 4 sections of the road (IA category (road 1) and IB category (roads 22, 23 and 46)). Selected counting places have the following marks, i.e. names: 1025 (Kraljevo 2), 1026 (Trstenik), 1027 (Pojate), 1046 (Vodice), 1050 (Prijanovci), 1052 (Pridvorica), 1057 (Prijepolje), 1156 (Mojsinje) , 1157 (Mrčajevci), 1183 (Trupale Bg-Ni), 1191 (Ineks), 1193 (Kneževići), 1194 (Zlatibor), 1195 (Kokin Brod 2), 1196 (Nova Varoš), 1198 (Gorjani), 1202 (Međuvršje ), 1207 (Prijepolje 2), 1208 (Velika Župa), 1225 (Lučina) and 1270 (Preljina).

*Figure 2. Traffic counting locations*

The purpose of the case study has been to predict two traffic intensity indicators: total monthly night traffic (TMNT) and average monthly night traffic (AMNT), at selected counting locations, using the method of supervised machine learning. The instances of the available data set are described by the following attributes: counter, year, month, TMNT and AMNT. The TMNT attribute represents the total number of vehicles that are registered by ABS at night (from 22.00 hours to 06.00 hours) during the period of one month. The AMNT attribute represents the average daily number of vehicles that are registered by ABS at night, on a monthly basis. In order to predict the total amount of night traffic per month models of machine learning, whose target variable is the TMNT attribute, have been created, while models whose target variable is the AMNT attribute have been created to predict the average night traffic per month. In both groups of machine learning models, the independent attributes are counter and month. The attribute year is used to classify the instances of the existing data set into two parts: for model training and for model testing. Instances relating to period from 2011 to 2017 have been selected as a set of data for model training, while instances relating to the period from 2018 to 2020 have been used for model testing.

Training, validation and testing of machine learning models have been performed in the data mining software Weka 3.9.5. This particular software represents a collection of machine learning algorithms used in discovery operations concerning data validity (Witten et al., 2017). It enables the performance of various data mining tasks, such as: data preparation for analysis, classification, regression analysis, clustering, learning through rules of association, selection of relevant attributes and data visualization. Each of these tasks is performed in a separate graphical user interface window of Weka software (Weka Explorer) and is opened by selecting the appropriate tab of Weka Explorer (Figure 3). The Preprocess window, shown in Figure 3, allows you to load and prepare the available data set for later analysis.

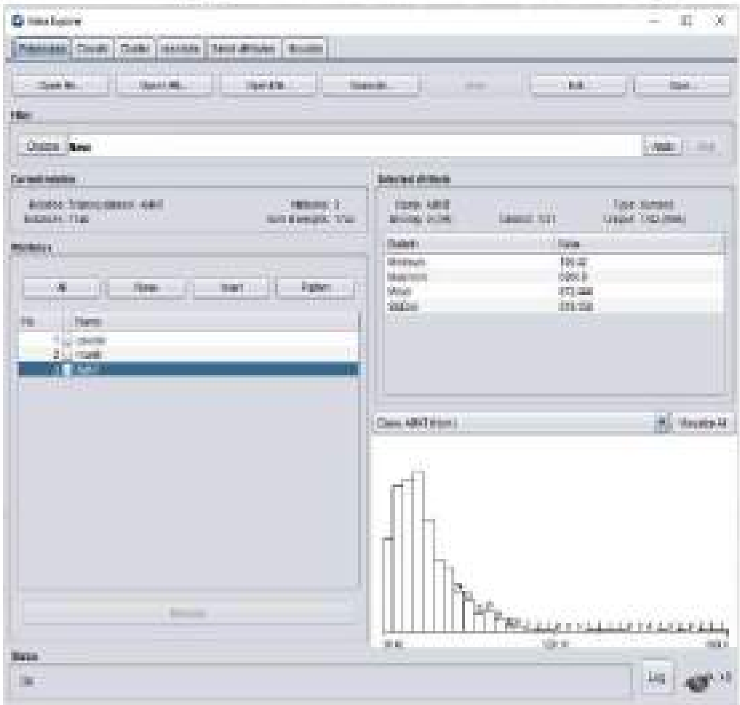

*Figure 3. Weka 3.9.5 software tool graphical user interface - data preparation window*

## 5. Results and Discussion

The following eight machine learning algorithms were to predict TMNT on the training data set in the Weka software tool: Linear Regression, Multilayer Perceptron, SMOreg, IBk (K-NN), M5P, Random Forest, Random Tree and REPTree. A 10-fold cross-validation, implemented in Weka software, has been applied to validate the model. The performance of the prediction model, measured on the training data set is shown in Table 1.

*Table 1. The performance of eight TMNT prediction models measured on a training data set*

| Algorithm | Correlation coefficient | Mean-absolute error | Root mean-squared error | Relativ-absolute error (%) | Root relativ-squared error (%) |
|---|---|---|---|---|---|
| LinearRegression | 0.6417 | 9718.52 | 14687.1 | 73.729 | 76.637 |
| MultilayerPerceptron | 0.6168 | 10197.2 | 15161.7 | 77.360 | 79.114 |
| SMOreg | 0.6373 | 9430.72 | 14931.6 | 71.546 | 77.914 |
| IBk | 0.9803 | 1985.10 | 3784.06 | 15.06 | 19.745 |
| M5P | 0.9434 | 4124.44 | 6840.50 | 31.29 | 35.694 |
| Random Forest | 0.9799 | 2004.84 | 3818.77 | 15.209 | 19.926 |
| Random Tree | 0.9803 | 1990.11 | 3784.91 | 15.098 | 19.749 |
| REPTree | 0.9701 | 2456.30 | 4650.40 | 18.634 | 24.266 |

Models based on Multilayer Perceptron, SMOreg algorithms, and Linear Regression have been rejected due to undoubtedly unsatisfactory performance (they had a correlation coefficient of 0.6417, 0.6168 and 0.6373, respectively). Therefore, in the next phase – in testing the machine learning model, the remaining five algorithms have been applied. The performance of these five prediction models, measured on a test data set is shown in Table 2. Comparing the metrics of the selected models, shown in Table 1 and Table 2, it is concluded that none of these models have a problem of overfitting. In addition, in all five models on the test data set, the correlation coefficient has high value.

*Table 2. The performances of the top five TMNT prediction models measured on a test data set*

| Algorithm | Correlation coefficient | Mean-absolute error | Root mean-squared error | Relativ-absolute error (%) | Root relativ-squared error (%) |
|---|---|---|---|---|---|
| IBk | 0.9391 | 4473.81 | 7373.93 | 32.8912 | 35.4526 |
| M5P | 0.8854 | 6238.81 | 10205.8 | 45.8673 | 49.0681 |
| Random Forest | 0.9382 | 4495.17 | 7438.49 | 33.0482 | 35.763 |
| Random Tree | 0.9391 | 4473.58 | 7374.1 | 32.8895 | 35.4534 |
| REPTree | 0.9303 | 4893.33 | 7833.42 | 35.9755 | 37.6618 |

Li & Xu (2021) propose a model for short-term traffic prediction based on the Support Vector Regression (SVR) method. The SVR method is based on the basic principles of the SVM method and is generalized for regression problems. The SVM method is implemented in Weka software called LibSVM. The SVR method in the Weka software tool is obtained by selecting the LibSVM classifier and one of its types: epsilon-SVR or nu-SVR. However, the LibSVM classifier applied to the training data set, in this case study, gave poor results (correlation coefficient: 0.0644 (epsilon-SVR) and 0.0281 (nu-SVR), respectively)). Therefore, the SVR algorithm was rejected in the first phase of this research.

In the research (Filipovska & Mahmassani, 2020) the best performance has been shown by models based on neural networks and SVM, if it is a case of class balancing. Without class balancing, the model based on a Random Forest algorithm has shown the best results. In this case study, the neural network model (MultilayerPerceptron) was rejected in the first phase because it showed worse results than all other models (Table 1). In contrast, the Random Forest algorithm showed excellent results in this case study, along with the IBk, Random Tree, and REPTree algorithms (Table 1 and Table 2).

The visualization of the prediction results received on the test data set has revealed that the model based on the IBk algorithm (K-NN) gives the results closest to the actual values. Therefore, the model based on the IBk algorithm has been selected as the best prediction model for TMNT. This case study confirmed the results of numerous studies, such as: Zhang et al. (2013), (Zou et al., 2015) and Zheng & Su (2014), which agree that the K-NN (IBk in Weka) algorithm gives excellent results in the short-term prediction of traffic flows.

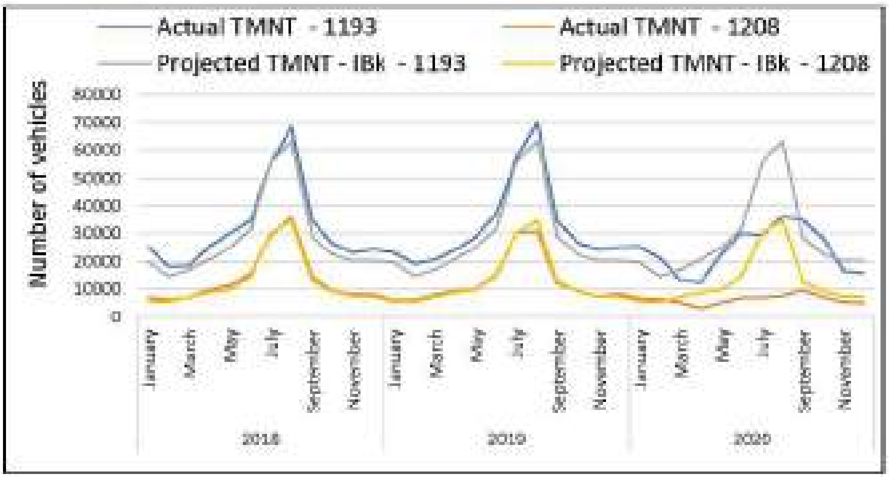


*Figure 4. Actual and projected total monthly night traffic (TMNT), at selected counters (ID: 1193 and ID: 1208), for the three selected years (2018, 2019 and 2020)*

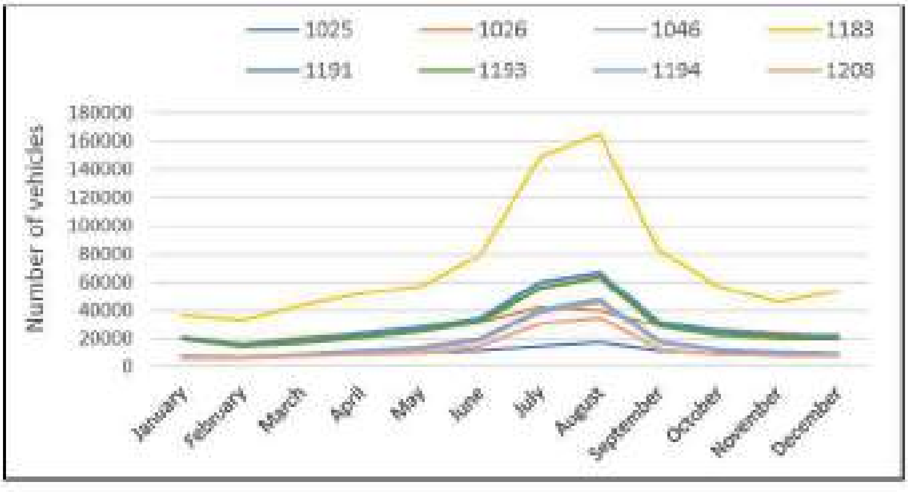


*Figure 5. Projected total monthly night traffic (TMNT) at selected counters for 2021*

The graph shown in Figure 4 shows the ratio of actual and projected TMNT for two selected traffic counting locations (1193 - Kneževići and 1208 - Velika Župa) and the period from 2018 to 2020. The TMNT projection has been performed using a model based on the IBk algorithm. The graph clearly shows that the TMNT prediction performed on the test data set closely follows the actual TMNT values in the observed period (Figure 4). The results of the TMNT prediction at eight selected traffic counting locations for 2021 are shown in Figure 5.

For AMNT prediction, the same eight machine learning algorithms have been applied to the training data set. The performance of the prediction models, measured on the training data set is shown in Table 3.

*Table 3. The performances of eight AMNT prediction models measured on a training data set*

| Algorithm | Correlation coefficient | Mean-absolute error | Root mean-squared error | Relativ-absolute error (%) | Root relativ-squared error (%) |
|---|---|---|---|---|---|
| LinearRegression | 0.6346 | 317.812 | 478.415 | 74.3936 | 77.2268 |
| MultilayerPerceptron | 0.608 | 334.371 | 494.495 | 78.2698 | 79.8224 |
| SMOreg | 0.6303 | 308.949 | 486.324 | 72.3191 | 78.5034 |
| IBk | 0.9801 | 64.9018 | 122.953 | 15.1922 | 19.8474 |
| M5P | 0.9445 | 133.975 | 220.096 | 31.3612 | 35.5284 |
| Random Forest | 0.9797 | 65.5395 | 124.075 | 15.3415 | 20.0285 |
| Random Tree | 0.9801 | 65.069 | 122.985 | 15.2314 | 19.8525 |
| REPTree | 0.9694 | 80.585 | 152.082 | 18.8634 | 24.5494 |

Models based on the Linear Regression, Multilayer Perceptron and SMOreg algorithms have been rejected due to unsatisfactory performance (correlation coefficients of 0.6346, 0.608 and 0.6303, respectively, have been recorded). Therefore, the remaining five algorithms have been applied in testing the machine learning model. The performance of these five prediction models, measured on the test data set is shown in Table 4. The best AMNT prediction model has been chosen in an identical manner as the best type of TMNT prediction model. The model based on the IBk algorithm has shown the best results this time, as well.

*Table 4. The performances of the top five AMNT prediction models measured on a test data set*

| Algorithm | Correlation coefficient | Mean-absolute error | Root mean-squared error | Relativ-absolute error (%) | Root relativ-squared error (%) |
|---|---|---|---|---|---|
| IBk | 0.939 | 146.428 | 239.814 | 33.1472 | 35.5591 |
| M5P | 0.8851 | 204.294 | 332.391 | 46.2465 | 49.2862 |
| Random Forest | 0.9381 | 147.128 | 241.896 | 33.3058 | 35.8678 |
| Random Tree | 0.939 | 146.420 | 239.819 | 33.1455 | 35.5599 |
| REPTree | 0.9286 | 161.299 | 257.180 | 36.5137 | 38.1342 |

The graph shown in Figure 6 shows the ratio of actual and projected AMNT for two selected traffic counting locations (1026 - Trstenik and 1046 - Vodice) and the period from 2018 to 2020. The AMNT projection has been performed using a model based on the IBk algorithm. The results of the AMNT prediction at eight selected traffic counting locations for 2021 are shown in Figure 7.

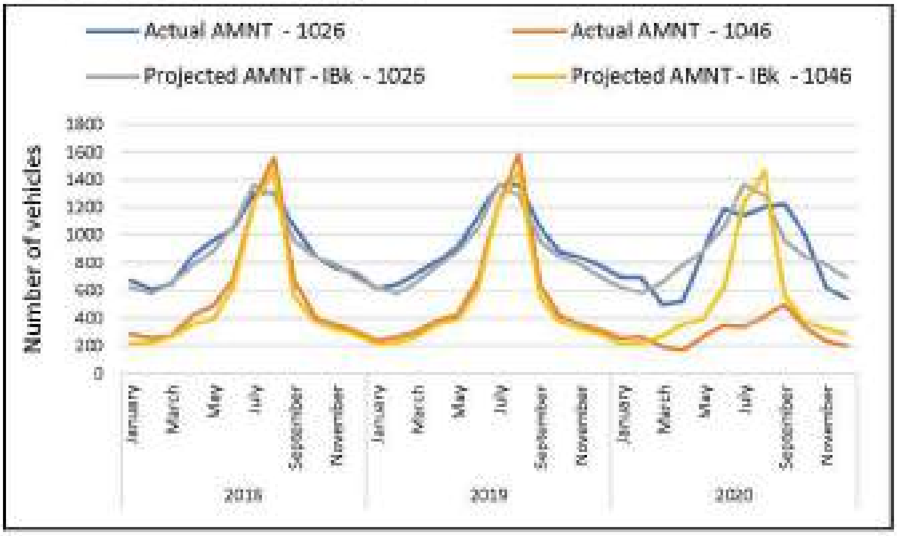


*Figure 6. Actual and projected average monthly night traffic (AMNT), at selected counters (ID: 1026 and ID: 1046), for the three selected years (2018, 2019 and 2020)*

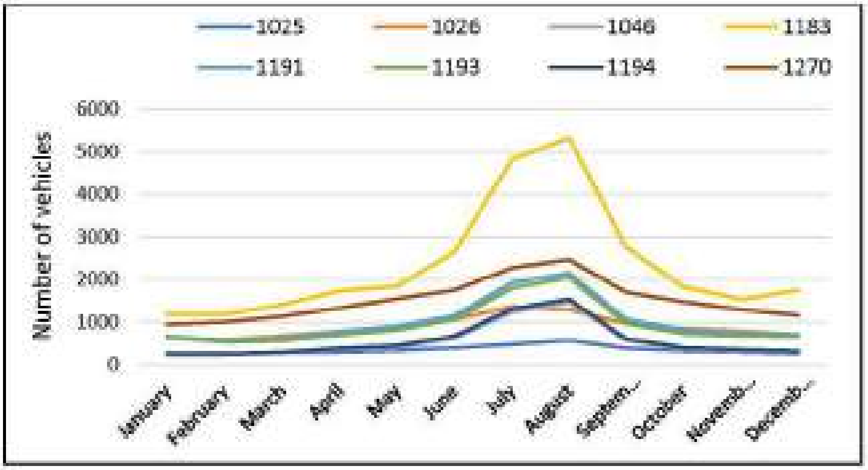


*Figure 7. Projected average monthly night traffic (AMNT) at selected counters for 2021*

In all the diagrams shown from Figure 4 to Figure 7, it is easy to see that the extreme values of TMNT, as well as of AMNT, occur for the months of July and August. This is because almost all counting places are located on the roads leading to popular tourist destinations, and July and August are the months when most people are on vacation and traveling.

## 6. Conclusion

The aim of this research has been to train and test predictive models on the existing data set on the volume of night traffic on state roads in Serbia and to predict the total and average amounts of night traffic per month for the following year.

In the conducted case study, using the Weka software tool, machine learning models for prediction of total monthly night traffic (TMNT) and average monthly night traffic (AMNT) have been trained, based on algorithms: Linear Regression, Multilayer Perceptron, SMOreg, IBk, M5P, Random Forest, Random Tree and REPTree. In the training data set, the IBk (K-NN) algorithm-based model and the models based on regression trees have shown a considerably better performance than the models from the functions category (Linear Regression, Multilayer Perceptron and SMOreg). Therefore, only these models have been tested on the test data set. The best performances have been shown by models based on the K-NN algorithm, so the prediction of TMNT and AMNT has been performed using these models. The case study has shown that the K-NN algorithm can be effectively applied in solving the problem of regression analysis of traffic data, even on relatively small data sets.

Future research will include the cluster analysis of traffic flows, especially the analysis of clusters in total and average monthly night traffic. As a result of this analysis, different patterns are expected in the volume of night traffic, on different sections of roads, at different periods of the year.

***Acknowledgement:*** This paper has been partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the project number 036012. The data used in the research have been provided by Public Enterprise "Roads of Serbia".

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 169-184*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta250322166r*

# MATHEMATICAL MODELLING OF NON-PERMUTATION FLOW SHOP PROCESSES WITH LOT STREAMING IN THE SMART MANUFACTURING ERA

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Received: 26 October 2021
Accepted: 21 March 2022
First online: 25 March 2022

*Research paper*

**Abstract:** *Industry 4.0 is leveraging the production capabilities of the industry. The deep digitalization that Industry 4.0 promotes enables to extend control skills to an exhaustive detail in the shop floors. Then, new planning strategies can be designed and implemented. We present mathematical models to represent non-permutation flow shop processes, incorporating Industry 4.0 features and customer-focused attention. Basically, we study the impact of lot streaming on the ensuing optimization problems, since the work-in-process inventory control is considerably enhanced by Industry 4.0 technologies. Thus, is possible to take advantage of subdividing the production lots into smaller sublots, as lot streaming proposes. To test this hypothesis we use a novel approach to non-permutation flow shop problems which requires a lot streaming strategy, incorporating total tardiness as objective function. Our analysis indicates that lot streaming improves results increasingly with the number of machines. We also find that the improvement is less steep with more sublots, increasing the computational cost of solutions. This indicates that it is highly relevant to fine tune the maximum number of sublots to avoid extra costs.*

**Key words**: *Scheduling, Mathematical Modelling, Non-Permutation Flow Shop, Lot Streaming, Industry 4.0, Total Tardiness.*

## 1. Introduction

Manufacturing systems have changed substantially in the last decade by the increasing digitalization of productive processes (Xu et al. 2018). This increases the accessibility, through the so-called Cyber-Physical Systems (CPS), to information that

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before remained confined inside the production machinery (Lee et al. 2015). With more access to information, often acquired in real time, it becomes possible to address more precisely decision problems that formerly could be only solved approximately (Dolgui et al. 2019). Thus, production planning processes can now be solved in a more efficient and integral way. Scheduling is one of the stages that will be more affected by the new technologies, since it is the last phase before starting the physical production (Ivanov et al. 2016; Bicakci & Kara 2019). Decision-making in scheduling involves solving NP hard problems, being thus at least as hard as any problem in which checking a solution requires polynomial time (Garey et al. 1976, Stanković et al. 2020). In this article we will focus on scheduling for non-permutation flow shop problems. Flow shop processes represent systems in which all the production orders are processed in the same sequence. That is, given a class $J$ of $n$ jobs (with $j$=1,2,...,$n$) and a set $M$ of $m$ machines (such tha $i$ =1, 2, ..., $m$), the operations on each job $j$ follows the same sequence 1, 2, ..., $m$ on machines. That is, the first operation on $j$ will be carried out on machine 1, the second on machine 2, and so on until the last operation is carried out by $m$ (Pinedo 2012). This is the production configuration applied by more than one quarter of the industries of the world (Pan et al. 2011).

Flow shop problems have been widely studied in the literature, but largely focusing on permutation sequences (Liao et al. 2006; Rossit et al. 2018). In those cases, a single ordering of the jobs is imposed over all the machines, i.e. on each machine $i$ all the $n$ jobs will be processed in the same order. For instance, given 4 jobs such that the processing sequence on the first machine is 2, 1, 3, 4, in the next machines the sequence will be the same (2,1, 3, 4). This condition does not respond to a production process rationale, since in general the machines can process the jobs in different sequences. The main reason for solving the problem restricted to permutation sequences is that the number of possible solutions is $n!$, while if this restriction is lifted, the number of possible cases raises to $n!^m$ (Potts et al. 1991). The general case, without the permutation constraint is that of non-permutation scheduling flow shop problems (NPFS). Note that the solutions to permutation scheduling problems constitute particular instances of NPFS solutions. The recent improvements in capacities for decision-making in production environments, makes the latter more treatable.

Nevertheless, to avoid the combinatorial explosion of seeking NPFS solutions, some strategies to reduce the search space are still needed. Our approach is to incorporate a technique that contributes to facilitate production activities, namely lot streaming (Trietsch & Baker 1993). In this treatment, the number of items to be produced by each job is partitioned such that each part is processed independently. Adding the lot streaming condition to flow shop problems has led to improved performances in the production processes (Sarin & Jaiprakash 2007; Cetinkaya & Duman 2021). Lot streaming does not require neither extra layouts nor new technologies (D'Amico et al. 2021), but demand more attention at the shop floor, since orders are now divided in several suborders. This division increases the demands on the information and control systems that have to keep track of more entities (Pan et al. 2011; Ferraro et al. 2019). It becomes thus interesting to analyze how this strategy may impact in the context of the new production environments where the information and control systems have been considerably enhanced. The implementation of lot streaming in non-permutation problems has not been widely analyzed, particularly when the focus is the quality of customer service. We analyze this problem in systems in which the compliance with the delivery date agreed on with the customer is the measure of the performance of the system.

The goal of this paper is to present new ways of addressing the problems of scheduling in the Industry 4.0 by focusing on the new challenges that the new paradigm poses for production planning processes. More specifically, this paper presents a novel MILP model for NPFS problems, where Total Tardiness is the objective function optimized by allowing lot streaming. This paper contributes to the literature on NPFS by presenting a concrete contribution, namely the introduction of new mathematical formulations and the ensuing results.

The rest of the paper is organized as follows. Section 2 introduces Industry 4.0 and decision making processes in that paradigm, and presents a brief NPFS literature review. Then, in Section 3, we develop new mathematical formulations, detailing their underlying assumptions. Section 4 presents and discusses the experimental design and the main results of our investigation.

## 2. Industry 4.0 concepts and Literature Review

In this section we review the relevant notions of Industry 4.0 needed for our analysis as well as the literature on lot streaming in non-permutation flow shop processes. Both issues become relevant in the last decade thanks to the technological advances that gave rise to the current fourth industrial revolution.

### 2.1. Industry 4.0 concepts

The main drivers of this revolution have been the Internet of Things (IoT) and Cyber-Physical Systems, which allow the connection among all the components in the shop floor, leading to the full digitalization of production. In this way, all the information generated in the production process becomes available to the different business functions of the firms (Xu et al. 2018; Dolgui et al. 2019). Figure 1 illustrates how different levels of decision-making, associated to the classical control of production structure ISA-95, are integrated by CPS.

The five levels of ISA-95 start at level 0, where the physical process of production is carried out (raw materials are transformed into end products). Next, level 1 is in charge of controlling the production tools, recording data as processing speed, temperatures of the tools and pieces, vibrations, etc. Level 2 incorporates control systems like PLC and SCADA, which can correct deviations in the production flow. At level 3 are the Manufacturing Execution Systems, in charge of production planning and quality control. At this level is where scheduling problems are solved and the compliance with the plan is monitored. Finally, the level 4, of Business Logistics Systems, takes care of the strategic decisions of the firm. CPS relate these systems by sharing their information among them, allowing its analysis in real time improving the global efficiency of decision-making (Lee et al. 2015; Grassi et al. 2020). This richness of information and the availability of powerful computing equipment at level 3 allow handling hard problems like NPFS.


*Figure 1. ISA-95 levels associated to CPS.*

### 2.2. Flow Shop Literature review and research gap

The literature on flow shop problems has a long history, starting with Johnson's first paper on the subject in 1954 (Johnson, 1954). While the largest part of that literature is centered on PFS, the branch devoted to NPFS is rich enough. A foundational result on these problems was published by Conway et al. (1967), which shows that when makespan is the objective function, permutation solutions are enough to yield the optimal schedule for up to 3 machines. In a much simpler way, this result had been stated already in (Johnson, 1954). This means that NPFS genuine solutions make sense for makespan maximization with more than 3 machines. Potts et al. (1991) studied instances in which NPFS solutions improve the makespan over PFS ones in

$\frac{1}{2}\sqrt{m}$ . Rebaine (2005) analyzed the ratio of the makespans of NPFS and PFS solutions in the presence of delays in the operations, showing that even with 2 machines PFS solutions cannot ensure the optimal result. Rossit et al. (2018b) studied the critical paths of NPFS and PFS solutions for 2 jobs and $m$ machines, while in (Rossit et al. 2021a) analyzed the processing times that allow PFS solutions to be better than NPFS ones, in the same case of 2 jobs and $m$ machines. Besides these theoretical contributions there are many empirical studies that show that under different settings NPFS solutions improve on those of PFS (Tandon et al. 1991; Strusevich & Zwaneveld 1994; Koulamas 1998; Jain & Meeran 2002; Nagarajan & Sviridenko 2009; Rudek 2011; Rossi & Lanzetta 2014; Benavides & Ritt 2016; Benavides & Ritt 2018).

As shown in Table 1, in most of these works the objective function is makespan. Only a few ones consider alternative goals, as for instance those related to delivery dates (for a more exhaustive list, see Rossit et al. 2018a). Liao et al. (2006) present a key result analyzing several single-objective functions and comparing the PFS and NPFS solutions: they show that NPFS solutions improve upon PFS ones, even for delivery date-related objective functions. Ying et al. (2010) ran a similar analysis and found that in the cases of delivery date functions, NPFS solutions improve over PFS ones even more than in the case of completion time-related functions. This is consistent with the findings of Liao & Huang (2010), who show that for total tardiness, NPFS solutions are indeed better than PFS solutions.

*Table 1. Main works related to Non-permutation flow shop scheduling. For further details see Rossit et al. 2018a.*

| Reference | NPFS | Lot streaming | Objective Function | Solution Approach |
|---|---|---|---|---|
| Potts et al. (1991) | ✓ | ✓ | Makespan | Exact |
| Tandon et al. (1991) | ✓ | x | Makespan | Heuristic |
| Strusevich & Zwaneveld (1994) | ✓ | x | Makespan | Exact |
| Koulamas (1998) | ✓ | x | Makespan | Heuristic |
| Jain & Meeran (2002) | ✓ | x | Makespan | Meta-Heuristic |
| Rebaine (2005) | ✓ | ✓ | Makespan | Exact |
| Liao et al. (2006) | ✓ | x | Total Tardiness (among others) | Meta-Heuristic |
| Nagarajan & Sviridenko (2009) | ✓ | x | Makespan | Exact |
| Liao & Huang (2010) | ✓ | x | Total Tardiness (among others) | Meta-Heuristic |
| Rudek (2011) | ✓ | x | Makespan | Exact |
| Ziaee (2013) | ✓ | x | Total weighted tardiness | Heuristic |
| Rossi & Lanzetta (2014) | ✓ | x | Makespan | Meta-Heuristic |
| Rossit et al. (2016) | ✓ | ✓ | Makespan | Exact |
| Benavides & Ritt (2016) | ✓ | x | Makespan | Heuristic |
| Rossit et al. (2018b) | ✓ | x | Makespan | Exact |
| Benavides & Ritt (2018) | ✓ | x | Makespan | Heuristic |
| Rossit et al. (2021a) | ✓ | x | Makespan | Exact |
| Rossit et al. (2021b) | ✓ | x | Total Tardiness | Meta-Heuristic |
| CURRENT STUDY | ✓ | ✓ | Total Tardiness | Exact |

Ziaee (2013) addressed NPFS with setup times depending on the schedule, under the goal of minimizing the Total Weighted Tardiness, by applying a two-stage method. The first stage yields a permutation solution while in the second stage a non-permutation local search improves it. Rossit et al. (2021b) studied NPFS problems in Industry 4.0 environments with missing operations, optimizing total tardiness, showing that NPFS solutions improved over PFS ones in average, in 98% of the cases. This indicates that NPFS solutions are relevant in digital manufacturing environments. Interestingly enough, there are no contributions analyzing NPFS problems with lot streaming and delivery date-related objective functions. As far as we know Rossit et al. (2016) is the only one that applies lot streaming strategies to find non-permutation schedules, but with makespan as objective function. We intend, thus, to extend that line of analysis, studying the same problem but under objective functions appropriate for production systems focused on the customer, as for instance seeking the minimization of total tardiness. These features are highlighted in the last row of Table 1, indicating that the current one is the only study incorporating NPFS and lot streaming as well as Total Tardiness as objective function.

## 3. Mathematical models

In this section we discuss the mathematical formulation of our problem. Since it involves Industry 4.0 and client-oriented production system (Wang et al. 2017; El Hamdi et al. 2019; Perez et al. 2022) some of the classical assumptions in the analysis of scheduling problems must be replaced. For instance, production orders are no longer make-to-stock but make-to-order, and thus, will not be released in bulk but according to demand. Then, the release date becomes a relevant feature of jobs. Other assumptions about this scheduling problem are:

- Preemption is not allowed
- Each machine can process only one job (or sublot) at a time
- Each job (or sublot) can be processed by only one machine at a time
- Processing times are standard and deterministic

We follow here the notion of Graham et al. (1979), in which $F\left|r_j\right|\sum_j T_j$

corresponds to NPFS without lot streaming, while $F\left|r_j, lot\ streaming\right|\sum_j T_j$ denotes the problem with lot streaming.

### 3.1. NPFS without lot streaming

**Sets**

$J$: Jobs, indexed by $\{j\}$

$M$: Machines, indexed by $\{i\}$

**Parameters**

$p_{i,j}$ processing time of unit of job $j$ at the machine $i$

$r_j$ release date of job $j$

$d_j$ due date of job $j$

$U_j$ Lot size of items produced by job $j$

$st_{i,j}$ setup time for processing job $j$ at machine $i$.

$\Omega$ a positive large number

**Variables**

$C_{ij}$ Completion time of job $j$ at machine $i$.

$T_j$ tardiness of job $j$.

$x_{j'ji}$ binary, 1 if job $j'$ is processed before job $j$ at machine $i$, 0 otherwise.

$$\min z = \sum_{j=1}^{n} T_j \quad (1)$$

$$C_{ij} \geq C_{(i-1)j} + p_{ij} \cdot U_j + st_{ij} + tr_{ij}, \quad \forall j, i > 1 \quad (2)$$

$$C_{ij} \geq C_{ij'} + p_{ij} \cdot U_j + st_{ij} - \left(1 - x_{j'ji}\right) \cdot \Omega, \quad \forall i, j \neq j' \quad (3)$$

$$x_{j'ji} + x_{jj'i} = 1, j \neq j' \quad (4)$$

$$C_{ij} \geq r_j + p_{ij} \cdot U_j + st_{ij}, \quad i = 1, \forall j \quad (5)$$

$$T_j = \max\left\{0, d_j - C_{(i=m)j}\right\}, \quad \forall j \quad (6)$$

$$T_j, C_{ij} > 0; x_{ij} \in \{0,1\} \quad (7)$$

Expressions (1)-(7) characterize the problem. (1) indicates the objective function, the minimization of total tardiness (which is computed according to equation (6)). Inequality (2) represents the precedence restriction: a job cannot be processed by machine $i$ until the processing has finished in machine $i$ - 1. Inequality (3) indicates that a job $j$ can be processed by machine $i$ after job $j'$ has released $i$, if and only if $j'$ precedes $j$ in the sequence. Equation (4) is the logic constraint according to which if job $j'$ precedes job $j$ on machine $i$, the opposite cannot be the case. Inequality (5) represents a capacity constraint on the first machine, according to which no job cannot start its processing before a request has been received in the form of a due release date, and the completion time depends on all the activities involved in its processing. Equation (6) determines the tardiness of each job with respect to its due date, considering only positive values of tardiness. Finally, (7) are the feasibility conditions on the variables.

### 3.2. NPFS with lot streaming

We have to introduce the expressions that correspond to the incorporation of lot streaming strategies. We keep expressions (1), (4) (6) and (7) of the previous subsection, while (2), (3) and (5) have to be adapted to consider sublots. Some additional constraints are also needed.

**Sets**

F: sublots, indexed by {f}

**Parameters**

$tr_{i,j}$ transfer time of a sublot of job j from machine i to machine i + 1.

$stm_{i,j}$ setup time for processing a sublot of job j at machine i.

**Variables**

$C_{i,f,j}$ Completion time of sublot f of job j at machine i.

$s_{f,j}$ sublot size of sublot f of job j.

$$\sum_{f=1}^{F} s_{fj} = U_j, \ \forall j \qquad (8)$$

$$s_{fj} \le y_{fj} \cdot \Omega, \quad \forall f, j \qquad (9)$$

$$C_{i(f=1)j} \ge C_{(i-1)(f=1)j} + p_{ij} \cdot s_{(f=1)j} + st_{ij} + tr_{ij}, \ \forall j, i > 1 \qquad (10)$$

$$C_{i(f=1)j} \ge C_{i(f=F)j'} + p_{ij} \cdot s_{(f=1)j} + st_{ij} - \left(1 - x_{j'j}\right) \cdot \Omega, \ \forall i, j \ne j' \qquad (11)$$

$$C_{i(f=1)j} \ge C_{i(f=F)j'} + p_{ij} \cdot s_{fj} + stm_{ij} \cdot y_{fj}, \ \forall i, j, f = 2, \ldots, F-1 \qquad (12)$$

$$C_{ifj} \ge C_{i(f-1)j} + p_{ij} \cdot s_{fj} + y_{fj} \cdot \left(stm_{ij} + tr_{ij}\right), \ \forall f, j, i = 2, \ldots M-1 \qquad (13)$$

$$C_{i(f=1)j} \ge r_j + p_{ij} \cdot s_{(f=1)j} + st_{ij}, \ i = 1, \forall j \qquad (14)$$

Expression (8) indicates that all the units of job *j* must be included in a sublot *f* of *j*. Since sublots are not fixed (i.e. the size of the sublots is determined by the optimization process), inequality (9) detects the non-empty sublots which require setups and displacement times. Equation (10) is a precedence inequality analogous to (2): the first sublot of a product cannot be processed by machine *i* until it has been finished at machine *i* – 1. (11) captures the same constraint as (3), namely that job *j* can be processed after *j'* has released machine *i*, if and only if *j'* precedes *j* in the sequence. This is done considering the first and last sublots of *j* and *j'*, $f = 1$ and $f = F$, respectively. Inequality (12) orders the sublots of the same job to be processed sequentially at a given machine. In turn, equation (13) indicates that a sublot cannot be processed simultaneously by two different machines. Constraint (14) replaces (5) ensuring that the first sublot of a job will not be processed until its release date has been received.

## 4. Experiments and results

We present here the experiment design and the results obtained by using exact methods (CPLEX). These experiments are in order to compare the models with and without lot streaming, analyzing the impact of using lot streaming strategies.

### 4.1. Experimental design

We aimed to detect whether including lot streaming strategies improve results in Industry 4.0 environments. In order to do that, we tested problems of different sizes (in jobs and machines) and different numbers of sublots. The number of jobs chosen was 4, 6, 8 and 10, as well as 3, 5 and 10 machines. We covered all the possible combinations yielding 12 different problems. In turn, for the problems with lot streaming we considered different numbers of sublots. To incorporate a larger number of sublots implies to extend the range of $f$, increasing the number of instances of expressions (8) – (14), with the consequence of enlarging the computation cost of analyzing the problems. For $f$ we chose 2, 3, 4 and 5, meaning that we had to solve 48 problems.

For the parameters defined in subsections 3.1 and 3.2 we selected the following values:

$p_{i,j}$ uniform distribution [1;5] (it corresponds to processing each unit of $U_j$).

$r_j$ uniform distribution [1;50]

$U_j$ uniform distribution [1:22]

$st_{i,j}$ uniform distribution [10;25]

$tr_{i,j}$ uniform distribution [1;4]

$stm_{i,j}$ uniform distribution [1;10]

For $d_j$ we used the following rule: $d_j = r_j + \sum_{i=1}^{m} p_{ij}$ .

Five data sets are generated for all the combinations of machines, jobs and sublots. Each data set corresponds to a well-defined problem where each parameter takes a value drawn from one of the probabilistic distributions presented above. Then, each problem is solved deterministically by CPLEX12.10, with a time limit of 3.600 seconds. The experiments are performed on an Intel Core i5-7200U PC with 8GB of RAM.

### 4.2. Results

Our analysis starts by considering the results on the impact of using lot streaming to solve an NPFS problem with total tardiness as objective function. Table 2 shows the value of the objective function with plain NPFS solutions and the improvement resulting from using lot streaming strategies. The improvements are expressed as percentages.

*Table 2. Improvement in the value of the objective function, with respect to the different number of sublots allowed. Results correspond to the average of all the runs.*

| *N* | *m* | NPFS | NPFS-lot streaming | | | |
|---|---|---|---|---|---|---|
| | | | 2*f* | 3*f* | 4*f* | 5*f* |
| 4 | 3 | 521 | 60.7% | 61.4% | 61.4% | 61.4% |
| | 5 | 768 | 27.1% | 35.4% | 37.0% | 37.2% |
| | 10 | 1241 | 90.7% | 95.2% | 98.5% | 100.0% |
| 6 | 3 | 1149 | 39.1% | 42.1% | 42.2% | 42.2% |
| | 5 | 1504 | 18.9% | 23.5% | 24.3% | 24.5% |
| | 10 | 2219 | 73.3% | 83.5% | 85.4% | 86.0% |
| 8 | 3 | 2058 | 30.0% | 30.2% | 30.2% | 30.2% |
| | 5 | 2523 | 12.3% | 15.9% | 16.0% | 16.0% |
| | 10 | 3513 | 60.9% | 69.9% | 72.0% | - |
| 10 | 3 | 3136 | 24.0% | - | - | - |
| | 5 | 3721 | - | - | - | - |
| | 10 | 4796 | - | - | - | - |

Table 2 shows clearly that lot streaming has a considerable impact in improving the objective function. In many cases those improvements are over 50%, and for some case, like the case of 4 jobs and 10 machines, the result is 100% better when 5 sublots are allowed for each job. This means that no product was delivered at a late date, complying with the agreed on delivery dates while without lot streaming total tardiness was 1241. Also in the cases where the improvement is not that large, it is over 10%, meaning that the whole system performance can be enhanced without requesting new machines or doubling resources, just exploiting production planning strategies.

These enhancements are related to the number of sublots: the more the lot is split in sublots, the larger the resulting improvement. This can be observed by comparing at Table 2, at the same row, moving to the right. Nevertheless, this improvement is not monotonic, since it reaches a maximum. The largest variations from a number of sublots to the next one obtain at the transition from no lot streaming to allowing 2 sublots. The improvement from further increases in the number of sublots is less pronounced. On the downside, notice that incorporating lot streaming strongly increases the computational cost of finding exact solutions. This can be seen in Table 2 by the use of "-" in the cases in which no satisfactory solution is found after an hour of running the solver. We mean by "satisfactory" here a solution that yields a better result with the incorporation of more sublots. So, for instance, if with 2 sublots total tardiness is 1136, when we increase the division to up to 3 sublots, the result will be less than 1136 (since the case of up to 3 sublots includes the case of 2).

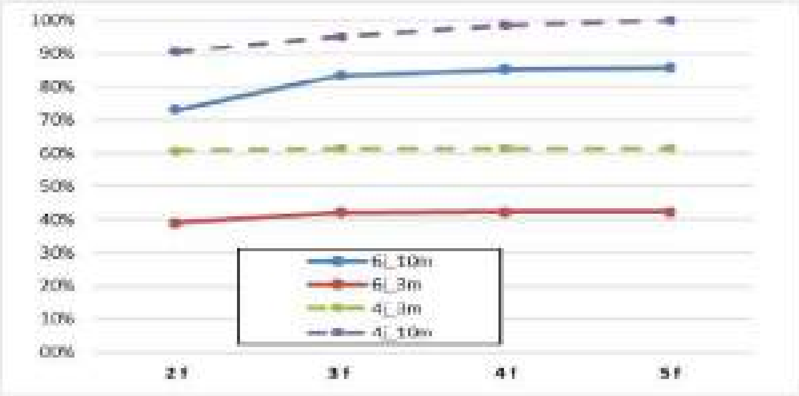


*Figure 2. Lot streaming objective function improvement with respect to different numbers of sublots*

On the other hand, the impact of lot streaming varies with the size of the problem. Figure 2 depicts the results for problems with 4 jobs and 3 and 10 machines, (dotted lines) and 6 jobs with 3 and 10 machines (solid lines). We can see that keeping the number of jobs fixed, lot streaming yields better results with more machines. In turn, if we fix the number of machines, a larger number of jobs worsen the objective function. Finally, all the curves have the same shape, with decreasing marginal increases as a function of the number of allowed sublots. That is, there seems to be a saturation number of sublots, after which the objective function no longer improves. We can analyze this more clearly seeing Table 3.

*Table 3. Number of sublots used in final solutions. (The values are presented in average).*

| *N* | *m* | *f_allowed* | *f_used* |
|---|---|---|---|
| 4 | 3 | 2 | 1.8 |
| | | 3 | 2.05 |
| | | 4 | 2.05 |
| | | 5 | 2.05 |
| | 5 | 2 | 1.95 |
| | | 3 | 2.65 |
| | | 4 | 3.1 |
| | | 5 | 3.25 |
| | 10 | 2 | 2 |
| | | 3 | 2.9 |
| | | 4 | 3.25 |
| | | 5 | 3.25 |
| 6 | 3 | 2 | 1.93 |
| | | 3 | 2.03 |
| | | 4 | 2.1 |
| | | 5 | 2.1 |
| | 5 | 2 | 1.97 |
| | | 3 | 2.6 |

| | | | |
|---|---|---|---|
| | | 4 | 2.73 |
| | | 5 | 2.93 |
| | 10 | 2 | 2 |
| | | 3 | 2.97 |
| | | 4 | 3.53 |
| | | 5 | 3.71 |
| 8 | 3 | 2 | 1.6 |
| | | 3 | 1.65 |
| | | 4 | 1.75 |
| | | 5 | 1.75 |
| | 5 | 2 | 1.93 |
| | | 3 | 2.58 |
| | | 4 | 2.75 |
| | | 5 | 2.75 |
| | 10 | 2 | 2 |
| | | 3 | 2.78 |
| | | 4 | 3.53 |
| | | 5 | - |
| 10 | 3 | 2 | 1.5 |

Table 3 shows that, even if a number of sublots are allowed, the optimal value of the objective function can be reached using fewer sublots. As shown by Table 2, we can see that allowing more sublots may improve the results in certain cases, but with an increasing computational cost. It is, thus, highly relevant to determine the useful maximal number of sublots that may allow to benefit from adding lot streaming to the search of solutions to NPFS.

*Table 4. Average CPU time for solving each problem to optimality.*

| *N* | *m* | *NPFS* | *NPFS-lt* | | | |
|---|---|---|---|---|---|---|
| | | | *2 f* | *3 f* | *4 f* | *5 f* |
| **4** | **3** | <sec | <sec | <sec | <sec | <sec |
| | **5** | <sec | <sec | 1,0 | 1,0 | 2,0 |
| | **10** | <sec | <sec | 2,0 | 2,0 | 2,0 |
| **6** | **3** | <sec | <sec | <sec | <sec | 1,0 |
| | **5** | <sec | <sec | 1,0 | 2,0 | 2,0 |
| | **10** | <sec | 1,0 | 2,0 | 3,0 | 3,0 |
| **8** | **3** | <sec | <sec | <sec | 1,0 | 2,0 |
| | **5** | 1,0 | 1,0 | 2,0 | 10,0 | 191,0 |
| | **10** | 1,0 | 1,0 | 3,0 | 11,0 | 429,0 |
| **10** | **3** | 2,0 | 1,0 | 4,0 | 4,0 | >3600 |
| | **5** | 2,0 | >3600 | >3600 | >3600 | >3600 |
| | **10** | 3,0 | >3600 | >3600 | >3600 | >3600 |

For a deeper analysis we examine the computational behavior of the problem according to the features of the problem (number of machines, jobs and allowed sublots). The results are shown in Table 4. It can be seen that for any problem size, lot streaming has a direct impact on the computational effort, increasing the time demanded to solve the problem. This effect is proportional to the maximum number of sublots allowed. The larger the number of allowed sublots, the larger the CPU time required by the solver to yield the optimal solution.

### 4.3. Discussion of results and future developments

Let us consider the cases in which allowing more sublots per job is associated to a reduction in the value of the objective function (Table 2), for instance, in the case of 4 jobs and 10 machines. In this case if we consider the information provided by Table 3, the average number of sublots does not change (it remains fixed at 3.25) when the maximum allowed number of sublots increases from 4 to 5 sublots. On the other hand, the objective function corresponding to these problems (Table 2) yields a lower value in the case of 5 allowed sublots than in the case of 4 sublots. This means that when the maximum number of sublots remains fixed at 4, some jobs are divided into 4 sublots (the average is over 3), but when 5 sublots are allowed the average is the same. This can be explained by the fact that when 5 sublots are allowed, some jobs that were split into 4 sublots in the case of a maximum of 4 sublots can now be divided into 5 sublots while some other jobs are split into 3 sublots. The composition of sublots must change, because the value of the objective function changes. This prevents us from considering that the solution structure will remain the same for both maximum numbers of sublots.

## 5. Conclusions

In this article we analyze the introduction of lot streaming to find optimal schedules in Industry 4.0 environments focused on the requests of customers. We seek non-permutation solutions appropriate to flow shop problems. We found that incorporating lot streaming strategies improves results, reducing the total tardiness of delivery. We detected that subdividing the number of items in more sublots has cumulative beneficial effects up to a point. Afterwards, adding more sublots does not improve further the results. On the other hand, the computational cost of lot streaming is considerably larger than those of finding solutions without lot streaming.

The main conclusion it that while some jobs can be divided into several sublots, others are more resistant to be split. If the jobs can be classified by their features (number of units, accumulated processing times, due dates, etc.), the optimizing process can be fine-tuned to allow more sublots only for the types of jobs that require them while keeping as low as possible the number of sublots of the other types. This will reduce the number of variables, and consequently the computational burden of the optimization process. But classifying jobs requires further research since the analyses presented here do not provide enough information on the best way of doing it.

This opens up the possibility of focusing the computational effort (in terms of variables and number of sublots) on those jobs. But detecting them may require a further and deeper analysis. A promising future line of research involves the possibility of running first a parametric analysis of the different types of instances to identify which jobs require this special attention. It would be interesting to design modelling tools able to take advantage of this hypothesis, orienting the computational resources (in terms of variables and restrictions) to those jobs that may need them rather than to the entire set of jobs.

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*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 5, Issue 1, 2022, pp. 185-204*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI: https://doi.org/10.31181/oresta040422196m*

# A NEW FUZZY GARCH MODEL TO FORECAST STOCK MARKET TECHNICAL ANALYSIS

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Received: 15 January 2022
Accepted: 14 March 2022
First online: 04 April 2022

*Original scientific paper*

***Abstract:*** *Decision making process in stock trading is a complex one. Stock market is a key factor of monetary markets and signs of economic growth. In some circumstances, traditional forecasting methods cannot contract with determining and sometimes data consist of uncertain and imprecise properties which are not handled by quantitative models. In order to achieve the main objective, accuracy and efficiency of time series forecasting, we move towards the fuzzy time series modeling. Fuzzy time series is different from other time series as it is represented in linguistics values rather than a numeric value. The Fuzzy set theory includes many types of membership functions. In this study, we will utilize the Fuzzy approach and trapezoidal membership function to develop the fuzzy generalized auto regression conditional heteroscedasticity (FGARCH) model by using the fuzzy least square techniques to forecasting stock exchange market prices. The experimental results show that the proposed forecasting system can accurately forecast stock prices. The accuracy measures RMSE, MAD, MAPE, MSE, and Theil-U-Statistics have values of 18.17, 15.65, 2.339, 301.998, and 0.003212, respectively, which confirmed that the proposed system is considered to be useful for forecasting the stock index prices, which outperforms conventional GARCH models.*

***Key words***: *Fuzzy time series, Membership function, trapezoidal fuzzy approach, GARCH model, Forecasting.*

## 1. Introduction

Forecasting is a significant feature in economics, commerce, various branches of science and marketing. It is a technique that predicts the future behavior of output on the basis of present and past output of yield and past trends. The economy of a nation to a great extent relies on upon capital business sector on upon capital

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business sector, forecasting of stock market and their drifts are important factor in attaining significant gains in financial market. In capital and derivative pricing, investment plans, fund distribution and risk control processes, the accurately computation and prediction of financial- volatility plays a vital role (Franke & Westerhoff, 2011; Haugom, Langeland, Molnár, & Westgaard, 2014; A. Y. Huang, 2011), also fuzzy-Garh models for forecasting financial volatility (Hung, 2011a, 2011b; Maciel, Gomide, & Ballini, 2016). The stock price has deep impact in financial event of the country and large-scale economics approach. However, predicting and forecasting the stocks trading, prices and movement is not an easy task because of the serious impact of full-scale financial variable, including general monetary condition, political interference, financial specialist's decision, sudden and unexpected change in security exchanges. Apart from the statistical models that have been used to understand and forecast variations in the stock market, a lot of attention has also been shifted to the applications of various soft computing application. There are different time series models proposed by the different researchers. Due to appropriateness and efficiency Fuzzy time series models are used in different studies (Bisht, Joshi, & Kumar, 2018; Iqbal & Zhang, 2020; Yu, 2005). Fuzzy set theory, provides an authoritative framework to handle with vague or ambiguous problems and can express linguistic values and human subjective decisions of natural language, (Zadeh, 1965). Fuzzy time series was first presented by (Song & Chissom, 1993, 1994). Furthermore, many fuzzy time series models were developed by researchers using different theories (Chen & Tanuwijaya, 2011; Egrioglu, Bas, Yolcu, & Chen, 2020; Hassan et al., 2020; Iqbal, Zhang, Arif, Hassan, & Ahmad, 2020; Lu, Chen, Pedrycz, Liu, & Yang, 2015; Wang, Lei, Fan, & Wang, 2016; Xiao, Gong, & Zou, 2009). Some analysts developed FTS forecsting models using probabilistic fuzzy set theory and reported significant results (Gupta & Kumar, 2019; W.-J. Huang, Zhang, & Li, 2012). Some fuzzy forecasting models in the environment of intuitionistic fuzzy set theory with equal length intervals are developed by (Abhishekh, Gautam, & Singh, 2018),(Bas, Yolcu, & Egrioglu, 2021) and also some work with unequal length intervals introduced by (Lei, Lei, & Fan, 2016) and (Iqbal & Zhang, 2020). In Addition, a novel method to forecast time series data was introduced by (Soto, Melin, & Castillo, 2018), using ensembles of IT2FNN models with fuzzy integrator optimization. There also some studies in which fuzzy based forecasting techniques are compared with classical models like ARIMA (Iqbal, Zhang, Arif, Wang, & Dicu, 2018). Technical analysis is a tool to predict future stock value developments by analyzing the past succession of stock costs. The generalized autoregressive conditional heteroscedasticity (GARCH) model is one of the famous econometric models used to estimates the volatility in financial market, stock markets. GARCH model is an econometric model, to describe an appropriate approach to estimate the in-monetarist markets volatility in monetarist markets, (Engle, 1982).

GARCH models are useful across an extensive range of applications, also they do have boundaries as this model is only part of a solution. Although these models are usually applied to return series, financial decisions are rarely based solely on expected returns and volatilities. These models are parametric specifications that operate best under relatively stable market conditions. GARCH is explicitly designed to model time-varying conditional variances, Generalized Auto-Regressive Conditional Heteroscedasticity models often failed to capture highly irregular phenomena, including wild market fluctuations (e.g., crashes and subsequent rebounds), and other highly unanticipated events that can lead to significant structural change. GARCH models often fail to fully capture the fat tails distribution observed in asset return series. A fat-tailed distribution is a probability distribution that has the property, along with the other heavy-tailed distributions, that its revelations excess skewness or kurtosis. This comparison is often made relative to the normal distribution, or to the exponential distribution. Heteroscedasticity explains some of the fat tail behavior, but typically not all of it. Fat tail distributions, such as student-t, have been applied in GARCH modeling, but often the choice of distribution is a matter of trial and error. For this purpose, fuzzy model is proposed known as Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (FGARCH) model in this paper. Although several fuzzy GARCH models based on different statistical and machine learning approaches are developed, such as (Hung, 2009, 2011a; Popov & Bykhanov, 2005), and (Maciel et al., 2016), but our proposed Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (FGARCH) model is the best option because it is useful in investment on assets returns but also operates best under wide market fluctuation.

In this paper, a new fuzzy model is proposed known as Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (FGARCH) with fuzzy least square techniques and fuzzy trapezoidal approach. The motivation to use trapezoidal membership function is that it outperforms the different types of membership functions when it comes to develop a fuzzy-model for decision making and applicable to real-world applications. The proposed fuzzy model is the best option because it is useful in investment on assets returns but also operates best under wide market fluctuation. The objectives of the current study are explained as: (i) to estimate the unknown parameter by using the Generalized Auto-Regressive Conditional Heteroscedasticity and forecasting fuzzy models, (ii) to articulate the fuzzy model by using the fuzzy least square technique, (iii) to evaluate the comparison between forecast produced from classical model and proposed fuzzy model and also select the best performance model from them.

The remaining paper comprises in the following stages. First section describes the introduction part. Second section briefly explains the earlier work done by the researchers in classical and fuzzy forecasting model. In third section, briefly described the methodology of the classical econometric model "Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH)" and fuzzy model "Proposed Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (FGARCH)"by using fuzzy least square method. This section also comprises concept of limitation in Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH), perceptive to move towards fuzzy model. Fourth section included the results obtained from classical and proposed models with comparing the efficiency of the both models by using different endorsements.

## 2. Basic Theories

### 2.1. Fuzzy Set

A fuzzy set $\tilde{Z}$ in the universe of information U can be defined as a set of ordered pairs and it can be represented mathematically as

$$Z^{\sim} = \{(x, \mu Z^{\sim}(x)) | x \in U\} \tag{1}$$

Here $\mu_{\tilde{Z}}(x)$ is degree of membership of x, which assumes values in the range from 0 to 1, i.e., $\mu_{\tilde{Z}}(x) \in [0,1]$.

### 2.2. Trapezoidal membership function

Trapezoidal membership function is described using the following equation

$$T(x; a, b, c, d) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{d-x}{d-c} & c \le x \le d \\ 0 & d \le x \end{cases} \tag{2}$$

Where, **x** represents real value within the universe of discourse. **a, b, c, d** represent a x- coordinates of the four heads of trapezoidal and values should validate the following condition a<b<c<d.

### 2.3. Fuzzy Time Series

The first time (Zadeh, 1965), proposed the fuzzy set theory, it provides a authoritative framework to handle with vague or ambiguous problems and can express linguistic values and human subjective decisions of natural language. Time series models had failed to consider the application of forecasting theory until fuzzy time-series was defined by (Song & Chissom, 1993, 1994).

## 3. Proposed Fuzzy-Based Methodology

### 3.1. Generalized Auto-Regressive Conditional Heteroscedasticity (p,q) Model

The generalized autoregressive conditional heteroscedasticity (GARCH) process is an econometric term proposed in 1982 by Robert F. Engle, an economist. In the year 2003, awarded by the Nobel Memorial Prize for Economics, to propose an approach to econometric model to estimate volatility in monetary markets.

Engle (Engle, 1982) and (Bollerslev, 1986) proposed the Generalized ARCH (p,q) model. The general representation of GARCH (p,q) process $(\varepsilon_t)$ is defined as,

$$\varepsilon_t = v_t \cdot \sqrt{h_t}, \tag{3}$$

where $v_t$: is white noise with $\sigma_v^2 = var(v_t) = 1$ and

$$h_t = \omega_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 + \sum_{j=1}^{p} \beta_j h_{t-1} \tag{4}$$

Where, in Eq. (4), $\omega_0$ is a constant, $\sum_{i=1}^{q}\alpha_i\varepsilon_{t-1}^2$ shows the Auto-regressive conditional heteroscedasticity term, $\sum_{j=1}^{p}\beta_j h_{t-1}$ shows the generalized autoregressive conditional heteroscedasticity term with the parameters $\alpha_0, \alpha_1, \ldots, \alpha_q$ and $\beta_0, \beta_1, \ldots, \beta_p \geq 0$. If $\sum_{i=1}^{q}\alpha_i + \sum_{i=1}^{p}\beta_i$, the shocks have a decaying impact of the future volatility (Fryzlewicz, 2007).

The general process for a GARCH model involves three steps. The first is to estimate a best-fitting of Auto-regressive model. The second is to compute Auto-correlations of the error terms. The third step is to test for implication. Two other widely used approaches to estimate and predict the financial volatility are the classic historic volatility method, and the exponentially weighted moving average volatility method.

Heteroscedasticity describes the irregular pattern of variation of an error terms, or variable, in a statistical model. In data where heteroscedasticity present, observations do not confirm to a linear pattern, instead, they tend to clusters. The result is that the conclusions and predictive values drawn from the model will not be reliable. GARCH an econometric model, that can be used to analyze a number of different types of financial data series, for instance, macroeconomic data. Financial institutions classically use this model to estimate the volatility of stock returns, bonds and market indices. They resulting information helps to determine the pricing and as well as supports to judge that, which assets will potentially provide higher returns. Furthermore, it helps to forecast the returns of current investments to support in their asset allocation, hedging, risk management and portfolio optimization decisions.

### 3.2. Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity

Proposed fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity Model is given as follows with fuzzy parameters:

$$\tilde{h}_t = \omega_0 + \tilde{\alpha}_1\varepsilon_{t-1}^2 + \tilde{\alpha}_2\varepsilon_{t-2}^2 + \ldots + \tilde{\alpha}_q\varepsilon_{t-q}^2 + \tilde{\alpha}_1 h_{t-1} + \tilde{\alpha}_2 h_{t-2} + \ldots + \tilde{\alpha}_p h_{t-p} \quad (5)$$

In the Eq. (5) $\tilde{h}_t$ is the estimated fuzzy variable used as output variable, $(\tilde{\alpha}_1, \tilde{\alpha}_2, \ldots, \tilde{\alpha}_{q+1}, \ldots, \tilde{\alpha}_{p+q})$ are the parameters with $q$ term known as fuzzy Auto-correlation parameters and fuzzy parameters with $p$ term known as fuzzy partial-Autocorrelation. The impreciseness and conciseness have been tackled by connecting parameters with $p$ and $q$ order into fuzzy parameters.

#### *3.2.1. Fuzzy Least Square Approach*

Fuzzy least square approach is an accumulation form of ordinary least square technique. This technique incorporates of goodness of fit and requires a distance between the fuzzy values estimated by the model and vague data that is really pragmatic. Mathematically it is expressed as:

$$d(\alpha_0, \alpha_1) = \left[\int_0^1 f(\eta) d^2\{(\alpha_0, \alpha_1)\eta\} d\eta\right]^{1/2}$$

where $\alpha_0$ *and* $\alpha_1$ are two fuzzy numbers. $\alpha_0$ is a trapezoidal fuzzy number with four points such as $\alpha_0 = \{a_{0w}, a_{0r}, a_{0u}, a_{0v}\}$ and $\alpha_1$ is another trapezoidal fuzzy number with four points such that $\alpha_1 = \{a_{1w}, a_{1r}, a_{1u}, a_{1v}\}$, and $f(\eta)$ is the weighting function for determining the distance square between two fuzzy numbers. In both fuzzy numbers $\alpha_0$ *and* $\alpha_1$, parameters $a_{0w}, a_{1w}$ represent the left fuzzy points, $a_{0r}, a_{1w}$ represent the left center points, $a_{0u}, a_{1w}$ represent the right center fuzzy points, $a_{0v}, a_{1w}$ represented the right fuzzy points.

### *3.2.2. Estimation of Parameter of Model by Fuzzy Least Square Approach*

The parameter of model is estimated by using the fuzzy least square method to gain a unique solution. The fuzzy least square method is defined by the sum of error distance between observed value $O_t(\eta)$ and estimated output value $E_t(\eta)$. Mathematically sum of error distance is represented as:

$$SSE = \sum_{t=1}^{q} \{d[O_t(\eta), E_t(\eta)]\}^2 \tag{6}$$

Where, in Eq. (6) $d(O_t(\eta), E_t(\eta))$ is mathematically represented as:

$$d(O_t(\eta), E_t(\eta)) = [\int_0^1 f(\eta) d^2((O_t)_\eta, (E_t)_\eta) d\eta]^{\frac{1}{2}} \tag{7}$$

where index $t$ denotes the non-fuzzy series of data used in observed value input $O_t(\eta)$ and estimated output value $E_t(\eta)$.

$$E_t(\eta) = \{f(a_w), f(a_r), f(a_u), f(a_v)\}$$

Now from the equation, each fuzzy parameter converted into a generalized auto-regressive conditional heteroscedasticity in the form of functions given below:

$$f(a_w) = \varepsilon_0 + \sum_{i=1}^{q} a_w \varepsilon_{t-i}^2 + \sum_{j=1}^{p} a_w h_{t-j}, \tag{8}$$

$$f(a_r) = \varepsilon_0 + \sum_{i=1}^{q} a_r \varepsilon_{t-i}^2 + \sum_{j=1}^{p} a_r h_{t-j}, \tag{9}$$

$$f(a_u) = \varepsilon_0 + \sum_{i=1}^{q} a_u \varepsilon_{t-i}^2 + \sum_{j=1}^{p} a_u h_{t-j}, \tag{10}$$

$$f(a_v) = \varepsilon_0 + \sum_{i=1}^{q} a_v \varepsilon_{t-i}^2 + \sum_{j=1}^{p} a_v h_{t-j}, \tag{11}$$

where in the above equations, $f(a_m)$ represent the left point function, $f(a_r)$ represent the left center point function, $f(a_u)$ represent the right center function, and $f(a_v)$ represent the right point function.

Now, estimated output value $E_t(\eta)$ expressed on $E_t(\eta) = [L_0, L_1]$, with $\alpha$-cut fuzzy interval for trapezoidal number can be represent as:

$$E_t(\eta) = [\{f(a_r) - f(a_m)\}\eta + f(a_m), f(a_v) - \eta\{f(a_v) - f(a_u)\}], \tag{12}$$

Similarly, observed value is $O_t(\eta)$ expressed on $O_t(\eta) = [L_0, L_1]$, such as

$$L_0 = \{f(a_r) - f(a_m)\}\eta + f(a_m), L_1 = f(a_v) - \eta\{f(a_v) - f(a_u)\}, \tag{13}$$

where $L_0$ represent the lower bound and $L_1$ represent the higher bound.

Now using the values, the observed and estimated output value is obtained by the sum of square error distance: $SSE = \sum_{i=1}^{q} d[O_t(\eta), E_t(\eta)]^2$. In the above expression, $d[O_t(\eta), E_t(\eta)]$ stands the square distance between the observed and estimated output which is shown as given below:

$$d^2(O_t(\eta), E_t(\eta)) = [L_0 - \{[f(a_r) - f(a_m)]\eta + f(a_m)\}]^2 +$$
$$[L_1 - \{f(a_u) + \eta[f(a_u) - f(a_v)]\}]^2$$

Now putting the above expression and weighting function in sum of square error (SSE) equation which is given below:

$$SSE = \sum_{i=1}^{q} \int_0^1 f(\eta)\, [L_0 - \{[f(a_r) - f(a_m)]\eta + f(a_m)\}]^2 \times |\varepsilon_{t-1} - h_{t-j}| +$$

$$[L_1 - \{f(a_u) + \eta[f(a_u) - f(a_v)]\}]^2 \times |\varepsilon_{t-1} - h_{t-j}|\, d\eta, \tag{14}$$

Using the equation (12) for finding the partial derivation with respect to $a_m, a_r, a_u$ *and* $a_v$ to the get simplified form of equations given as:

$$\sum_{i=1}^{q} 2\int_0^1 \eta(\eta-1)x_{ij}\left[L_0-\{f(a_i)-f(a_{ie})\}\eta+f(a_{ie})\right]d\xi=0 \tag{15}$$

$$\sum_{i=1}^{q} 2\int_0^1 \eta^2 x_{ij}\left[-L_0+\{f(a_i)-f(a_{ie})\}\eta+f(a_{ie})\right]d\xi=0, \tag{16}$$

$$\sum_{i=1}^{q} 2\int_0^1 \eta\; x_{ij}\left[-L_1+f(a_i)-\eta\{f(a_i)-f(a_{ii})\}\right]d\eta=0, \tag{17}$$

$$\sum_{i=1}^{q} 2\int_0^1 \eta(\eta-1)x_{ij}\left[L_1-f(a_i)+\eta\{f(a_i)-f(a_{ii})\}\right]d\eta=0 \tag{18}$$

Now by solving the integral of the above equations and putting the values in the equations encompassing the following equation:

$$a_{m_0}\sum_{i=1}^{q}x_{i0}x_{ij}+a_{m_1}\sum_{i=1}^{q}x_{i1}x_{ij}+\Lambda+a_{m_1}\sum_{i=1}^{q}x_{i_p}x_{ij}$$

Where $x_{i0}$=1 and $j=0,1,2,\Lambda\ p$ after simplification, the standard form of above equation is given as:

$$a_{m_0}\sum_{i=1}^{q}x_{i0}x_{ij}+a_{m_1}\sum_{i=1}^{q}x_{i1}x_{ij}+\Lambda+a_{m_1}\sum_{i=1}^{q}x_{i_p}x_{ij}=\sum_{i=1}^{q}c_i x_{ij}.$$

Now

$$a_r\sum_{i=1}^{q}x_{i0}x_{ij}+a_{r_1}\sum_{i=1}^{q}x_{i1}x_{ij}+\Lambda+a_{r_p}\sum_{i=1}^{q}x_{i_p}x_{ij}$$

Where $x_{i0}$=1 and $j=0,1,2,\Lambda\ p$ after simplification, the standard form of above equation is:

$$a_r\sum_{i=1}^{q}x_{i0}x_{ij}+a_{r_1}\sum_{i=1}^{q}x_{i1}x_{ij}+\Lambda+a_{r_p}\sum_{i=1}^{q}x_{i_p}x_{ij}=\sum_{i=1}^{q}k_i x_{ij}.$$

Now

$$a_{u_0}\sum_{i=1}^{q}x_{i0}x_{ij}+a_{u1}\sum_{i=1}^{q}x_{i1}x_{ij}-\Lambda+a_{u_p}\sum_{i=1}^{q}x_{i_p}x_{ij}$$

Where $x_{i0}$=1 and $j=0,1,2,\Lambda\ p$ after simplification, the standard form of above equation is:

$$a_{u_0}\sum_{i=1}^{q}x_{i0}x_{ij}+a_{u1}\sum_{i=1}^{q}x_{i1}x_{ij}+\Lambda+a_{u_p}\sum_{i=1}^{q}x_{i_p}x_{ij}=\sum_{i=1}^{q}g_i x_{ij}. \tag{19}$$

$$a_{v_0}\sum_{i=1}^{q} x_{i0}x_{ij} + a_{v_1}\sum_{i=1}^{q} x_{i1}x_{ij} + \Lambda + a_{v_n}\sum_{i=1}^{q} x_{i_n}x_{ij}$$

Where $x_{i0}=1$ and $j = 0,1,2,\Lambda\ p$ after simplification, the standard form of above equation is:

$$a_{v_0}\sum_{i=1}^{q} x_{i0}x_{ij} + a_{v_1}\sum_{i=1}^{q} x_{i1}x_{ij} + \Lambda + a_{v_n}\sum_{i=1}^{q} x_{i_n}x_{ij} = \sum_{i=1}^{q} s_i x_{ij} \qquad (20)$$

In these above equations i=1, 2..., q, $c_i, k_i, g_i,$ *and* $s_i$ are the outcomes of integral calculation of the above equations. These simple form of equations (15), (16), (17), (18) are represented in the form of matrix.

$$\left.\begin{aligned} A_m &= C \\ A_r &= K \\ A_u &= G \\ A_v &= S \end{aligned}\right\} \qquad (21)$$

In Eq. (21), *m* represents the left point matrix, *r* represents the left center point matrix, *u* represent the right center point matrix, *v* and represent the right center point matrix of trapezoidal membership function. Where *C, K, G* and *S* represent the matrix which are obtained after solving the integral. These matrixes are represented as:

$$m = \{a_{m_0}, a_{m_1}\Lambda\ a_{m_n}\}^T, \quad C = (\sum_{i=1}^{q} C_{i-1}x_{i-1} + \Lambda)^T$$

$$r = \{a_{r_0}, a_{r_1}\Lambda\ a_{r_n}\}^T, \quad K = (\sum_{i=1}^{q} K_{i-1}x_{i-1} + \Lambda)^T$$

$$u = \{a_{u_0}, a_{u_1}\Lambda\ a_{u_n}\}^T, \quad G = (\sum_{i=1}^{q} G_{i-1}x_{i-1} + \Lambda)^T$$

$$v = \{a_{v_0}, a_{v_1}, \Lambda\ a_{v_n}\}^T, \quad S = (\sum_{i=1}^{q} S_{i-1}x_{i-1} + \Lambda)^T$$

where $A = X^T X$ and $X = \begin{bmatrix} 1 & \cdots & x_{1_h} \\ \vdots & \ddots & \vdots \\ 1 & \cdots & x_{q_h} \end{bmatrix}$ matrix, X is a data matrix and A is the positive definite with rank = n+1. If matrix $A = X^T X$, then inverse of matrix A can be easily determined. Then equation problem consists of unique solution:

$m = A^{-1}C$ , $\quad r = A^{-1}K$ , $\quad u = A^{-1}G, v = A^{-1}S$

## 4. Computational Analysis

The stock prices index of Gold as input variable from year 2009 to 2017 is given in Appendix A.

*Step 1.* In our proposed model, possibility of successes is given into five linguistic terms, each linguistic term is represented by the degree of trapezoidal fuzzy numbers. For example,

*Very low interval*

$l_1$= [0.0551 0.0726 0.0826 0.0996]

$$l_1 = \begin{cases} 0 & x < 0.0551 \\ \frac{x-0.0551}{0.0726-0.0551} & 0.0551 \le x \le 0.0726 \\ 1 & 0.0726 \le x \le 0.0826 \\ \frac{0.0996-x}{0.0996-0.0826} & 0.0826 \le x \le 0.0996 \\ 0 & x > 0.0996 \end{cases}$$

$l_1$= [$0.0551 - 0.0275(1-\eta)$ $\quad 0.0996 + 0.0275(1-\eta)$]

Low interval

$l_2$= [ 0.0826 0.0996 0.1271 0.1441]

$$l_2 = \begin{cases} 0 & x < 0.0826 \\ \frac{x-0.0826}{0.0996-0.0826} & 0.0826 \le x \le 0.996 \\ 1 & 0.0996 \le x \le 0.1271 \\ \frac{0.1441-x}{0.1441-0.1271} & 0.1271 \le x \le 0.1441 \\ 0 & x > 1322.5 \end{cases}$$

$l_2$= [$0.0826 - 0.0275(1-\eta)$ $\quad 0.1441 + 0.0275(1-\eta)$]

Similarly, other computations are also computed regarding average interval, high interval and very high interval, and further arranged the linguistic variable according to the order as follows

i. $\widetilde{K}_{verylow_k}$ = $l_1$= [$0.0551 - 0.0275(1-\eta)$ $\quad 0.0996 + 0.0275(1-\eta)$]

ii. $\widetilde{K}_{low_k}$ = [$0.0826 - 0.0275(1-\eta)$ $\quad 0.1441 + 0.0275(1-\eta)$]

iii. $\widetilde{K}_{average_k}$ = [$0.1271 - 0.0275(1-\eta)$ $\quad 0.1886 + 0.0275(1-\eta)$]

iv. $\widetilde{K}_{high_k}$ = [$0.1716 - 0.0275(1-\eta)$ $\quad 0.2226 + 0.0275(1-\eta)$]

v. $\tilde{K}_{veryhigh_i} = [0.2056 - 0.0275(1-\eta) \qquad 0.2671 + 0.0275(1-\eta)]$

The above expression (i), (ii), (iii), (iv) and (v) shows very low, low, average, high and very high possibility of success for the nth observations. Each linguistics variables are represented as observed prospective output.

*Step 2.* Now, used the partial derivation of Eqs. (12), (13), (14) and (15) which is show into a following simplified form of equation given as:

$$\sum_{i=1}^{g} 2\int_0^1 \eta(\eta-1)x_{ij} \left[L_0 - \{f(a_r) - f(a_m)\}\eta + f(a_m)\right] d\xi = 0$$

$$\sum_{i=1}^{g}\left[\frac{1}{2}x_{ij}f(a_m) - x_{ij}L_0\right] = 0 \tag{22}$$

$$\sum_{i=1}^{g} 2\int_0^1 \eta^2 x_{ij} \left[-L_0 + \{f(a_r) - f(a_m)\}\eta + f(a_m)\right] d\xi = 0,$$

$$\sum_{i=1}^{g}\left[4x_{ij}L_0 - 5f(a_r)x_{ij} + f(a_m)x_{ij}\right] = 0 \tag{23}$$

$$\sum_{i=1}^{g} 2\int_0^1 \eta \; x_{ij}[-L_1 + f(a_v) - \eta\{f(a_v) - f(a_u)\}]d\eta = 0,$$

$$\sum_{i=1}^{g}\left[\frac{2}{3}f(a_u)x_{ij} - L_1x_{ij} + \frac{1}{3}f(a_v)x_{ij}\right] = 0 \tag{24}$$

$$\sum_{i=1}^{g} 2\int_0^1 \eta(\eta-1)x_{ij}[L_1 - f(a_v) + \eta\{f(a_v) - f(a_u)\}]d\eta = 0$$

$$\sum_{i=1}^{g}\left[\frac{1}{2}f(a_v)x_{ij} - L_1x_{ij}\right] = 0 \tag{25}$$

*Step 3.* After solving the integral and putting the values of above equations we get the matrix form of equations shown as:

$$m = A^{-1}C, \qquad r = A^{-1}K, \qquad u = A^{-1}G, \qquad v = A^{-1}S$$

where

$A = X^T X$

and $X = \begin{bmatrix} 1 & \cdots & x_{1_h} \\ \vdots & \ddots & \vdots \\ 1 & \cdots & x_{q_h} \end{bmatrix}$,

Matrix A is the positive definite with rank = n+1. If matrix $A = X^T X$, then inverse of matrix A can be easily determined. Then equation problem consists of unique solution.

$$A=\begin{bmatrix} 0.2032 & -0.0482 & -0.0173 & 0.0737 & 0.0532 & -0.0626 & 0.0613 & 0.0387 \\ -0.0482 & 0.4229 & 0.3145 & -0.1760 & 0.4474 & 0.4718 & -0.2032 & -0.5697 \\ -0.0173 & 0.3145 & 0.3816 & -0.1533 & 0.3684 & 0.3459 & -0.1657 & -0.5291 \\ 0.0737 & -0.1760 & -0.1533 & 0.1481 & -0.1800 & -0.2208 & 0.1043 & 0.2478 \\ 0.0532 & 0.4474 & 0.3684 & -0.1800 & 0.7109 & 0.5123 & -0.2705 & -0.5616 \\ -0.0626 & 0.4718 & 0.3459 & -0.2208 & 0.5123 & 0.7365 & -0.1598 & -0.7122 \\ 0.0613 & -0.2032 & -0.1657 & 0.1043 & -0.2705 & -0.1598 & 0.2270 & 0.1765 \\ 0.0387 & -0.5697 & -0.5291 & 0.2478 & -0.5616 & -0.7122 & 0.1765 & 1.1042 \end{bmatrix}$$

*"Very Low" Opportunity of Interval*

The possibility of very low interval for the $N^{th}$ observation is written as:

$$\widetilde{K}_{verylow_t} = l_1 = [0.0551 - 0.0275(1-\eta)\ 0.0996 + 0.0275(1-\eta)] \qquad (26)$$

Using equation (26), interval of very low possibility for the $N^{th}$ observation is to estimate the observed value at different η values. Here we have selected the η values that lies between [0, 1] from table .After putting the value of η = 0.086 in the equation (26), we have evaluated the value of $L_0 = -0.073$ and $L_1 = 0.0361$

Now following the procedure described in section 3 of this paper, the estimated model of "very low opportunity interval" obtained from observations is shown as:

$\widetilde{h}_t$ = (26.523 32.7861 42.667 103.37) + (25.409 32.014 51.406 101.881) $\varepsilon^2_{t-1}$ + (15.1531 27.179 36.716 82.8758) $\varepsilon^2_{t-2}$ + (28.355 34.023 45.5677 106.771) $\varepsilon^2_{t-3}$ + (22.942 31.841 42.475 123.931) $\varepsilon^2_{t-4}$ + (25.043 29.587 38.879 79.749) $h_{t-1}$ + (30.048 43.198 65.913 131.927) $h_{t-2}$ + (22.945 38.4413 64.478 92.9316) $h_{t-3} + h_\varepsilon$

The above equation of model represents the "Very Low" linguistic category case that consist of fuzzy parameter in the form of trapezoidal membership function parameters. Similarly, at other levels, the possibility intervals can be computed by following this procedure.

*Step 4. Fuzzy logical relationships*

To find the fuzzy logical relationship, fuzzified datasets are arranged according to the years. The fuzzified values are given in table 1.

*Table 1. Actual prices of Gold stock index with sets of fuzzy*

| Years | Stock index Prices (returns*100) | Fuzzy Sets |
|---|---|---|
| 2010 | 1.485 | $F_4$ |
| 2011 | 60.39 | $F_{31}$ |
| 2012 | 21.89 | $F_{12}$ |
| 2013 | 44.96 | $F_{28}$ |
| 2014 | 29.064 | $F_{13}$ |
| 2015 | 99.956 | $F_{55}$ |
| 2016 | 69.98 | $F_{41}$ |
| 2017 | 13.88 | $F_{15}$ |

Fuzzy logical relationships are designed from above fuzzified datasets and are presented in table 2. According to the rule of fuzzification, if the time series observation F(t-1) is fuzzified as $F_4$ in year 2010 and F(t) as $F_{31}$ in year 2011, then $F_4$ is mapping into $F_{31}$. In the same manner sets of fuzzy $F_{31}$ in year 2011 is interrelated to $F_{12}$ in year 2012, sets of fuzzy $F_{12}$ in year 2012 is interrelated to $F_{28}$ in year 2013, sets of fuzzy $F_{28}$ in year 2013 is interrelated to $F_{13}$ in year 2014, sets of fuzzy $F_{13}$ in year 2014 is interrelated to $F_{55}$ in year 2015, sets of fuzzy $F_{55}$ in year 2015 is interrelated to $F_{41}$ in year 2016, sets of fuzzy $F_{41}$ in year 2016 is interrelated to $F_{15}$ in year 2017 so in this way all year fuzzy relationship datasets are formed.

*Table 2. Fuzzy logical relationships*

| Years Relationships | Fuzzy Logical Relationships |
|---|---|
| 2010 → 2011 | $F_4 \rightarrow F_{31}$ |
| 2011 → 2012 | $F_{31} \rightarrow F_{12}$ |
| 2012 → 2013 | $F_{12} \rightarrow F_{28}$ |
| 2013 → 2014 | $F_{28} \rightarrow F_{13}$ |
| 2014 → 2015 | $F_{13} \rightarrow F_{55}$ |
| 2015 → 2016 | $F_{55} \rightarrow F_{41}$ |
| 2016 → 2017 | $F_{41} \rightarrow F_{15}$ |

*Fuzzy logical relationship groups (FLRG's)*

Using the table 2, fuzzy logical relationship groups (FLRG's) are formed which are given in the table 3. In group 1, relationship of fuzzy $F_4$ related to $F_{33}$ is mapping in the same way, the fuzzy relationship of $F_{33}$ is mapping on $F_{12}$, $F_4$ is mapping on $F_{28}$ in group 3, $F_{28}$ is mapping on $F_{13}$ in group 4, $F_{13}$ is mapping on $F_{55}$ in group 5, $F_{55}$ is mapping on $F_{41}$ in group 6, $F_{41}$ is mapping on $F_{15}$ in group 7. There is no relationship of fuzzy that consist of more than one set that can be merged into another group. Relationship of fuzzy group are shown in below given table.

*Table 3. Fuzzy logical relationship groups*

| Fuzzy Relationship Groups | Fuzzy set Groups |
|---|---|
| Group 1 | $F_4 \rightarrow F_{31}$ |
| Group 2 | $F_{31} \rightarrow F_{12}$ |
| Group 3 | $F_{12} \rightarrow F_{28}$ |
| Group 4 | $F_{28} \rightarrow F_{13}$ |
| Group 5 | $F_{13} \rightarrow F_{55}$ |
| Group 6 | $F_{55} \rightarrow F_{41}$ |
| Group 7 | $F_{41} \rightarrow F_{15}$ |

*Step 5. Fuzzy Forecasted Prices*

Using the methods of fuzzy logical relationship groups by Song (Song & Chissom, 1994), forecasted output is determined. All the relationship groups from the above table consist of case 1 which is stated as that in one to one relationship such as $F_j \rightarrow F_k$ then highest degree occurred in $F_k$ at interval $\mu_k$. Forecasted output of the fuzzy generalized auto-regressive conditional heteroscedasticity model is written in below column of table. In this table, year 2011 is forecasted value using the fuzzified interval midpoint values of 2010. The relationship of fuzzy group of year 2010 is $F_4 \rightarrow F_{31}$, according to fuzzification case 1, the highest degree of $F_{31}$ interval is $\mu_{31}$ = [1.489, 38.525], so the forecasted output of the year 2011 is the midpoint of $\mu_{31}$ which is equal to 20.005. In the same manner all the forecasted prices are obtained which are given in table 4.

*Table 4. Forecasted prices of stock index*

| Year | Actual prices of index (returns*100) | Forecasted prices of index | Fuzzy Relationship Groups | Midpoints of intervals |
|---|---|---|---|---|
| 2010 | 1.485 | | $F_4 \rightarrow F_{31}$ | 20.005 |
| 2011 | 13.88 | 20.005 | $F_{31} \rightarrow F_{12}$ | 30.649 |
| 2012 | 21.89 | 30.649 | $F_{12} \rightarrow F_{28}$ | 37.646 |
| 2013 | 29.064 | 37.646 | $F_{28} \rightarrow F_{13}$ | 52.064 |
| 2014 | 44.96 | 52.064 | $F_{13} \rightarrow F_{55}$ | 72.148 |
| 2015 | 60.39 | 72.148 | $F_{55} \rightarrow F_{41}$ | 99.132 |
| 2016 | 69.98 | 99.132 | $F_{41} \rightarrow F_{15}$ | 128.569 |
| 2017 | 99.956 | 128.569 | | |

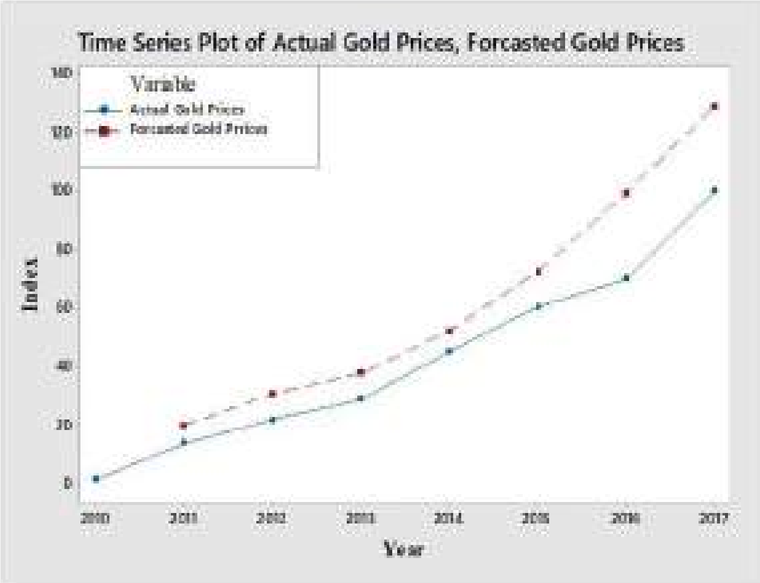


*Figure 1. Comparison graph of Actual and Forecasted prices of stock index*

In figure.1, it is shown that the actual prices of Gold prices of stock index from year 2010 to 2017 are near to forecasted prices obtained from fuzzy generalized auto-regressive conditional heteroscedasticity from year 2010 to 2017. This graph reflects the regular component which means year to year variation existing in the fuzzy forecasted prices which do not follow any pattern. In actual prices of stock index, from year 2010 to 2013, price pattern shows minor change in trend movement and from year 2013 to 2016 there is a slightly movement and from year 2016 to 2017 there is a slightly downward movement seen in the prices pattern. The forecasted prices pattern shows slightly movement from year 2011 to 2013 and from 2013 to 2015, there is a upward trend seen in prices trend. From year 2016 to 2017, drastic upward movement are seen in forecasted prices.

### 4.2. Comparison between (GARCH) (p,q) model and (FGARCH) (p,q) model

It is important to know that, which model is performing best and give significant results among classical and proposed fuzzy models. Comparison between GARCH model and proposed FGARCH model is evaluated by using different estimation criteria. Results obtained through GARCH and proposed FGARCH models by using different evaluation methods are given in the table 5.

From above evaluation empirically, criteria's results of proposed Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (Fuzzy-GARCH) is smaller and efficient than Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH), which depict that proposed Fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (Fuzzy-GARCH) perform effectively and efficient as compared to Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH).

*Table 5. Different evaluation criteria result obtained from GARCH and Proposed Fuzzy-GARCH*

| Evaluation criteria | GARCH | Fuzzy-GARCH |
|---|---|---|
| Root Mean Square (RMSE) | 72.5341 | 18.170093 |
| Mean Absolute Deviation (MAD) | 62.009312 | 15.6507 |
| Mean Absolute Percentage Error (MAPE) | 101.48869 | 2.339601 |
| Mean Square Error (MSE) | 2081.9607 | 301.998 |
| Theil-U-Statistics | $8.53701 \times 10^{-14}$ | 0.003212 |

To determine whether proposed fuzzy GARCH is appropriate and best model in forecasting than GARCH, we compare the properties of the both classical and proposed model which are given below:

i. Input and output information used in GARCH depend upon a previous function whereas in proposed FGARCH model information are totally based on the fuzzy function.

ii. GARCH model work on the larger observation datasets whereas proposed FGARCH is applicable on small observation as well as larger observations.

iii. GARCH model provides confidence interval whereas proposed FGARCH models give the possibility parameters intervals, which make informal for the forecasted to deal with the possible conditions.

iv. GARCH deals with the conventional fact such as time-fluctuating volatility and volatility crowding, whereas proposed FGARCH deals with forecasting of volatility effect and give more accurate result than classical GARCH.

From above comparison, proposed FGARCH model provides the best forecasted results and best scenario in possibility situation and provide to be effective in spotting the small data outliers.

## 5. Conclusions

This study is based on basic idea of Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH) in forecasting the prices of stock exchange. A new method based on fuzzy theory is proposed with different mathematical computations and relate this computation in forecasting the stock exchange to determine the efficiency of this model with existing GARCH model. The pragmatic results of the MSE, MFE, MAPE, MAD and RMSE, normalized mean square error (NMSE) of FGARCH model shown in table 4.7 are smaller as compared to GARCH model, which indicates that proposed FGARCH forecasting accuracy is better and perform well than GARCH model. Theil –U-statistic of both models is equal to zero which depicts that Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH) and proposed fuzzy Generalized Auto-Regressive Conditional Heteroscedasticity (GARCH) perfectly forecast the stock prices. The likelihood practice is sensitive to the preliminary value selection and the distribution of data. The presence of uncertainty in data series makes questionable of using the likelihood technique to resolve the uncertainty due to unknown distribution. This limitation is vital in aspects of the forecasting with low accuracy. Future research needs improvement in fuzzy GARCH model regarding estimation of parameters and variability in order to improve the accuracy of model to forecast time series data.

Appendix A: Stock Prices Index of Gold (base 2009-2017)

| Date | Gold prices index | Returns of Gold prices | Date | Gold prices index | Returns of Gold prices |
|---|---|---|---|---|---|
| 12/31/2009 | 1134.72 | | 1/31/2014 | 1244.27 | 0.018292 |
| 1/31/2010 | 1117.96 | -0.01499 | 2/28/2014 | 1299.58 | 0.04256 |
| 2/28/2010 | 1095.41 | -0.02059 | 3/31/2014 | 1336.08 | 0.027319 |
| 3/31/2010 | 1113.34 | 0.016105 | 4/30/2014 | 1298.45 | -0.02898 |
| 4/30/2010 | 1148.69 | 0.030774 | 5/31/2014 | 1288.74 | -0.00753 |
| 5/31/2010 | 1205.43 | 0.04707 | 6/30/2014 | 1279.1 | -0.00754 |
| 6/30/2010 | 1232.92 | 0.022297 | 7/31/2014 | 1310.59 | 0.024027 |
| 7/31/2010 | 1192.97 | -0.03349 | 8/31/2014 | 1295.13 | -0.01194 |
| 8/31/2010 | 1215.81 | 0.018786 | 9/30/2014 | 1236.55 | -0.04737 |
| 9/30/2010 | 1270.98 | 0.043407 | 10/31/2014 | 1222.49 | -0.0115 |
| 10/31/2010 | 1342.02 | 0.052935 | 11/30/2014 | 1175.33 | -0.04012 |
| 11/30/2010 | 1369.89 | 0.020345 | 12/31/2014 | 1200.62 | 0.021064 |
| 12/31/2010 | 1390.55 | 0.014857 | 1/31/2015 | 1250.75 | 0.04008 |
| 1/31/2011 | 1360.46 | -0.02212 | 2/28/2015 | 1227.08 | -0.01929 |
| 2/28/2011 | 1374.68 | 0.010344 | 3/31/2015 | 1178.63 | -0.04111 |
| 3/31/2011 | 1423.26 | 0.034133 | 4/30/2015 | 1198.93 | 0.016932 |
| 4/30/2011 | 1480.89 | 0.038916 | 5/31/2015 | 1198.63 | -0.00025 |
| 5/31/2011 | 1512.58 | 0.020951 | 6/30/2015 | 1181.5 | -0.0145 |
| 6/30/2011 | 1529.36 | 0.010972 | 7/31/2015 | 1128.31 | -0.04714 |
| 7/31/2011 | 1572.75 | 0.027589 | 8/31/2015 | 1117.93 | -0.00929 |
| 8/31/2011 | 1759.01 | 0.105889 | 9/30/2015 | 1124.77 | 0.006081 |
| 9/30/2011 | 1772.14 | 0.007409 | 10/31/2015 | 1159.25 | 0.029743 |
| 10/31/2011 | 1666.43 | -0.06344 | 11/30/2015 | 1086.44 | -0.06702 |
| 11/30/2011 | 1739 | 0.041731 | 12/31/2015 | 1075.74 | -0.00995 |
| 12/31/2011 | 1639.97 | -0.06039 | 1/31/2016 | 1097.91 | 0.020193 |
| 1/31/2012 | 1654.05 | 0.008512 | 2/29/2016 | 1199.5 | 0.084694 |
| 2/29/2012 | 1744.82 | 0.052023 | 3/31/2016 | 1245.14 | 0.036655 |
| 3/31/2012 | 1675.95 | -0.04109 | 4/30/2016 | 1242.26 | -0.00232 |
| 4/30/2012 | 1649.2 | -0.01622 | 5/31/2016 | 1260.95 | 0.014822 |
| 5/31/2012 | 1589.04 | -0.03786 | 6/30/2016 | 1276.4 | 0.012104 |
| 6/30/2012 | 1598.76 | 0.00608 | 7/31/2016 | 1336.66 | 0.045083 |
| 7/31/2012 | 1594.29 | -0.0028 | 8/31/2016 | 1340.17 | 0.002619 |
| 8/31/2012 | 1630.31 | 0.022094 | 9/30/2016 | 1326.61 | -0.01022 |
| 9/30/2012 | 1744.81 | 0.065623 | 10/31/2016 | 1266.55 | -0.04742 |
| 10/31/2012 | 1746.58 | 0.001013 | 11/30/2016 | 1238.35 | -0.02277 |
| 11/30/2012 | 1721.64 | -0.01449 | 12/31/2016 | 1157.36 | -0.06998 |
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*Financial support:*
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*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:*
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**OPERATIONAL Research in Engineering Sciences**: Theory and Applications / editor-in-chief Željko Stević. - [Štampano izd.]. - Vol. 5, issue 1 (2022)- . - Belgrade : Regional Association for Security and crisis management : European Centre for Operational research, 2022- (Belgrade : C štampa). - 25 cm

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