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Paper Type: Research Paper

Overall Productivity Assessment Using the Performance Objectives Productivity (PO-P) Approach: A Case Study

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Abstract

During my travel to the research case industry to advice internship placed students of our university, I have communicated with company owners that there is a problem related with productivity measurement and improvement. So that we have decided to assess the overall productivity of the company with the considerations of potential sub systems with in it. The existing system overall productivity level have been measured through Performance Objectives Productivity (PO-P) approach. In the case company six subsystems where identified: technology, production, marketing, ergonomics, values and goals and materials. Afterwards, their importance to the company have been prioritized using paired comparison analysis technique. By using Pareto analysis; technology, marketing, ergonomics and production have been identified as potential subsystems. By using PO-P approach the productivity of these four potential subsystems has been measured. As a result, productivity indices of production, marketing, technology, and ergonomics subsystems are 0.7379, 0.6661, 0.7882 and 0.7156 respectively. This resulted the existing system overall productivity of 0.652.

Keywords: Overall productivity assessment, PO-P approach, Productivity index, Potential subsystems, Sewing thread and yarn manufacturing.

1 | Introduction

In Ethiopia the economic impact of the textile sector for national GDP has been remarkable and this declares the beginning of modernizing the sector in the country in the late 1930s. The employment opportunity created by this sector is very prominent in job creation so that the graduated students from textile and manufacturing field are recruited to this sector. Due to the fact that the sector in Ethiopia demands a lot of man power either skilled or unskilled of textile sector is considered as number one priority sector by the Government's Industrial Development Strategy [1]. In such important industries evaluation of the levels of productivity is very essential to indicate the level of the performance and the continuity of the business. The performance of machines, machine tools, components etc. are measured in terms of efficiency, effectiveness and productivity by different scholars using different techniques, tools and models. This was done to take the commitment for

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further improvement of the working environment. Productivity is a useful indicator to analyze the performance of an organization, measuring productivity is a prerequisite to improve productivity.

In the above sense, Perdana and Saroso [2] tried to measure the performance of Thoshiba IS 350 GS 350 Ton machine in terms of productivity to explore the main causes. So that they tried to implement repairing production machine to improve productivity based on the OEE value achievement [2]. On the other research, two-stage data envelopment analysis model was used to calculate/measure the effectiveness and efficiency of petrochemical companies from the perspective of human health was calculated using two stage data envelopment analysis model. In this research five input indicators were analyzed to improve the health indicators [3]. In addition to this, research conducted by Hosseinzadeh Lotfi and Jahanbakhsh [4] revealed that the performance in terms of efficiency and effectiveness of a DMU can be calculate using DEA, but in rather to better performance assessment and show the efficiency and effectiveness distinction, it's needed to apply ICCR and IBCC models that can handling simultaneously efficiency and effectiveness, but they do not define the total performance [4]. In any manufacturing organization, enhancement of productivity is very prominent. But before improvement there should be a method to measure the productivity of that organization. The same thin was done by Halder et al. [5] to mark the possible major factors of productivity in Ready Made Garments (RMGs) sector in Bangladesh. During their study multi-criteria decision-making tool such as FAHP was used for evaluating the best criterion among several criteria to select the factor that directly affects the productivity of the sector. Finally they concluded that the result of this study provided a better solution the sector to increase the productivity [5].

The measurement the productivity of the machine, machine tools, work sections or the subsystem etc. within the system, it requires the consideration of other components within them [6]. For this research the selected case company called "Edget Yarn and Sewing Thread Share Company" is found in Sarbet, Addis Ababa, Ethiopia. The topic of overall productivity assessment of this case company came in mind after observing the company and discussed with the management staffs which is interesting and important. During our discussion they told me that they want to improve the overall productivity of the company but we agreed on to measure the current level of productivity intensively.

In general, the sector was chosen for a number of reasons. Firstly, through the researcher understanding of the case company's problems related with productivity during term paper works for partial fulfillment of different M.Sc. courses. The researcher needs to determine overall productivity of the company as a system by considering different subsystems within it. Therefore, it requires continuous productivity assessment and improvement. The aggregate measurement program is smart which combines productivity of the components within the systems [7]. Secondly, the Government of Ethiopia has planned to generate employment opportunities by the sector for about 48,000 citizens [8]. Therefore the objective of the study is overall productivity assessment of Edget Yarn and Sewing Thread Share Company so as to bring prioritized potential subsystems those needs for further system level improvement.

2 | Materials and Methods

The model designated as Performance Objectives Productivity (PO-P) has been used to assess the productivity level of the case company from the productivity level of the components/subsystems of the case company. Using the model the overall productivity level of the case company is developed by considering the productivity of potential sub systems/components those made the case company. Productivity Index (PI) of components/subsystems again developed from the productivity indices of the Key Performance Areas (KPA's) of that component/subsystem [9].

Therefore, using this hierarchical approach the data were collected from May 17, 2021 to September 3, 2021 to determine the overall productivity of the case company. These collected data sourced from different work sections of the case company namely production department, purchasing department, human resource office, maintenance office, marketing department, from the staffs' clinic and management staffs. Now we see how the model is developed to assess the overall productivity of the case company/system.

u= the component/subsystem.

v = the KPA.

y = the performance objectives.

W = the weightage factor.

Oyvu = the Performance Value (PV) of POy in KPAv in component/subsystem u.

O'yvu = the Objectivated Output (OO) of PO-y in KPAv in component/subsystem u.

PI of component/ subsystem S, is given by,

$$PI = \sum_{u=1} W_u (PI)_u, \quad (1)$$

where, PI= $\sum_{U=1} Wu = 1$,

(PI)u the PI of the sub system u is determined as,

$$(PI)_u = \sum_{v=1} W_{vu} (PI)_{vu}, \quad (2)$$

where, $\sum_{v=1} Wvu = 1$, for all us,

(PI) vu, the PI of key performance area, v of component/subsystem u is given by,

$$(PI)_{vu} = \sum_{y=1} W_{yvu}\left(\frac{O_{yvu}}{O'_{yvu}}\right), \quad (3)$$

where, $\sum_{y=1} Wyvu = 1$, for all u and v.

Substituting the value of (PI)vu from *Eq. (3)* in *Eq. (2);* (PI)u of a subsystem u, can be summarized as

$$(PI)_u = \sum_{y=1} \sum_{v=1} W_{vu} W_{yvu}\left(\frac{O_{yvu}}{O'_{yvu}}\right). \quad (4)$$

The value of (PI)u from *Eq. (4)* can be substituted in *Eq. (1)* to provide PI, the PI of a system S, and is summarized as

$$PI = \sum_{u=1} \sum_{v=1} \sum_{y=1} W_u W_{vu} W_{yvu}\left(\frac{O_{yvu}}{O'_{yvu}}\right). \quad (5)$$

To make it clear, PO-P approach follows the following procedure shown in *Fig. 1* to identify the sub system with low productivity so as to bring continuous improvement.

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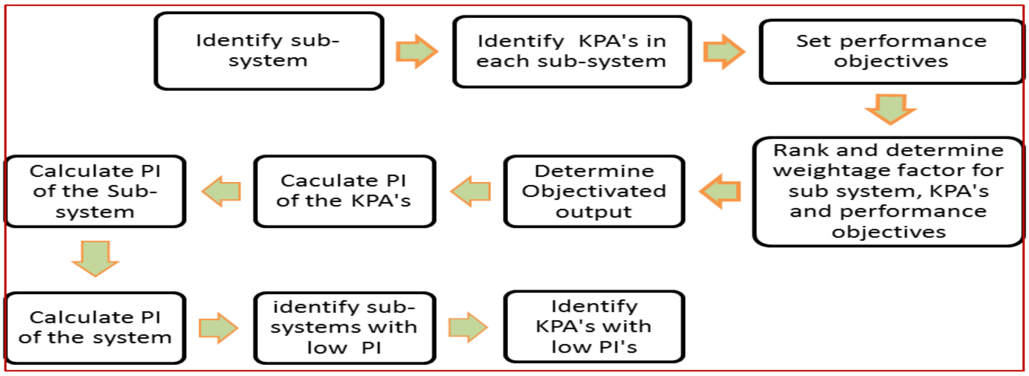

Fig. 1. The procedure of PO-P approach to assess productivity [9].

The steps in *Fig. 1* shows that the procedure that we follow to measure the productivity of the system. Through these steps there are a number of decisions made by the discussion of the researcher and the case company management staffs

3 | Result and Discussion

3.1 | Identification of Subsystems under the Case Company

In any manufacturing industries there are always the considerable list of subsystems those developed the systems as a functional unit [10]. Under the concerned yarn and tread manufacturing company the following sub systems have been identified and each sub-system has been coded in short version to simplify them for the next analysis.

I. Production component/subsystem (G).
II. Technology component/subsystem (H).
III. Material component/subsystem (I).
IV. Marketing component/subsystem (J).
V. Ergonomics component/subsystem (K).
VI. Goals and values component/subsystem (L).

3.2 | Ranking and Determining Weight for Subsystems using Paired Comparison Analysis Technique

Using the technique shown in *Table 1* the importance of the identified of subsystems relative to each other have been carried out and scores have been allocated to show how much more important one on the other. The relative weights are assigned by the company management staffs.

Then consolidate the comparisons so that each option is given a percentage importance.

1= is given to the component/subsystem when Minor difference is between the relative importance.

2= is given to the component/subsystem when Medium difference is between the relative importance.

3= is given to the component/subsystem when Major difference is between the relative importance.

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Table 1. Paired comparison analysis results.

	H	I	J	K	L	Score
G:	H-2	G-3	J-3	K-1	L-1	G=3
	H:	H-2	H-2	H-2	H-2	H=10
		I:	I-1	K-1	I-1	I=2
			J:	K-1	J-2	J=5
				K:	K-1	K=4
					L:	L=1

* Source: the case company management staffs.

Based on paired comparison analysis technique here in *Table 1* we can see that the subsystem designated by 'H' is the most important of all subsystems that critically determines the productivity of the company which is followed by the subsystem 'J' and so on.

Table 2. Identified sub-systems with respective relative marks and cumulative distribution.

Sub-Systems	Total Relative Marks for Each	Cumulative Total	Percentage	Percentage Cumulative
H	10	10	40	40
J	5	15	20	60
K	4	19	16	76
G	3	22	12	88
I	2	24	8	96
L	1	25	4	100

* Source: own arrangement from *Table 1*.

Depending on relative marks assigned for each sub systems in *Table 2*, Pareto (80/20 rule) has been done. This tool has been done based on the percentage cumulative relative marks to show the potential subsystems among the givens for further attention and improvement. In addition, it used to identify the potential subsystems those determines the productivity of the systems in general critically.

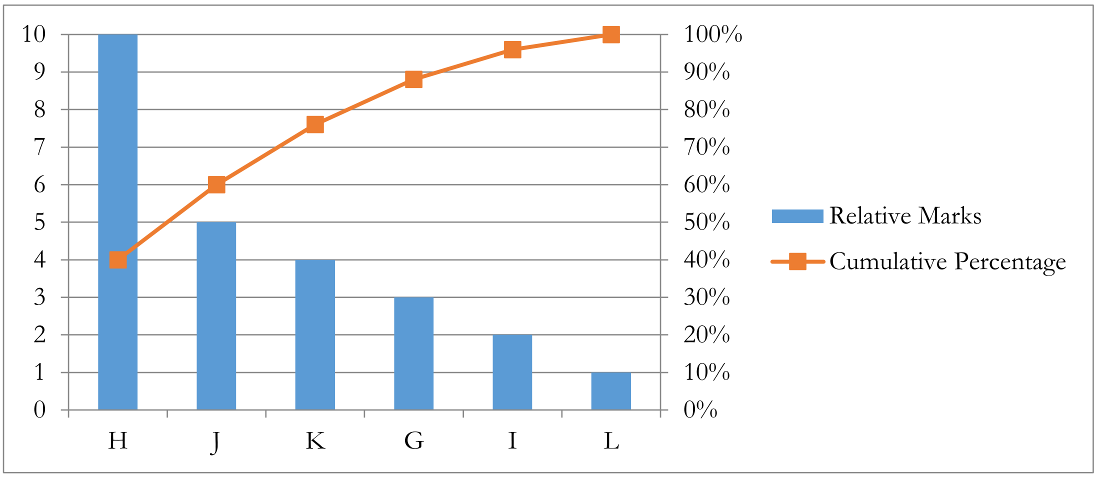

Fig. 2. Pareto curve (Source: own development using excel).

Based on the Pareto curve in *Fig. 2*, with cumulative percentage, technology (H), marketing (J), ergonomics (K) and production (G) components/sub systems have been identified as potential problems areas. These sub systems are considered as the candidates to be used for further productivity analysis and improvement.

3.3 | KPAs for Potential Subsystems

Table 3. The Identified of KPAs for potential subsystems with their relative weight.

Sub-systems	KPAs	Relative Weight (%)
Production (G)	Labor Usage	25
	Tangible Assets Usage	15
	Levels of Defects	40
	Others areas	20
Technology (H)	Products planning and development	45
	Research and Development	55
Marketing (J)	Sales related issues	30
	Market Analysis	50
	Marketing mix (promotion)	20
Ergonomics (K)	Levels of personal fineness to the work	30
	Workplace environment	50
	Any other issues	20

* Source: from the respected personnel of each sub-system.

Once the potential sub-systems have been identified using the Pareto analysis, KPAs have been decided with their respective weight out of 100% with the discussion of the personnel from each subsystem. Here also tried to consider the possible KPAs identified by the management staffs.

3.4 | PI for KPAs and Subsystems

Table 4. Analysis of PI for production KPAs and the subsystem itself.

Sub-System	KPAs	Relative Weight	Performance Objectives	Relative Weight	OO	PV
Production	Labor Usage	25%	Direct labor utilization: standard hrs recovery/direct labor attendance hrs	60%	0.7	0.65
			Cost effectiveness: standard hrs recovery/personnel expenses	20%	0.75	064
			Ethiopian labor utilization of the company	20%	0.8	078
	Tangible asset Usage	15%	Capacity usage: standard hrs recovery/personnel expense	100%	0.85	072
	Levels of Defects	40%	Index of defect free outputs: value of defect free output/value of total outputs	100%	1	0.95
	Other Areas	20%	-	-	-	-

* Source: from the respected personnel of production sub-system & management staff.

As we see from *Table 4* each key performance area has its own performance objectives. In the same manner, performance objectives under each key performance area have weight out of 100%, OO and PV. Using these three as an input PI of each key performance area have been determined. Once PI of each KPAs have been settled, using the relative weight of each KPAs as an additional input, the PI of the production sub system have been calculated in the following way:

$$(\mathrm{PI})_{vu} = \sum_{y=1} W_{yvu}\left(\frac{O_{yvu}}{O'_{yvu}}\right).$$

Using this formula, the PI of KPAs for production subsystem in *Table 4* became:

Labor Usage: $(PI)_{vu} = 0.6 * (0.65 \div 0.7) + 0.2 * (0.64 \div 0.75) + 0.2 * (0.78 \div 0.8) = 0.9232$,

Levels of Defects: $(PI)_{vu} = 1 * (0.95 \div 1) = 0.95$,

Tangible Assets Usage: $(PI)_{vu} = 1 * (0.72 \div 0.85) = 0.8471$,

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Hence, PI for production sub-system became: $(PI)_u = 0.25 * 0.9232 + 0.4 * 0.95 + 0.15 * 0.8471 = 0.7379$.

Table 5. Analysis of PI for marketing KPAs and the subsystem itself.

Sub-System	KPAs	Relative Weight	Performance Objectives	Relative Weight	OO	PV
	Sales related issues	30%	Sales: absolute monetary	25%	51.6 million	2.5 million
			Profitability: profit/sales	75%	0.145	0.14
	Market Analysis	50%	Is production capability a limiting factor?	35%	1	0.83
			Is demand a limiting factor?	15%	1	0.94
			Do products mix (quality) and prices mixes are satisfying customers?	50%	0.86	0.78
Marketing	Marketing mix (promotion)	20%	Does Ethiopian government supports in creating demand for yarn and thread?	-	-	-
			Are marketing department effortful starting from the manufactures to market their product?	-	-	-
			Are the products exported?	-	-	-
			Does Ethiopian minister of trade and investment gives support for marketing activities?	-	-	-

* Source: from the respected personnel of production sub-system & management staff.

As we see from *Table 5* each key performance area has its own performance objectives. Using relative weight, OO and PV of the performance objectives as an input PI of each key performance area have been determined. Once PI of each KPAs have been calculated, using the KPAs namely contained sales related issues, marketing mix (promotion) and market analysis and their respective relative weight the PI of the marketing sub system have been calculated.

$(PI)_{vu} = \sum_{y=1} W_{yvu(\frac{O_{yvu}}{O'_{yvu}})}$, using this formula PI of KPAs for marketing subsystem in *Table 5* became:

Sales related issues: $(PI)_{vu} = 0.25 * (2.5 \div 51.6) + 0.75 * (0.14 \div 0.145) = 0.7362$,

Market Analysis: $(PI)_{vu} = 0.35 * (0.83 \div 1) + 0.15 * (0.94 \div 1) + 0.5 * (0.78 \div 0.86) = 0.8903$,

Hence, the PI for marketing sub-system became: $(PI)_u = 0.3 * 0.7362 + 0.5 * 0.8903 = 0.6661$.

As we see from *Table 6* each key performance area has its own performance objectives. Using relative weight, OO and PV of the performance objectives as an input PI of each key performance area have been determined. Once PI of each KPAs have been calculated, using the KPAs namely level of personal fitness to the work, workplace environment and other issues and their respective relative weight the PI of the ergonomics sub system have been calculated.

$(PI)_{vu} = \sum_{y=1} W_{yvu(\frac{O_{yvu}}{O'_{yvu}})}$, using this formula, the PI of KPAs for Ergonomics sub-system in *Table 6* became:

Levels of personal fineness to the work, $(PI)_{vu} = 0.4 * (0.4 \div 0.6) + 0.45 * (0.53 \div 0.82) = 0.5568$,

Workplace environment, $(PI)_{vu} = 0.25 * (0.56 \div 0.7) + 0.25 * (0.65 \div 0.8) + 0.25 * (0.4 \div 0.6) + 0.25 * (0.67 \div 0.75) = 0.7931$,

Other issues, $(PI)_{vu} = 0.75 * (0.6 \div 0.8) + 0.15 * (0.45 \div 0.5) + 0.1 * (0.25 \div 0.4) = 0.76$, Hence, for PI for Ergonomics sub-system became:

$(PI)_u = 0.3 * 0.5568 + 0.5 * 0.7931 + 0.2 * 0.76 = 0.7156.$

Table 6. Analysis of PI for Ergonomics KPAs and the subsystem itself.

Sub-System	KPAs	Relative Weight	Performance Objectives	Relative Weight	OO	PV
Ergonomics	Levels of personal fineness to the work	30%	Does the mgt consider work-experience for the job?	40%	0.6	0.4
			Does the feeling of the workers goods for the job they are assigned?	10%	-	-
			Do the recruited staffs trained before using the available machines?	45%	0.82	0.53
			Do the workers fit the physical requirements of the working-environment?	5%	-	-
	Workplace environment	50%	Do the supporting-facilities timely delivered to workers to aid the staffs in doing the job?	25%	0.7	0.56
			Do working-tools advanced?	25%	0.8	0.65
			Does the workplace-environment at satisfying level?	25%	0.6	0.4
			Doe work-load distribution is balanced throughout the workers?	25%	0.75	0.67
	Other issues	20%	Are there rules, regulations and policies to shape the work culture	75%	0.8	0.6
			Is there any solution mechanism to solve problems emanate and disrupt the working environment from workers?	-	Not Detected	
			Is work-schedule & rotation fairly implemented?	15%	0.5	0.45
			Is there any staffs cased in unusual environmental stress	10%	0.4	0.25

*Source: from the respected personnel of production sub-system & management staff.

As we see from *Table 7* each key performance area has its own performance objectives. Using relative weight, OO, and PV of the performance objectives as an input PI of each key performance area have been determined. Once PI of each KPAs have been calculated, using the KPAs namely design and development and R&D/innovation and their respective relative weight the PI of the technology sub system have been calculated.

$(PI)_{vu} = \sum_{y=1} W_{yvu(\frac{O_{yvu}}{O'_{yvu}})}$, using this formula PI of KPAs for technology subsystem in *Table 7* became:

Products planning and development: $(PI)_{vu} = 0.1 * (0.83 \div 0.9) + 0.2 * (0.84 \div 0.87) + 0.6 * (0.75 \div 0.8) = 0.8478$,

Research and development: $(PI)_{vu} = 0.25 * (0.7 \div 0.75) + 0.3 * (0.6 \div 0.67) + 0.25 * (0.95 \div 1) = 0.7395$,

Hence, for PI for technology sub-system became: $(PI)_u = 0.45 * 0.8478 + 0.55 * 0.7395 = 0.7882.$

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Table 7. Analysis of PI for technology KPAs and the subsystem itself.

Sub-System	KPAs	Relative Weight	Performance Objectives	Relative Weight	OO	PV
	Products planning and development	45%	Is the yarn and thread manufacturing unit uses locally available low cost technology?	10%	When necessary	
			Is yarn and thread manufacturing unit equipped with Ethiopian Machineries?	10%	0.9	0.83
			Is the design getting approved before production run?	20%	0.87	0.84
			Is there any CAD facility?	-	-	-
			Is there local planning practice next to final design?	-	-	-
			Are there any process of verification and validation of design?	60%	0.8	0.75
Technology			Is there department assigned to search new available technologies?	-	-	-
	R&D/innovation	55%	Is there a system to do gap analysis in the meantime and future regarding technology?	25%	0.75	0.7
			Does the company ready to take measure when costumer requirement is not fulfilled?	30%	0.67	0.6
			Is there quality-manual to guide mfg department?	25%	1	0.95
			Is the mfg department uses strength, weakness, opportunity and threat analysis to direct the future?	20%	Not available	

*Source: from the respected personnel of technology sub-system & management staff.

Table 8. Analysis of PI for production KPAs and the subsystem itself.

Sub-Systems	Relative Weight	KPAs	Relative Weight	PI of KPAs	PI of Subsystems
Production	12%	Labor Usage	25%	0.9232	0.7379
		Tangible Assets Usage	15%	0.8471	
		Levels of Defects	40%	0.95	
		Other issues	20%	-	-
Technology	40%	Products planning and development	45%	0.8478	0.7882
		Research and Development	55%	0.7395	
Marketing	20%	Sales related issues	30%	0.7362	0.6661
		Market Analysis	50%	0.8903	
		Marketing mix (promotion)	20%	-	
Ergonomics	16%	Levels of personal fineness to the work	30%	0.5568	0.7156
		Workplace environment	50%	0.7931	
		Other issues	20%	0.76	

*Source: own rearrangement from *Table 2* and results of *Table 4*, *Table 5*, *Table 6* and *Table 7*.

Using *Table 8* Now is the time to determine the productivity of the systems in general with the consideration of the potential sub stems identified by the combination of paired comparison analysis and Pareto curve. In other words, it meant that using the relative weight of each potential subsystem and their respective PI the, the PI of the case company can be calculated.

Therefore, using PI of components/subsystems in *Table 8* the overall productivity of the system, Edget Yarn and Sewing Thread Share company can be calculated, using the formula, and became 0.12*0.7379+0.4*0.7882+0.2*0.6661+0.16*0.7156 = 0.652.

4 | Conclusion and Recommendation

Productivity of the system, Edget Yarn and Sewing Thread Share Company, has been measured by using the aggregate productivity measurement approach called PO-P approach. Using the model the overall productivity level of the case company is developed by considering the productive of potential sub systems/opponents those mage the case company. PI of components/subsystems again developed from the productivity indices of the KPA's of that component/subsystem.

In this research, using PO-P approach and Pareto, potential areas namely technology subsystem, production subsystem, ergonomics subsystem, and marketing subsystem have been identified. Finally, the productivity level of the case company have been assess based on the result we got from subsystems.

In general, the researcher suggested that any team(s) and/or individual(s) for future improvement of the overall productivity of their company should utilize the output of this research. In particular the case company business owner(s) should focus on the identified potential subsystems namely marketing subsystem, ergonomics subsystem, production subsystem and technology subsystem for improvement of the system productivity with the consideration of the performance objectives with in them.

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Paper Type: Research Paper

Entrepreneurial Team Characteristics, Social Interactions and the Success of Information Technology Start-Ups

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Abstract

Entrepreneurial teams significantly influence the growth, profitability, and innovation of new businesses, specifically in Information Technology (IT) start-ups. However, there is limited knowledge about the impact of personal characteristics of entrepreneurial team members and their social interactions on the success of their business. This paper explores the effect of entrepreneurial team characteristics and their social interactions on the success of IT start-ups. The study employed a quantitative research design and data from 213 entrepreneurial teams in IT start-ups. The findings showed that heterogeneity, experience, self-efficacy, commitment, trust, and social interactions of entrepreneurial team members have a significant positive influence on the success of IT start-ups. Implications of the findings for policy, practice, and research development are discussed.

Keywords: Business success, Entrepreneurial team, Start-up, Personal characteristics, Social interactions.

1 | Introduction

Worldwide businesses have been revolutionized by digital entrepreneurship [151]. Based on Baregheh et al. [13] start-up is a firm trying to solve a problem while the solution is ambiguous and the firm cannot guarantee success. Some other scholars define a start-up as a technology-based company that aims to create new products or services in extreme uncertainties [3], [98], [110]. Start-ups are initiated with an ingenious idea using technology and over time turn into a powerful technology and avant-garde sustainable firm that persist over time [86], [116]. Exploring the factors that shape a start-up's success has been the focus of a growing number of studies [17], [21], [56].

Business success is defined by growth indicators, contributing back to society, profitability, innovation, public recognition, work-life balance, firm survival/continuity, satisfied stakeholders (employees and customers), personal satisfaction, and utility or usefulness [54].

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In entrepreneurship, the concept of success is usually associated with monetary factors and the financial performance of the company. Some authors have also defined success from a tangible perspective, such as profitability, firm revenue, and the creation of personal wealth [4]. One of the strong components of the success of every startup is innovation. Organizations that cannot adapt themselves to new developments and research dies in the market [102].

The entrepreneur and team play a vital role in the success of new ventures [19]. Entrepreneurial teams have a high impact on new ventures' success [31]. An entrepreneurial team consists of two or more people who have a shared interest and participate in the development of an entrepreneurship project and are known as a part of the team [16], [33]. A lot of new businesses are launched by entrepreneurial teams. Ventures created as teams have a positive effect on the survivability, profitability, and growth potential of new businesses [103]. 40% of new ventures fail within the first year, and over 60% of failures are attributed to problems with the entrepreneurial team [44]. Improving the performance of the entrepreneurial team and the success of the entrepreneurial venture has been a significant concern for researchers [147]. Therefore, investigating entrepreneurial teams' characteristics and their social interactions is an essential topic in business success.

In this study, indicators such as profitability, growth, innovation, and survival have been used to evaluate start-ups' success. the innovative behavior in the team members is essential to survival and entrepreneurial teams' development [50]. Many entrepreneurs start their businesses in a team. Teams provide high potential for resources, such as human capital, time, money, and useful social connections. Heterogeneous teams are effective in dealing with the complex problems that are common to entrepreneurial firms. This is due to the importance of diversity in perceptions, skills, abilities, and knowledge in a heterogeneous team to solve complex and ambiguous problems [53], [58], [104], [138].

The characteristics of the entrepreneurial team mainly influence the launch of new investments [119]. Generally, entrepreneurial team characteristics have significant effects on entrepreneurial ventures' performance [29]. Examining these characteristics and their influence on start-ups' success is crucial because most of the investments in new ventures are led and established by teams, rather than individuals [62], [121]. Entrepreneurship scholars argued that the advantage of startup teams comes from the variety of their characteristics, skills, and knowledge. However, there is limited knowledge about the impact of personal characteristics of entrepreneurial team members and their social interactions on the success of their business. As far as we know, the effect of team characteristics and social interactions of the entrepreneurial team members on the success of start-ups has received less attention than it deserves in Iranian research.

New technology-based firms play critical roles in the development of the economy specifically in developing countries. This is due to the potential of the firms for high growth and the creation of innovative products and processes, as well as new industries. These firms have also beneficial consequences for the local market, stakeholders, partner companies, and regional development. Compared to single entrepreneurs, entrepreneurial teams in technology-based firms demand high skills of individuals, and the firms are highly capable of managing uncertainties, risks, and volatilities related to high technologies and new ventures [42].

In particular, this study investigates the impact of heterogeneity, experience, self-efficacy, commitment, trust, and social interactions of entrepreneurial team members on the success of IT start-ups. The findings of the present study also extend previous research on the relationship between entrepreneurial team characteristics and the success of start-ups created by the team.

2 | Theoretical Background

Exploring the factors that construct start-ups' success is of critical importance in the current business environment that is constantly challenged by the generation of new technologies and processes [59]. As suggested by scholars [39], [40], over 60% of IT businesses are launched by entrepreneurial teams. In this section, the literature on entrepreneurial teams, start-ups' success, team characteristics, and social interactions of entrepreneurial team members are reviewed and hypotheses are proposed. In the following sections, we first review the related literature on personal characteristics of entrepreneurial teams including heterogeneity, experience, self-efficacy, commitment, and trust and then present the literature on social interactions of the entrepreneurial team that are hypothesized to influence start-ups' success.

2.1 | Review of the Literature And Theories

People who have high educational backgrounds and experience are attracted to the job market easily, therefore, they are less likely to be attracted to entrepreneurship. Individuals who are characterized by upper levels of human capital are interested more to be an entrepreneur if they can create valuable opportunities. In order to create the invaluable opportunity, they need to have partners to create their entrepreneurial team [105]. Entrepreneurial team composition and its effect on venture performance have been one of the main focuses of studies in this research field [55], [133], [137], [150]. The entrepreneurial team generates a composition that influences business performance. However, there are still debates among scholars about the ideal entrepreneurial team combination [48]. To better understand the concept of the entrepreneurial team, we first define the concepts of team and group. To define a team, we need to look at the differences between a team and a group. Scholars argue that a team is different from a group [78], [119] in its characteristics and purposes [134]. A group is defined as two or more people who are interdependent and interact with each other to achieve specific goals [112], [118]. A team is a group of people who take on tasks and outcomes related to those tasks. They share the results [32] and have the potential to provide more resources such as human capital, time, money, and useful social connections [43]. According to previous studies [51], [85], [91], [113], [140], about 80% of new investments are team-based.

An entrepreneurial team is a form of collective entrepreneurship that emerged during the 1990s [77]. In entrepreneurial teams, the founders mostly establish a team to start a new venture that has a significant influence on the team performance and success of the new venture [89]. Prior studies [82], [149] defined an entrepreneurial team as a social group in which two or more people contribute to achieving a common goal, are committed to the team and business, share common responsibilities and risks and consequently influence the company's strategic decision-making, shared risks and interests. In the literature [2], an entrepreneurial team consists of two or more people who have a stake in the company, actively participate in the investment, and influence the company's strategic decision making.

An entrepreneurial team in the current business environment consists of more human and social capital than an individual that enables effective dealing with uncertainties and irregularities related to creating a new venture [30], [90]. The term "social capital" was first used in studies to refer to community relationships. In management research, social capital is a key factor of a company's success [74]. Social capital is a new concept of capital that it has been introduced during the 1990s. Social capital is related to the analysis of entrepreneurship and small business as those recent concepts of capital [143]. Social capital plays an essential role in strengthening entrepreneurship performance and activities improvement in human resources [107], [129]. In the workplace, social capital leads to exchanging experience and knowledge among staff. Moreover, it increases participatory competition which is one of the most important focuses of entrepreneurship [81]. According to Kwon and Adler [87] value can be created by social capital. Social capital can bring about a shared understanding among people as well as compel individuals to pursue common goals. Thus, social capital displays a series of integrated resources for economic and social activities. Individuals like to share their information and knowledge when social interactions are well and friendly. Many studies have demonstrated that social capital is a key factor in both the knowledge and information-sharing behavior of people [25], [64], [139], [141]. Social interaction can be facilitated by social capital since as we mentioned above, social capital affects information and knowledge sharing [52].

Despite the diversity of definitions of entrepreneurial teams, the literature has emphasized that entrepreneurial teams have a significant impact on the success of the investment in new ventures and determine the success of the venture [103]. Schumpeter [115], [123] was one of the first researchers who emphasized the role of innovation in the process of entrepreneurship. One of the elements of economic development is "innovation" which is an essential concept in Schumpeter's theory of economic development and refers to a change in the available manufacture system to be presented by the entrepreneur to reduce costs and make profits. Innovativeness displays an establishment's tendency to support and engage in creative processes, experimentation, new ideas, and novelty that may consequence in new products, technological processes, and new services. Economic development is a process of changing the economic balance from lower points to higher, and according to the Schumpeterian discussion, such changes occur through innovation. In cases of successful development, such as the adoption of brand new technologies and the evolution of production techniques, growth has been accompanied by innovations. The changes enhance productivity and growth. Hence, economic development is continuing innovations process [93]. Several researchers emphasized the prominence of sustainable development and entrepreneurship as boosting behavior within the entrepreneurial establishment for competitive advantage by achieving economic success, social practices, and an innovative environment [88], [94], [117]. Results of the prior studies [85], [113], [121] suggest that the majority of investments are established by teams and not individuals. The increasing number of new venture creation by teams has encouraged the authors to focus on entrepreneurial teams as a determinant of investment success in new ventures [62], [67].

2.2 | Team Characteristics and Social Interactions

In this study, we examined heterogeneity, experience, self-efficacy, commitment, and trust as the entrepreneurial team characteristics that affect stat-ups' success. Previous researchers have studied the correlation between team performance and team members' diversity. However, the results of these studies are not consistent. Some researchers support team heterogeneity and its significant effect on team performance and concluded that heterogeneous teams are effective in dealing with complicated problems which are common in entrepreneurial firms, while others believe that team heterogeneity may reduce team performance [146]. The heterogeneity of an entrepreneurial team may nurture innovation, improve the performance of an organization [149], and boost the amount of information available to the team [69]. However, it makes working together difficult for members of the team [142]. Ko et al. [84] illustrated that despite familiarity among team members, particularly high levels of age and gender diversity have negative effects on team productivity in new ventures' success. As Chowdhury [30], highlighted, diversity is often considered as a "double-edged sword" or a "mixed blessing" for its contrasting influence on the effectiveness of a team. In other words, it may have a negative or positive impact on the effectiveness of the team. Based on the results of previous research [40], team heterogeneity can be further categorized into two dimensions. The first dimension reflects visible attributes, such as demographic details (e.g., age, gender, or ethnic background) and visible job-related attributes, such as functional expertise, industry background, and education. The second dimension refers to less visible attributes such as personality traits, beliefs, attitudes, motivation, values, and internal team processes. Recent research has suggested that personality characteristics affect entrepreneurial performance that can be extended to the level of the entrepreneurial team [37]. Entrepreneurs have been characterized by three main characteristics including the need for achievement, locus of control, and risk-taking propensity [26], [57]. Need for achievement has long been suggested as a personal characteristic of entrepreneurs that motivates and enables entrepreneurial behavior that is positively related to a company's success [79]. Previous studies have shown that entrepreneurs have a higher need for achievement than non-entrepreneurs [15], [45], [71], [92]. The importance of risk-taking in business has been also emphasized by prior researchers. Generally, entrepreneurship is inherently associated with risk-taking [57]. In today's fast-paced and insecure markets, risk-taking plays a crucial role in business growth [100]. The term 'locus of control' indicates to what extent people believe they can handle the events that influence them. Individuals with an external locus of control believe that they are responsible for whatever happens to them [106] Research results show that entrepreneurs have an internal locus of control [79] and a high level of internal locus of control at the team level increases the effectiveness and efficiency of an entrepreneurial team. According to Baptista et al. [12] the experiences of founders may affect the success of startups. The experience of entrepreneurial team members is expected to positively influence the success of new businesses. The previous experience of the entrepreneurial teams decreases the risk of business failure significantly [132]. In entrepreneurial teams, four specific types of experience may be relevant including prior shared experiences in the team, prior founding experience in the team, heterogeneity of experience, and combined industry experience represented by the team [122]. Scholars suggested that experienced entrepreneurs have faster access to the initial financial resources and earn more capital to invest than inexperienced ones. As a result, entrepreneurial teams with experienced members create better results [72] and they can prevent the company from failure in the future [126]. According to the results of previous research [119], earlier industrial experiences boost the probability of a successful start-up, because the entrepreneurial team has a high knowledge of industrial methods and procedures. Self-efficacy [9] is defined as one's believes in their ability to perform entrepreneurial roles and tasks successfully [23], [73]. Self-efficacy is an important determinant of human behavior. Individuals avoid performing a specific behavior if they have low self-efficacy. While those with high self-efficacy engage in performing the behavior [49]. Self-efficacy in the context of entrepreneurship has been conceptualized as entrepreneurial self-efficacy [65]. Entrepreneurial self-efficacy indicates an individual's belief in his/her ability to perform duties and roles that result in entrepreneurial behavior and it is a significant characteristic that differentiates entrepreneurs from non-entrepreneurs [27]. In addition to being a perceived ability at the individual level, self-efficacy also reflects collective abilities. Understanding collective self-efficacy is very important [7], [10]. Collective self-efficacy is defined as the collective believes of group members in their ability to produce high levels of achievement [8]. Self-efficacy is an important factor that determines a new venture's success [70]. Commitment is a mental framework or psychological state that commits a person to achieve a related goal [95]. The commitment of a team is a process in which team members feel loyal and trust each other. Trust and loyalty among team members encourage them to consider the views of other team members to make decisions [30]. Highly committed individuals tend to focus their time and energy on achieving goals, do not give up easily, and improve work strategies to overcome challenges and difficulties [124]. In addition to entrepreneurship procedure, 'commitment' is important for initiating a start-up and implementing productive business activities [130]. Trust forms the basis of social and economic relations and enables entrepreneurs to face uncertain conditions. In general, an entrepreneur needs to obtain others' trust including customers, employees, partners, and suppliers [96]. Trust is an influential component in increasing the effectiveness of entrepreneurial teams, specifically when the team members have a high internal locus of control [79]. As highlighted by prior researchers [35] trust is defined as the extent to which team members allow themselves to be vulnerable to others' actions. It also increases the willingness to share information between members of the entrepreneurial team so that they successfully run through unpredicted scenarios [80]. Moreover, trust is the most important factor for building a strong social interaction, cooperation, solidarity, and team spirit [47]. Members of an entrepreneurial team should focus on building team trust and loyalty in order to improve team performance. In entrepreneurial teams, trust is as an important factor that contributes to the success of a business [91]. Through social interactions, team members communicate with each other to exchange and combine ideas, resources, and information and obtain common goals [29].

Social interaction theory is made up of three dimensions; Trust, Interpersonal Interactions, and Perceived Profit. Interpersonal interactions play an important role in the sharing of knowledge and information. Two main dimensions of Interpersonal interactions are social interactions and trust. Social interactions demonstrate time spent, the sequence of communication between members, and the power of relationships. Social interactions create conditions by which people can share their knowledge and information. Trust refers to a series of specific beliefs that are related to the generosity, integrity, and ability of other members. In social interactions theory, trust is considered an essential factor for the process of social interaction. Trust maintains and creates relationships between individuals. There is more willingness to share information and cooperate between people when there is trust among them

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[52], [108]. Moreover, social interaction in an institution is related to affective commitment to that institution, and it is a contributor to the process of organizational commitment [66].

Social interaction not only allows each member to suggest different methods, views and ideas but also encourages members to compare different options and approaches [30]. The quality of social interaction is an important drive through which tacit knowledge is created and communicated in teams. The more social interactions in groups and teams, the more tacit knowledge is shared [114]. The quality of social interactions within the entrepreneurial team has a positive effect on the success of the firm. Researchers showed social interaction in teams facilitates innovation [46], [91], [127]. Furthermore, strong social interactions make the team more confident in their creative abilities [38]. In the literature, different team characteristics and social interactions of the entrepreneurial team have been examined. *Table 1* presents the articles that explored the team characteristics and social interactions of entrepreneurial teams and highlights the gaps in the literature.

Table 1. The literature on entrepreneurial team characteristics and social interactions.

Author(s) and Year	Heterogeneity	Experience	Self-Efficacy	Commitment	Trust	Social Interaction
Zhao and Feng [149]	✓					
Jin et al. [76]	✓					
Morrissette [99]					✓	
Khan et al. [80]	✓					
Indrawati et al. [73]			✓			
Khan et al. [80]					✓	
Prakash et al. [106]	✓					
Tasnim et al. [130]				✓		
Khan et al. [79]	✓					
Cassar [23]				✓		
Homberg and Bui [69]	✓					
Hechavarria et al. [65]			✓			
Weisz et al. [142]	✓					
Dautzenberg and Reger [41]	✓					
Cassar and Friedman [24]			✓			
Schjoedt and Kraus [119]		✓				
Chen and Wang [29]						✓
Lechler [91]						✓

This research tested seven hypotheses. The main hypothesis is that entrepreneurial team characteristics and their social interactions have either a positive or negative impact on the success of IT startups. The sub-hypotheses are the heterogeneity, experience, self-efficacy, commitment, trust, and social interactions of entrepreneurial team members have either positive or negative impacts on the success of IT startups.

Fig. 1 depicts the research model of this study. Based on the reviewed literature, we developed and tested the model. More specifically, we tested the relationship between heterogeneity of entrepreneurial teams and start-ups' success based on previous studies [11], [20], [63], [75], [97], [122]. Following prior research works [5], [23] the relationship between entrepreneurial team members' experience and start-up's success was tested. We also tested the association between entrepreneurial team members' self-efficacy [101], commitment [14], trust [47], [99], and social interactions [91] and their start-up's success.

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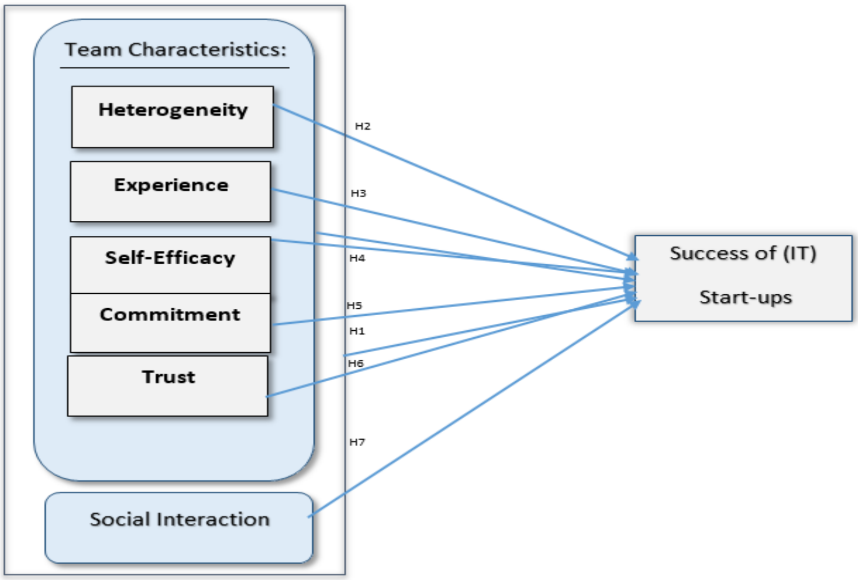

Fig. 1. The proposed research model.

3 | Method

3.1 | Sample and Procedure

This study employed quantitative research. Heterogeneity, experience, self-efficacy, commitment, trust, and social interactions of entrepreneurial team members are selected as the independent variables. The success of a start-up serves as the dependent variable. Data were collected from members of entrepreneurial teams of Information Technology (IT) start-ups in Tehran, the capital city of Iran. The start-ups were selected from a list of available start-ups registered in the Pardis Technology Park and the Presidential Deputy for Science and Technology. The statistical population consisted of 471 start-ups in the field of IT in Tehran. The sample size was calculated using Morgan's table. The sample was selected using the simple random sampling method. The data were collected using a questionnaire administered in both paper and electronic forms. We evaluated the reliability of the questionnaire using Cronbach's alpha [125]. The questionnaire Cronbach's alpha was 0.928 and the mean value of variance extracted was higher than 0.5 and the validity and reliability of the structures were confirmed. Of the participants, 133 (62.4%) were male and 80 (37.6%) were female. Majority of the participants aged between 25 and 30 (78, 36.6%) followed by 20–25 (57, 26.8%), 30–35 (46, 21.6%), 35–40 (15, 7%), 40–45 (9, 4.2%), 15–20 (5, 2.3%), 45–50 (2, 0.9%) and 50–55 (1, 05%). Regarding educational qualifications, the majority of the participants had a Master's degree (109, 50.7%) and Bachelor's degree (74, 34.7%) followed by a doctoral degree (22, 10.3%) and a Diploma (8, 3.7%). The majority of the participants had between 0 and 5 years of experience in the business (139, 65.3%) followed by 5–10 (47, 22.1%) and over ten years of experience (27, 12.6%).

3.2 | Measures

The questionnaire was designed based on validated items in previous studies and measured demographic characteristics, self-efficacy, experience, commitment, trust, social interaction of individual members of the entrepreneurial teams.

To measure the dimensions of heterogeneity, we used validated questionnaires. Specifically, we used the items developed by Wheeler et al. [144] to measure the need for achievement (10 items, e.g., "continual opportunities for personal growth and development"; $\alpha = 0.718$). Locus of control was measured using [120] questionnaire (11 items, e.g., "Overall, my skills and abilities will help me start a business."; $\alpha = 0.767$) and risk-taking was measured using [36] questionnaire (2 items, e.g., "when confronted with decision-making situations involving uncertainty, my firm Typically adopts a bold, aggressive posture to maximize the probability of exploiting potential opportunities"; α= 0.611).

The items developed by Campion et al. [22] were employed to measure the demographic diversity of the entrepreneurial teams (3 items, e.g., "team members have different backgrounds and experiences"; α= 0.630).

Using the questionnaire developed by Stephens [128], we measured the experience of the participants (5 items, e.g., "the reasons for developing a business network; the services received from a business network; their exposure to formal business networks; and finally, the benefits of a business network."; α= 0.727). The items developed by Högl [68] and Dampérat et al. [38] were employed to measure self-efficacy (9 items, e.g., "I have confidence in my ability to produce new ideas. "; α= 0.869). The items developed by Bishop and Scott [18] were employed to measure the entrepreneurial team members' commitment (8 items, e.g., "I am proud to tell others that I am part of this team."; α= 0.866) and the items developed by Chen and Wang [29] were employed to measure the participants' trust (4 items, e.g., "Entrepreneurial team members are willing to share things without anything to hide."; α= 0.837). We also used the items developed by Tsai and Ghoshal [135], Chen and Wang [29] to measure the social interactions of the participants (4 items, e.g., "With people of which units do you spend the most time together in social occasions?"; α= 0.706).

Finally, to evaluate the dimensions of success, including growth [145] we used 7 items (e.g., "has the market value of your firm increased or decreased relative to your competitors over the past 12 months?"; α= 0.674), profitability [131] was measured 8 items (e.g., "Do you think that that management of accounts receivable affect profitability? Why or why not?"; α= 0.827) and innovation [111] was evaluated with 6 items (e.g., "Compared with our competitors, our product modifications and innovations have a better market response."; α= 0.779). The participants were asked to indicate their agreement on all items using a 7-point Likert scale (1= strongly disagree to 7= strongly agree). They were also asked to provide their demographic data including age, gender, educational qualifications, and work experience. Of 250 questionnaires distributed, 226 were received out of which 13 were incomplete and were not used in our analysis. We used 213 questionnaires in the final analysis.

4 | Results

4.1 | Confirmatory Factor Analysis (CFA) and Correlations

A CFA was conducted using AMOS software [60] to measure the extent to which the constructs of this study (team characteristics, social interactions, and success) were distinct. The findings of this study show that heterogeneity, experience, self-efficacy, commitment, trust, and social interactions of the entrepreneurial team members have a significant positive influence on start-up success. To ensure the discriminant validity of the constructs in the scale, mean, standard deviations, variances, and correlations between variables were measured for each construct in this study. The results are presented in *Table 2*.

Table 2. Means, standard deviations, variance, and correlations among variables in the study.

Variable	Mean	Std. Deviation	Variance	1	2	3	4	5	6	7
Heterogeneity	5.478	0.803	0.702	1.000	.306	.379	.297	.344	.346	.310
Experience	4.811	0.968	0.939	.306	1.000	.315	.409	.221	.261	.281
Self-Efficacy	5.574	0.847	0.717	.379	.315	1.000	.784	.639	.598	.311
Commitment	5.519	0.944	0.892	.297	.409	.784	1.000	.602	.471	.285
Trust	5.669	0.958	0.919	.344	.221	.639	.602	1.000	.632	.219
Social Interaction	5.620	0.824	0.678	.346	.261	.598	.471	.632	1.000	.184
Success	5.669	0.969	0.952	.310	.281	.311	.285	.219	.184	1.000

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The model fitted the data well because χ2/df was < 3. The calculated significance level for the model fit (p-Value) in all indicators was less than 0.05. Comparative Fit Index (CFI) values, Goodness of Fit Index (GFI), and Tucker-Lews Index (TLI) for all the indicators were higher than 0.90, Root Mean Square Error of Approximation (RMSEA) was less than the 0.05 threshold, and Root Mean square Residual (RMR) index was close to zero for all of the indicators [1]. The CR value for the construct was above 0.7, which shows the appropriate internal stability of the measurement models. The results of our analysis also showed a good model fit for the impact of heterogeneity of entrepreneurial teams on the start-ups' success ($\chi2$ /df= 2.463, $p < 0.05$, GFI= 0.936, CFI= 0.902, TLI= 0.859, RMSEA= 0.08, RMR= 0.065). In addition, the factor loadings of heterogeneity variables on the start-ups' success also supported the significant impact of heterogeneity on the start-ups' success and confirmed the second hypothesis on the significant positive effect of heterogeneity on start-ups' success (*Fig. 2*).

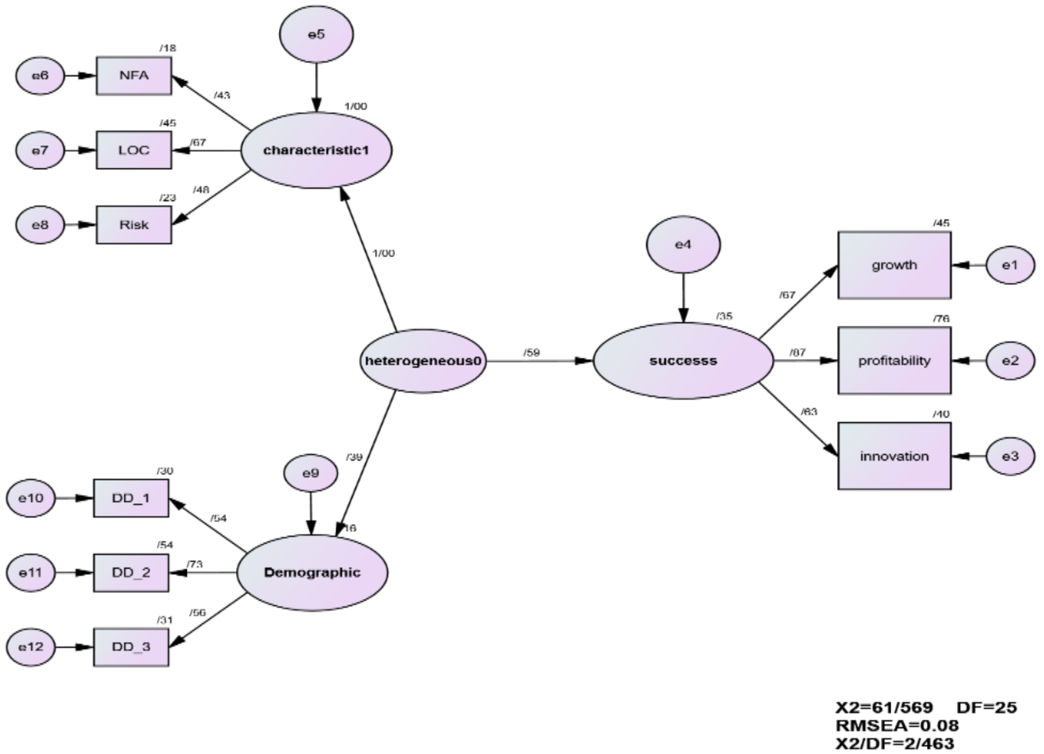

Fig. 2. Impact of heterogeneity on success.

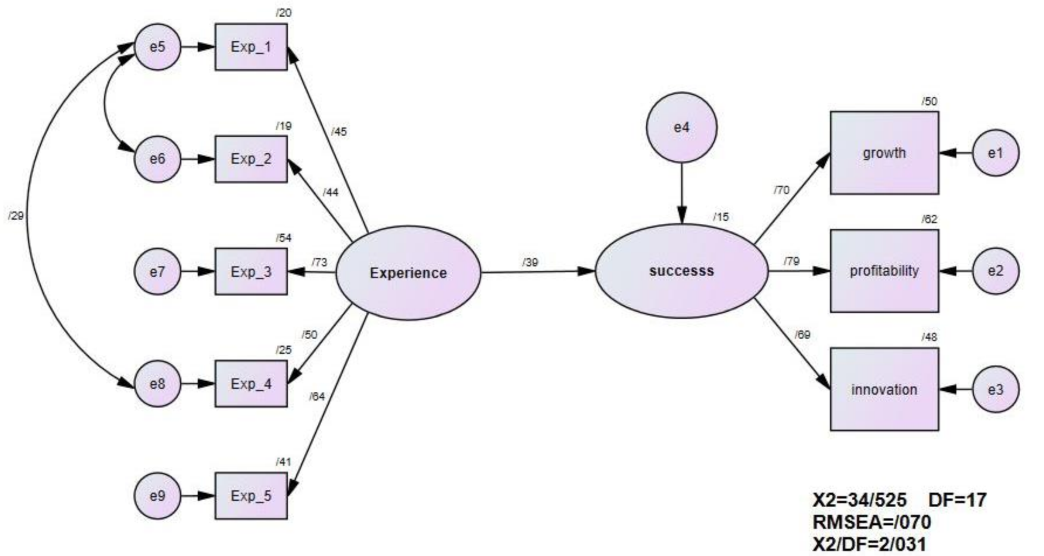

Fig. 3. Impact of entrepreneurial team members' experience on start-ups' success.

Results showed a good model fit for the impact of experience on success (χ2 /df= 2.031, p <0.05, GFI= 0.962, CFI= 0.956, TLI= 0.927, RMSEA= 0.070, RMR= 0.079). In addition, factor loading between the entrepreneurial team members' experience and their start-up's success supported the significant impact of experience on start-ups' success and confirmed the third hypothesis (*Fig. 3*).

Results also showed a good model fit for the impact of the entrepreneurial team members' self-efficacy on their start-ups' success (χ2 / df = 1.723, p <0.05, GFI= 0.931, CFI= 0.959, TLI= 0.948, RMSEA= 0.058, RMR= 0.066). Factor loading of the entrepreneurial team members' self-efficacy on the start-ups' success has also supported the significant impact of entrepreneurial team members' self-efficacy on the start-ups' success and confirmed the fourth hypothesis (*Fig. 4*).

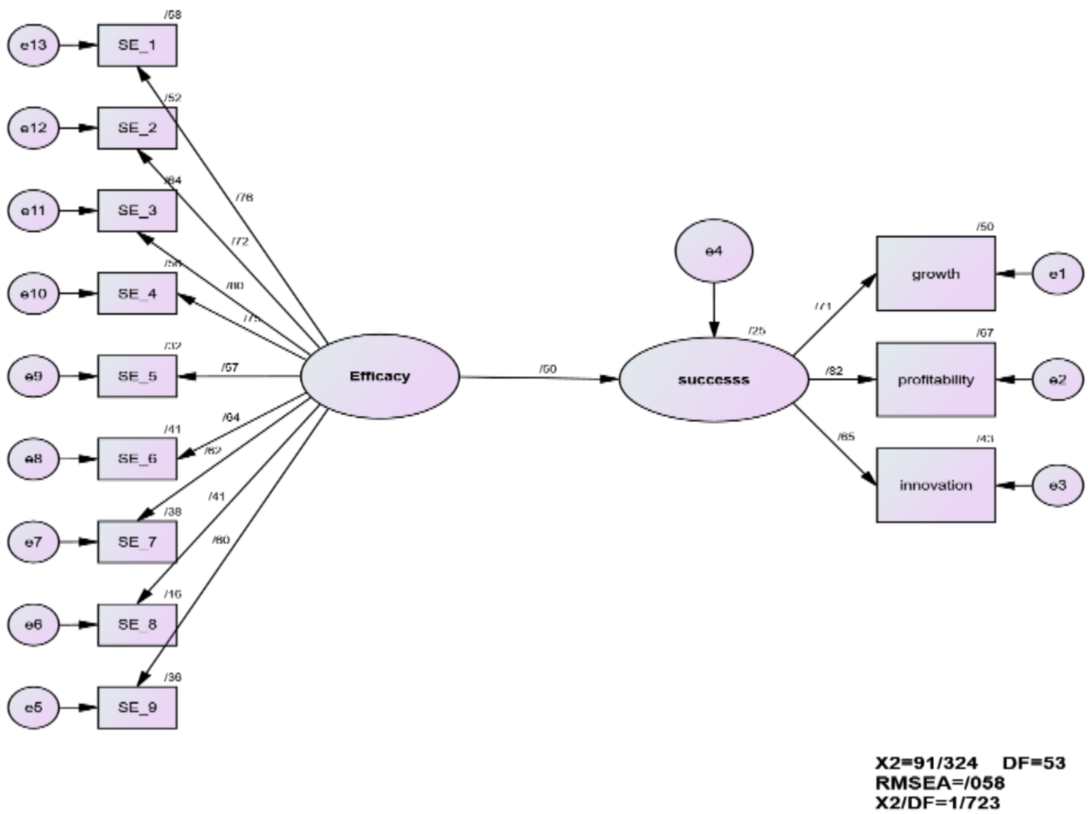

Fig. 4. Impact of entrepreneurial team members' self-efficacy on start-ups' success.

Our results also showed a good model fit for the impact of commitment on success (χ2 /df = 1.406, p <0.05, GFI= 0.952, CFI= 0.978, TLI= 0.972, RMSEA= 0.046, RMR= 0.052). Factor loading of commitment on success has also supported the significant impact of entrepreneurial team members' commitment on the start-ups' success and confirmed the fifth hypothesis (*Fig. 5*).

Additionally, the results of the analysis showed a good model fit for the impact of trust on success (χ2 / df= 0.738, p<0.05, GFI= 0.987, CFI= 0.995, TLI= 0.997, RMSEA= 0.000, RMR= 0.028). Factor loading between entrepreneurial team members' trust and start-ups' success also supported the significant impact of entrepreneurial team members' trust on the start-ups' success that confirmed the sixth hypothesis (*Fig. 6*).

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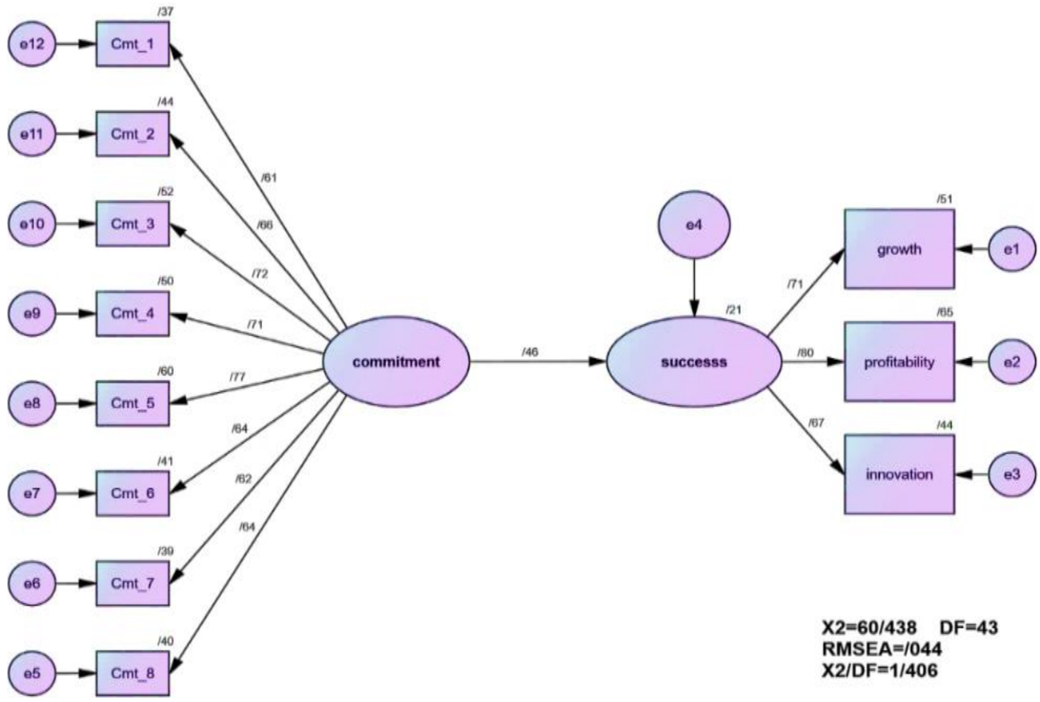

Fig. 5. Impact of entrepreneurial team members' commitment on start-ups' success.

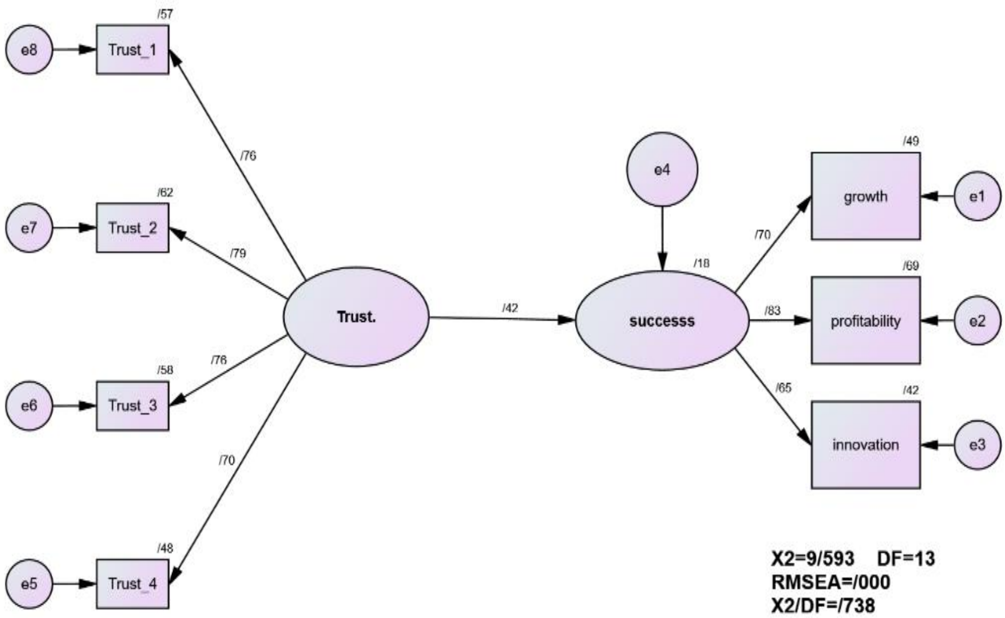

Fig. 6. Impact of entrepreneurial team members' trust on start-ups' success.

The results of our analysis also showed a good model fit for the impact of social interaction on success ($\chi 2/$ df= 1.140, $p < 0.05$, GFI= 0.982, CFI= 0.996, TLI= 0.992, RMSEA= 0.026, RMR= 0.049). Factor loading of social interactions on success also supported the significant impact of entrepreneurial team members' social interactions on start-ups' success and confirmed the seventh hypothesis (*Fig. 7*).

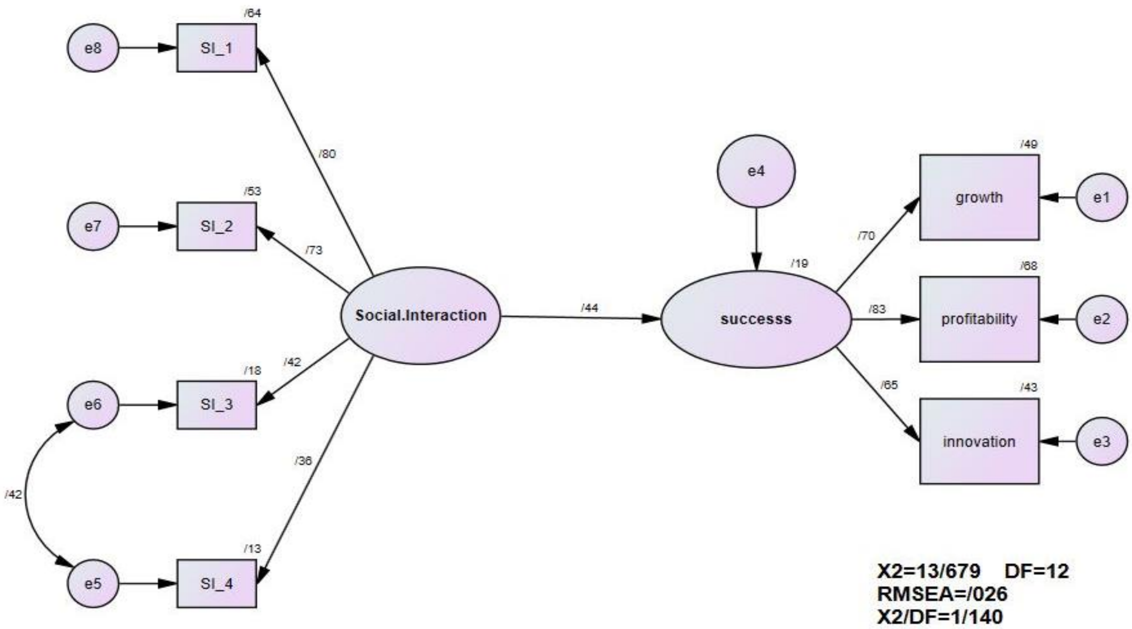

Fig. 7. Impact of entrepreneurial team members' social interaction on start-ups' success.

4.2 | Structural Model of the Impact of Study Variables on Start-Ups' Success

To test the validity of the first hypothesis that proposed the significant positive impact of team characteristics and social interactions on the start-ups' success, a structural model was developed using the procedures of Structural Equation Modeling (SEM) and maximum likelihood estimation. Model analysis suggested a good model fit ($\chi2$ /df= 1.516, p <0.05, GFI= 0.81, CFI= 0.90, TLI= 0.88, RMSEA= 0.049, RMR= 0.1). Our analysis showed that team characteristics (heterogeneity, experience, self-efficacy, commitment, trust) and social interactions have a significant positive effect on the start-up's success (p < 0.05). Therefore, all research hypotheses were confirmed (*Fig. 8*).

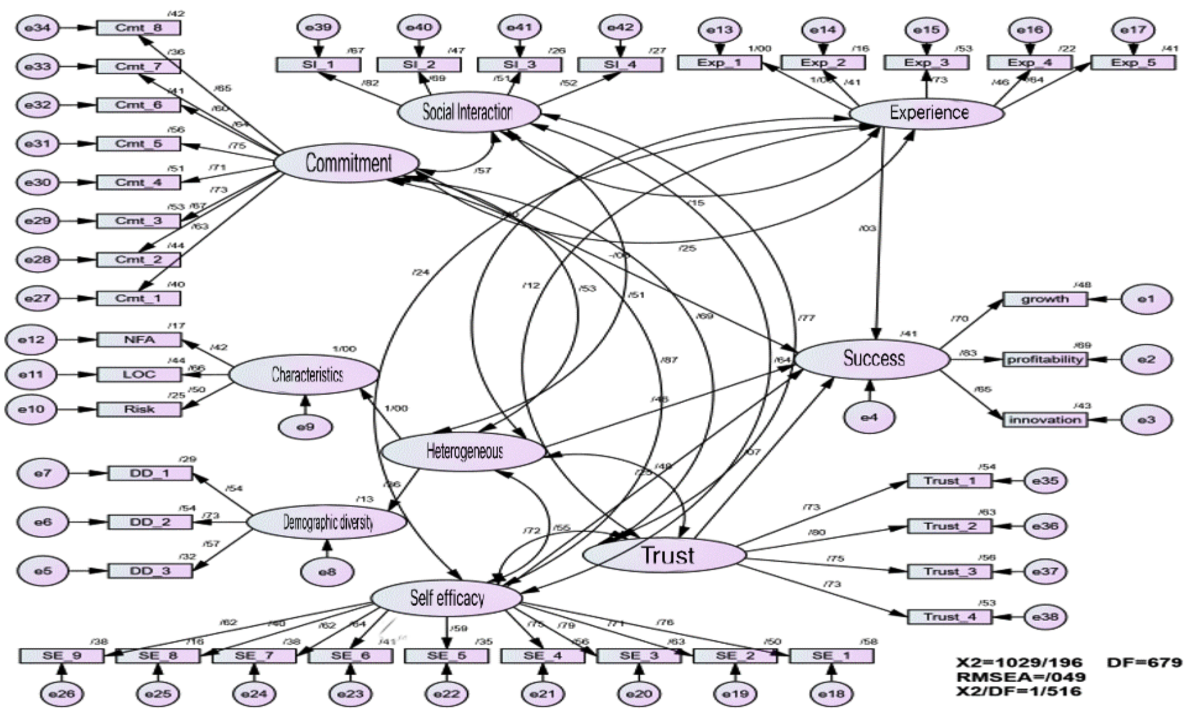

Fig. 8. Impact of personal characteristics and social interactions of entrepreneurial teams on start-ups' success.

5 | Discussion

The main purpose of this study was to investigate the influence of personal characteristics and social interactions of entrepreneurial teams on the success of IT start-ups. Findings indicated that team characteristics including heterogeneity, experience, self-efficacy, commitment, and trust as well as social interactions have a significant positive effect on the start-ups' success. This finding contributes to the growing number of studies on entrepreneurial teams. Specifically, this study extends previous research that suggested entrepreneurial teams' traits has a significant impact on their entrepreneurial performance [149]. Furthermore, this finding adds to the knowledge that the composition and traits of the senior management team have a significant impact on organizational outcomes [61], [76].

The findings of this study showed that the heterogeneity of entrepreneurial teams has a significant positive effect on the start-ups' success. This research contributes to the limited literature on entrepreneurial teams and start-ups' success [11], [30], [83], [97], [142], [148]. The literature also indicated that experience is important for a business's success since it helps people learn from previous experiences [23]. In this study, the effect of experience on success was investigated. The findings of this research supported previous studies in that the experience of entrepreneurial teams has a significant positive effect on the start-ups' success [5], [23], [34], [72], [136]. The effect of self-efficacy on success has been also investigated in the literature [27], [28], [65] and the findings of the present study showed that self-efficacy of entrepreneurial team members has a significant positive effect on the start-up's success.

Previous studies have also suggested that employees' commitment is significantly impactful on the success of entrepreneurial companies [14]. The findings of this study also supported the studies highlighted that commitment has a significant positive effect on start-ups' success [6], [14], [30], [109], [130].

The results of this study also show that trust has a significant positive effect on the start-ups' success. A meta-analysis of studies on trust in teams showed that there is a significant positive relationship between trust and team performance [99]. Finally, the findings of the present study showed that social interactions have a significant positive effect on the start-ups' success. This finding supports previous research [91] that suggested social interaction is essential in shaping new investments.

6 | Conclusions

The present study has empirically revealed the positive significant influences of team characteristics and social interactions of entrepreneurial teams on start-up success. The present study was conducted on IT start-ups. Therefore, the generalizability of the results to other businesses and contexts demands further research. The findings of this research have several implications for entrepreneurs, entrepreneurial teams, and business consultants. In this regard, novice entrepreneurs who seek to create a team may use the findings of this study to improve these characteristics in their team so that they improve the probability of their business success. This study is the starting point for future research on the impact of entrepreneurial teams on different aspects of the business. Furthermore, to increase the reliability and better explain the relationships between the entrepreneurial team and start-ups' success, future research should explore the role of moderators or mediators in the relationships that emerged from this study.

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Identifying Key Indicators for Developing the Use of Blockchain Technology in Financial Systems

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Abstract

Internet-based financial systems and communications have entered a new phase with the advent of blockchain technology and cryptocurrencies. The new economic system with its transparency, privacy, and peer-to-peer networking, has attracted the attention of economists. The advent of cryptocurrencies has brought new blood into the veins of blockchain technology and accelerated its growth. After a decade of cryptocurrency lifetime, it is necessary to identify key components to develop the use of this technology. The aim of this study is to identify the indicators needed to develop the use of blockchain technology and cryptocurrencies in financial systems. A total of six indicator groups were identified including technology, legislation, cybersecurity, regulatory methods, public acceptance, and investment. For this purpose, the three-round Delphi study is used to elicit expert opinions. Calculation of Kendall's W coefficient shows a high degree of concordance of experts' opinions in determining the indicators. The indicators presented in this research can be a helpful guide for governments and economic sections to develop the use of blockchain technology in financial systems.

Keywords: International financial system, Blockchain, Cryptocurrency, Delphi method.

1 | Introduction

Globalization is commonly defined as the expansion and continuity of the economy, communications, and technology around the world. Globalization over time, with its impact on the industrial, social, and economic areas, has led to fundamental changes in financial systems.

Also, technological advances in computer science and communications have accelerated changes in financial systems [1]. With the development of Internet-related technologies, organizations are adopting e-business and e-commerce technologies to increase productivity and respond more quickly to the needs of their customers [2]. In the field of financial systems and e-commerce, new platforms have emerged that are able to provide products and services with high speed and efficiency [3].

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The advent of blockchain technology has made it possible to securely transfer unique value samples (such as money, assets, and contracts) over the Internet without the intermediary approving or reviewing the process [4]. Blockchain technology and cryptocurrencies are expected to quickly become an important aspect of the global financial market and revolutionize financial communications [5]. Blockchain technology and cryptocurrencies in the area of economics have created new challenges in both the field of financial systems and new international currencies [6]. Blockchain technology has received the approval of many technology experts in the financial industry due to its benefits and practical capabilities in the financial system. Several major banks in Europe and the United States have begun testing blockchain technology in their internal systems. Blockchain-based financial technology in banking and payment systems offers new alternative solutions [7]-[9]. Also, over the past decade, the tendency of people and companies to use cryptocurrencies and their growing popularity has led to the increasing importance of cryptocurrencies as an alternative to traditional Fiat currencies [10], [11]. The aim of this study is to identify the indicators needed to develop the use of blockchain technology and cryptocurrencies in financial systems. In fact, this research seeks to answer the question of what actions are needed to be taken to develop the use of blockchain and cryptocurrency in financial systems. This paper is done by eliciting the insights of a group of experts using a three-round Delphi study. The statistical population of the research is comprised of experts in finance, IT, and academic members.

2 | Literature Review

2.1 | Blockchain

Over the past decade, Bitcoin's success as the first cryptocurrency has attracted the attention and interest of economists in blockchain technology. Blockchain is a kind of distributed ledger. The distributed ledger has a broader concept of blockchain technology, and blockchain has a broader concept of cryptocurrency and even financial issues [12]. Blockchain technology provides a distributed shared database and a consensus system. Blockchain, as a distributed shared database, only allows new data to be placed on blocks without updating or deleting existing data. This is to prevent manipulation and review. Blockchain enables information sharing and data transfer on a large network without relying on an integrated central system [13]. Consensus systems are a key element of any blockchain system to reach a consensus on data sharing and distribution of transactions across nodes [14].

The blockchain's integration, flexibility, and transparency features make it an attractive option for companies to revolutionize their business processes and use it to solve the challenges ahead [15]. With development and integration of modern technologies such as business process management, artificial intelligence, cloud computing and the Internet of Things (IoT) with blockchain technology, new opportunities are created for various industries [14]. Blockchain-based financial technology (FinTech) banking companies can offer services such as peer-to-peer lending, capital management and international financial remittances. Blockchain-based FinTech payment companies cover a wide range of personal, commercial, service and international payments [8], [9].

2.2 | Cryptocurrency

Cryptocurrency is a technology artifact and a financial transaction tool. It is predicted that cryptocurrencies will quickly become an important aspect of the global financial industry. Cryptocurrencies have created a new online payment system that offers new features and facilities. This peer-to-peer system enables direct online payment without being connected to a central financial system or financial institution. These distributed systems operate without the need for the control, monitoring and physical center that is common in conventional financial systems. Divided into very small units and transparency of transactions are the characteristics of the cryptocurrencies [16]. In year 2008, for the first time, Satoshi Nakamoto introduced a digital asset with distributed database called Bitcoin. Bitcoin is the most successful decentralized digital currency as the first cryptocurrency, at present. Many programmers began to create

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cryptocurrencies with different features and functions, observing the common success of Leadership, Bitcoin [12], [16], [17].

Palmié et al. [8] reviewed blockchain technology and related FinTech, and analyzed their impact on financial systems. The impact of blockchain on banking, payment systems, crowdfunding, insurance technology (InsurTech), regulatory technology (RegTech) and wealth management has been expressed. They concluded that new innovations have a disruptive effect on traditional and established financial systems, and that disruptive innovation ecosystems need more attention. Nawari and Ravindran [18] believe that the implementation of decentralized technology in any industry will make major changes. The results show that systems based on blockchain technology can be effective and promising due to their flexibility, powerful security, identity features, ease of programming and smart contract technology in the development of security and performance of automation systems. Qiu et al. [9] examined the impact of blockchain technology on changing financial systems in the field of international financial exchanges. They compared the strengths and weaknesses of the old and new systems based on SWOT analysis. They concluded that not in the short term, but in the long run, new technologies such as Ripple will revolutionize financial systems.

FinTech is developing rapidly based on cryptocurrency. Cryptocurrency will have a huge impact on e-business tools, e-commerce and financial systems [19]. At the following, the literature of the cryptocurrency is investigated from various point of views. Bach et al. [20] investigated the technology growth of distributed systems in the field of consensus algorithms. One of the most important issues in developing a consensus system is scalability. The ability of blockchain networks respond to demands on global scale is one power, increased memory, increased storage, and improved consensus mechanisms. Shanaev et al. [21] investigated the consequences of establishing rules and regulation for cryptocurrencies. They believe that strict laws and increased government control over the cryptocurrency market will reduce the price of cryptocurrencies. Allen et al. [19] examined the important points in the design of cryptocurrency rules and regulations. Making rules by increasing trust can lead to the growth of the cryptocurrency market and the growth of innovation. Guo and Yu [22] identified and analyzed the security risks of blockchain and cryptocurrencies by identifying the real hacker attacks and bugs against cryptocurrency-related platforms. Security risks are classified into six groups of high-level risks, including network attacks, endpoint security, intentional misuse, code vulnerabilities, data protection and human negligence.

Chokor and Alfieri [23] studied the long-term and short-term impacts of regulation in the cryptocurrency market. The purpose of developing regulatory methods is divided into three categories: The first purpose is to counteract risks in order to create financial stability. The second goal is to restrict criminal activities and money laundering transactions. The third goal is to generate revenue for the government by implementing appropriate laws and preventing tax evasion. Yeong et al. [24] examined the level of acceptance of cryptocurrencies among Information Technology (IT) enthusiasts in Malaysia. They identified important drivers that predict people's behavior toward accepting digital currency. Factors of performance expectation, facilitating conditions, social influence, and price value significantly influence a person's acceptance behavior. Böyükaslan and Ecer [25] identified the drivers to invest in blockchain technology and cryptocurrencies. Researchers have done a number of activities to prioritize investment drivers in cryptocurrencies. Strong cryptography has been identified as the most important investment driver.

The literature survey demonstrates that despite numerous and scattered researches on the application of cryptocurrencies in financial systems, there is no comprehensive study in identifying and classifying key indicators based on previous research to develop the use of cryptocurrencies in financial systems. The aim of this study is to pay attention to the current knowledge gap by identifying the necessary indicators to develop the use of cryptocurrencies in financial systems.

3 | Methodology

Given that only a decade has passed since the introduction of cryptocurrencies globally and the novelty of the subject, research in this area is very limited. In the lack of sufficient research and scientific experience, the Delphi study was used to derive specialized insights into identifying the indicators needed to develop the use of blockchain technology in financial systems. In addition to being a predictor of the future, the Delphi method has many applications in qualitative research. In this way, a panel of experts is formed. The basis of this approach is to gather feedback and reach a consensus among the panel participants [26]. Since the participants in the subject are knowledgeable and expert, the ideas collected in this way will be very helpful [27]. Since the Delphi technique came into existence in the 1950s, it has been widely used in researches. Some of them can be mentioned as business efficiency enhancements [28], project management [29], supply chain futures [30], (IT) [31]-[33].

Delphi studies may be combined with quantitative data collection (index scoring) and the use of quantitative approaches in data analysis to provide a more accurate and realistic analysis. Triangulation is one of the strategies to increase the validity of qualitative research that can improve the validity of the research which is used in this research [31]. There is no clear agreement on the number of an effective Delphi study rounds, and it should also be noted that adding more steps may result in lower response rates [34]. There are different methods for analyzing the data, but in the Delphi technique, descriptive statistics are usually used to check the data obtained at each round [31], [35]. More complicated techniques such as Kendall's W, used in this study, provide a tool for investigating changes between Delphi rounds [30]. The Delphi technique uses descriptive statistics to evaluate and compare expert responses. The Likert scale was used to quantify responses and the Kendall's W coefficient was used to obtain the concordance of responses and to identify the convergence created in the Delphi rounds. In the Kendall's W, $W = 0$ denotes the level of no conformity and $W = 1$ denotes the level of full conformity. There is no general consensus value for W indicating an "acceptable" value of consistency, but it is used as a comparative indicator between successive stages of the Delphi study [31]. This paper utilizes the three-round Delphi method to gain insights of experts on: What parameters develop the use of blockchain technology and cryptocurrencies in financial systems? In this research, two methods of literature survey and semi-structured interview and questionnaire are used to collect data. After defining the research topic, previous documents and researches in the field of research were reviewed and related parameters were extracted. According to the subject and protocol set for the selection of panel members of experts, Delphi panel members were identified and selected using non-probabilistic sampling methods.

The statistical population of this study, or panel of experts, is comprised of financial experts, (IT) specialists, and academic members in Iran, who work in the field of cryptocurrency. Expert panel members were selected by non-probability sampling and a combination of purposive (judgmental) and snowball (chain-referral) sampling methods. In total, 23 experts from the financial experts, IT specialists and academic members were interviewed. The descriptive characteristics of the panel members are described in *Table 1*.

Purposive and snowball sampling method is used in this study. In this method, after identifying or selecting the first group of experts (Purposive), they are used to identify and select the next group (snowball). Interviews begin with the first expert and during the interview they are asked to introduce new experts to the interview. Similarly, other sample units are identified and selected. Interviews continue until the information received is saturated, incremental learning is very low and no new parameters are introduced.

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Table 1. Descriptive characteristics of panel members.

Property	Specification	Relative Frequency	Relative Frequency Percentage
Job	Academic member	3	13%
	financial experts	8	35%
	IT specialists	12	52%
Education	B.Sc.	6	26%
	M.Sc.	12	52%
	PH.D	5	22%
Age	20-29	9	39%
	30-39	10	43%
	40-49	4	18%
Work experience	Up to 10 years	5	22%
	10 to 15 years	11	48%
	More than 15 years	7	30%
Gender	Female	3	13%
	Male	20	87%

Round one. The first questionnaire is sent as an open-ended question that acts as a strategy for generating ideas and its purpose is to reveal all issues related to the title under study [36]. Interviews are useful and enlightening when gathering information [37]. After collecting the questionnaires, responses are organized, comments similar to composition, grouping and repetitive and marginal themes are eliminated as short as possible [38]. In the first Delphi round, the results of previous studies and the list of extracted parameters was presented to the panel members. The questionnaire was provided to the experts and a semi-structured interview was conducted with them. The experts were asked to express their views, parameters and factors that are not listed and are important to them.

The questionnaire consists of four parts: first part provides some explanations about the blockchain technology, cryptocurrency and as well as parameters extracted from previous studies. Second part identifies respondent's area of expertise. And third part is an open ended question in which experts are asked to explain parameters that lead to the development of the use of blockchain technology and cryptocurrencies in financial systems. Each respondent was interviewed for more details [37].

After preparing the data, it was coded in two steps to structure the data and organize them. With the identification of codes in the first step (parameters) and pattern codes in the second step (indicators), they were used to create a structured questionnaire as a tool in the second round. The validity of the indicators extracted from the Delphi first round and the related questions were confirmed by a number of experts.

Round two. From the second round onwards, most of the structured questionnaires are used, and similar individuals in the first round are asked to rank each indicator using the Likert scale. Here, cases of agreement and disagreement are identified and a space is created for identifying new ideas, correcting, interpreting, deleting and explaining their strengths and weaknesses [39]. In the second round, a questionnaire consisting of the factors extracted from the Delphi first round was developed and re-sent to the panel members to evaluate the indicators. The questionnaire was structured and similar people were asked in the first round to quantify each indicator using the Likert scale while expressing their opinions about the parameters and indicators. The third section was used to evaluate the indicators using a 5-point Likert scale, in which the "least agreement" is indicated by the number one and the "most agreement" by the number five. Using descriptive statistics, the score of each indicator was calculated and ranked based on the score. Kendall's W concordance coefficient was calculated to determine the degree of consensus of experts.

Round three. At this round, the panel members, taking into account the average scores of the indicators, prioritized them according to their importance. The experts were also asked to state their reasons for disagreement if necessary. Kendall's W concordance coefficient was calculated to determine the degree of consensus of experts.

4 | Analysis and Discussion

4.1 | Round One of Delphi

At this round, through a semi-structured interview method, the research question was asked to determine the parameters that cause the development of the use of blockchain technology and cryptocurrencies in financial systems. Twenty-three experts answered questions. After receiving the answers and reviewing the views of experts, the researchers prepared the data with the information obtained from studying the literature and accompanied by two experts. After preparing the data, it was coded in two steps to structure the data and organize them. In the first step of coding, parameters and in the second step of coding, indicators were extracted. At this round, the validity of the extracted indicators was confirmed by two experts.

Based on the findings, 60 parameters were extracted. The parameters were classified into 6 indicator groups. Factors derived from the first round are listed in *Table 2*.

Table 2. Developing indicator of using blockchain technology and cryptocurrencies in financial systems.

1. Technology Growth
Technology growth of platforms (software and hardware)
Development of Blockchain-based software
Development of innovation in blockchain and cryptocurrency
Installation of cryptocurrency ATMs around the world
Using cryptocurrency POSs in service centers around the world
Creating different cryptocurrency for different purposes
Increasing efficiency and speed in consensus systems
Development of technology in cryptocurrency wallets and exchanges
Development of technology in smart contracts
Production of cryptocurrency high-performance mining device
Increase the speed of transaction network of blockchain (TPS)
Achieving global scalability
Development of ICT infrastructure
2. Legislation (Rule and Regulation)
Enacting international regulation agreed by countries in the field of blockchain and cryptocurrency
National legislation of countries in the field of blockchain and cryptocurrency
Making appropriate regulations by international financial systems
Establishing regulation by the World Bank
Establishing regulation by the International Monetary Fund (IMF)
Establishing regulation by the FATF
Making appropriate rules for international exchanges
Enacting property laws and dispute resolution rules
Enacting tax laws
Making investment rules
3. Development of Cybersecurity
Increasing cybersecurity of blockchain network
Development of proper cybersecurity for cryptocurrencies
Development of cybersecurity in the field of blockchain-based software
Development of cybersecurity in the field of IoT
Increasing cybersecurity of cryptocurrency wallet
Increasing cybersecurity by hardware upgrades
Increasing cybersecurity of exchanges
Development of cybersecurity to prevent infiltration of hackers
Development of cybersecurity to prevent cyber spying

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Table 2. Continued.

4. Development of Regulatory Methods
Development of RegTech for blockchain-based software
Achieving proper monitoring technology for cryptocurrencies
Development of surveillance technology to prevent cybercrime
Improvement of monitoring and controlling systems to prevent tax evasion
Improving Know Your Customer (KYC) and identification methods
Development of Anti-Money Laundering (AML) methods
Development of Combating Financing of Terrorism (CFT) methods
Making regulatory frameworks for cryptocurrency transfer
Establishing distributed regulatory
5. Public Acceptance
Increasing public trust in the cryptocurrency and blockchain-based softwares
Increasing desire of people to use cryptocurrency and blockchain-based softwares
Increasing interest of financial systems to use cryptocurrency and blockchain-based FinTech
Increasing interest of governments to use cryptocurrency and blockchain-based softwares
Using in financial systems, banking and payment
Creating and using national stablecoin by governments in domestic financial transactions
Promoting the use of cryptocurrency as a medium of exchange
Public awareness of the advantages of using cryptocurrency and blockchain
Using cryptocurrencies in international trade by merchants and companies
Acceptance of Initial Coin Offering (ICO)
Acceptance and use of cryptocurrency by service centers
6. Increasing Investment
Increasing investment in blockchain technology
Increasing investment in blockchain-based applications
Increasing the total market capitalization of cryptocurrencies
Increasing investment in the cryptocurrency platforms and tools
Increasing the turnover of cryptocurrencies
Increasing the turnover of cryptocurrencies to an appropriate percentage of the turnover of global trade
Public participation in the initial investment of projects by purchasing ICOs
Using national stablecoin to increase total market capitalization

4.2 | Round Two of Delphi

The second round of Delphi consisted of a structured questionnaire and similar people in the first round were asked to quantify each indicator using the Likert scale while expressing their views on the parameters and indicators. In the second round, the panel members agreed to group the parameters and scored the obtained indicators. Ranking results of the indicators are presented in *Table 3*. Expert responses have a concordance degree of 0.27 according to Kendall's W coefficient of concordance (W = 0.27).

Table 3. Ranking of extracted indicators in Delphi round two.

Indicators	Mean	Std. Deviation	Ranking
Technology growth	4.56	0.66	1
legislation (Rule and Regulation)	4.47	0.79	2
Development of cybersecurity	4.17	0.93	3
Development of regulatory methods	4.13	0.54	4
Public acceptance	4.08	0.51	5
Increasing investment	3.39	0.89	6

4.3 | Round Three of Delphi

In the third round, another questionnaire was provided to the participating experts in the previous stage. They were requested to prioritize indicators based on importance while viewing the ranking obtained from round 2 based on average scores given to each indicator. Then, they comment on ranking and prioritize the results. According to the experts' prioritization of six indicators at this round, the highest priority was assigned 6 and the lowest priority 1 to allow calculating the average and Kendall's W coefficient of concordance. At this round, a higher value of Kendall's W coefficient of concordance (W = 0.54) was obtained. The results of prioritization of indicators are presented in *Table 4*.

Table 4. Prioritizing the importance of indicators in Delphi round three.

Indicators	Mean	Std. Deviation	Prioritizing
legislation (Rule and Regulation)	5.26	0.61	1
Technology growth	4.78	1.31	2
Development of cybersecurity	3.82	1.37	3
Development of regulatory methods	3.17	1.19	4
Public acceptance	2.26	1.32	5
Increasing investment	1.78	1.12	6

4.4 | Discussion

Blockchain and cryptocurrencies have created a new paradigm in financial systems and financial transactions. These phenomena have opportunities and threats that need to be identified in order to take advantage of those opportunities and repel their threats, tactfully. In the first round of Delphi, by coding the first and second steps and approval by experts, the initial model of the research is obtained. By creating pattern codes in the second step, the researcher can use approaches such as tabular representation (*Table 2*) or visual representation (*Fig. 2*) for analysis. *Fig. 2* shows the model of indicators needed to "develop the use of blockchain technology and cryptocurrencies in financial systems".

This study describes the indicators that need to be realized in order to create the conditions for developing the use of blockchain and cryptocurrencies in financial systems. The six indicators based on pattern codes include technology growth, legislation (Rule and Regulation), development of cybersecurity, development of regulatory methods, public acceptance, and increasing investment.

Technology growth

The growth of the technology is important in both hardware and software platforms [40]. Production of servers and mining devices with higher efficiency, global expansion of cryptocurrency ATMs, and expansion of cryptocurrency Point of Sales (POSs) in stores and service centers are examples of the growth of technology [41]. Also, due to the advantages of cryptocurrencies, various application software is being developed based on them, which will increase the public use of this technology [42]. One of the important parameters in the growth of blockchain technology is the growth of consensus systems in this technology. As a result, the possibility of developing consensus systems with high efficiency and speed and optimal consumption of energy is very important [14]. A panel member stated:

One of the most important issues in the development of cryptocurrencies is the scalability or ability of the network to respond to the demand of the network. The ability of cryptocurrencies to respond to global demand is one of the challenges of this technology for its ambitious goals in the future, which can be solved by the growth of technology and innovation.

Legislation (Rule and Regulation). Leading countries in the field of cryptocurrencies have developed an initial support framework for companies operating in the field of cryptocurrencies [21], [43]. The existence of international law will provide a good framework for national legislation so that governments can provide the right legal framework to support cryptocurrencies [19]. Establish laws to protect private companies, making regulations to provide the documents required for accounting and taxation, developing identification regulations, and determining the ways to comply with anti-money laundering regulation, are very important in the development of cryptocurrencies [7]. A panel member stated:

To develop the use of cryptocurrencies, it is necessary to compile the required laws in the areas of cryptocurrency mining, taxation, ownership, investment, and exchange. In all economic activities, rules and regulations protect the rights of both parties.

Development of cybersecurity

High security is one of the key features of cryptocurrencies. However, there have been criticisms of security problems in this system by critics that need to be clarified [44]. As now, the cryptocurrencies themselves have not been hacked, but that some ancillary services such as wallets created for support have had security problems [22]. In cryptocurrency systems, there are risks such as stealing private key of cryptocurrency from wallets, hacking exchanges, hacking applications of cryptocurrency and blockchain due to program design flaws, phishing attacks, using cryptocurrencies as payment methods in ransomware, using power of hacked computers to mine cryptocurrencies, and vulnerability of smart contracts due to design flaws [45], [46]. Development and increase of cybersecurity will be possible with the coordinated development of hardwares and softwares [8]. A panel member stated:

The importance of developing appropriate cybersecurity for applications of cryptocurrency in areas such as the IoT, cryptocurrency wallets, cryptocurrency exchanges, and smart contracts to prevent the infiltration of hackers and intelligence services is increasing day by day.

Development of regulatory methods

Developing regulatory methods based on RegTech helps governments and regulatory centers monitor the implementation of rules by companies and individuals [47]. Cryptocurrency is one of the main areas considered in the development of regulatory methods. Like any other tool, cryptocurrencies can have dual function, meaning that in addition to their widespread use in legal activities, they can also be used in criminal activities [23]. Regulatory systems and RegTech companies are trying to develop identification methods and KYC. Another important issue in the development of regulatory methods is tax management and trade monitoring [8]. A panel member stated:

Development of regulatory methods in financial systems and the possibility of monitoring trade and preventing tax evasion, is very effective in increasing government support for cryptocurrencies and the use of cryptocurrency-based financial systems in the world.

Public acceptance

Potential applications and features of cryptocurrency in various fields have created hope for solving various challenges [48]. This gradually increases the desire of people, government and organizations for this technology. The use of cryptocurrency in business processes, property management and FinTech is expanding [8]. Also, cryptocurrencies are proposed as alternatives to Fiat currencies for use in payments and financial transactions [11]. Public awareness of the advantages of cryptocurrencies, increasing the use of cryptocurrencies in peer-to-peer payments, and acceptance of cryptocurrencies by service and shopping centers will build public acceptance [24]. Establishing trust in online relationships is essential [49]. By achieving an appropriate percentage of trust and acceptance in the global level, we can expect this technology to gain an appropriate percentage of global turnover [19]. A panel member stated:

Proper understanding of investors and users about the uncertainty of financial asset markets and cryptocurrencies, and the future value of the cryptocurrency market can be effective in controlling fear and uncertainty and increasing their trust.

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Increasing investment

Policies adopted on investment and the use of cryptocurrency vary across countries. The developed countries support private companies and government organizations to invest in cryptocurrency market, platforms and applications in order to take advantage of opportunities [8], [50]. One of the most interesting and challenging phenomena created by cryptocurrency is the ICO. Entrepreneurs and development teams use ICOs to raise capital without applying the usual business rules [51]. Increasing total market capitalization of cryptocurrencies will expand the use of cryptocurrency in international financial exchanges, as well as have a direct impact on the development and increase of investment in this technology [52]. A panel member stated:

I. Sustainable investment in research and development of any new technology, especially cryptocurrencies, is of particular importance. Also, increasing the total capital of the cryptocurrency market will have a direct impact on the development of investment in this field.
II. In the second round, the developing indicators of the use of blockchain technology and cryptocurrencies in financial systems were ranked.
III. In the third round, the experts have arranged the importance of the indicators according to the results of the second round. *Table 5* shows the comparison of rankings based on the average score of round 2 and prioritization based on importance score in round 3. The results in this table show the high consensus in the opinions of experts.

Table 5. Comparison of the indicators group rank based on second and third round of Delphi.

Round 3		Rank	Round 2	
Prioritize Indicators	**Mean**		**Mean**	**Ranking Indicators (Likert Points)**
legislation (Rule and Regulation)	5.26	Top	4.56	Technology growth
Technology growth	4.78		4.47	legislation (Rule and Regulation)
Development of cybersecurity	3.82		4.17	Development of cybersecurity
Development of regulatory methods	3.17		4.13	Development of regulatory methods
Public acceptance	2.26		4.08	Public acceptance
Increasing investment	1.78	Down	3.39	Increasing investment

The difference between the two rounds is the "technology growth" and "legislation" indicators. In the second round, the "technology growth" indicator has the highest agreement among experts as the first indicator. This shows that there is the most consensus on "technology growth" or, in other words, on “necessity of the growth of blockchain technology and cryptocurrencies to develop their use in financial systems ". The "legislation" indicator replaces the "technology growth" indicator in the third round and is the first priority in the third round. At present, during this period of blockchain and cryptocurrency development, the importance of "legislation" is the first priority, which is logical. Because any technology requires rules and appropriate legal infrastructure for further development. After a period of growth in technology and limited use in the world, Blockchain needs legislation to continue its growth process. During this period of development of blockchain and cryptocurrencies, which has been met with initial acceptance in countries, the need for "legislation" has become more important. This is a continuous process. With the growth of technology, the related rules will gradually be completed, and the growth process in the growth cycle of blockchain technology will continue.

5 | Conclusion

This article provides a framework for “indicators needed to develop the use of blockchain technology and cryptocurrencies in financial systems” and provides an understanding by extracting insights of the panel of experts through the use of Delphi study. Given limited literature in this field, this study states parameters needed to develop the use of blockchain technology and cryptocurrencies, also examines the priority of their importance. The indicators for expanding the use of cryptocurrencies and blockchain in international financial exchanges have been expressed in order to effectively use advantages of this new technology. The main indicators include technology growth, legislation, development of cybersecurity, development of regulatory methods, public acceptance, and increasing investment. The indicators are presented in *Fig. 1*.

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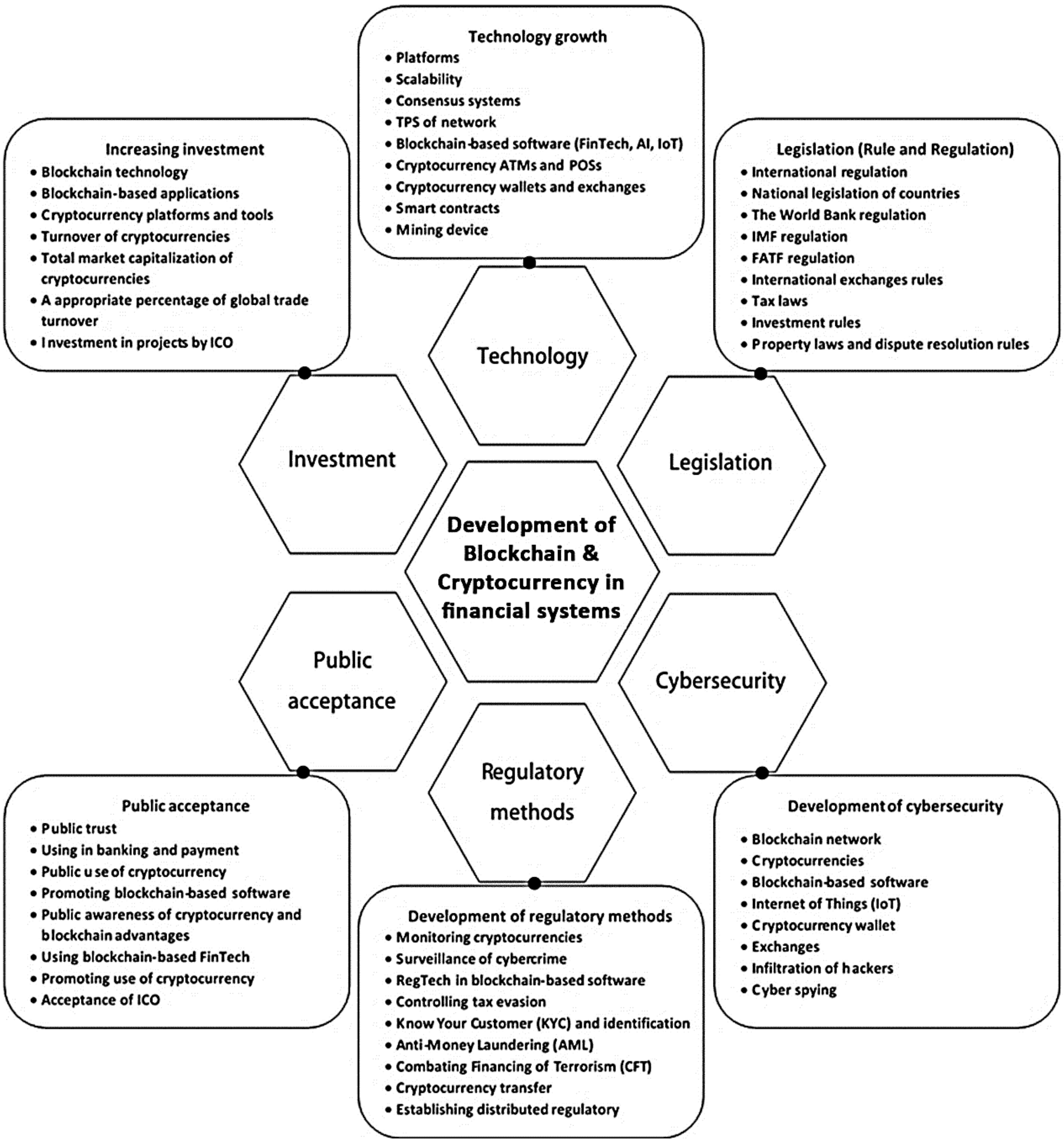

Fig. 1. The indicators needed to develop the use of blockchain and cryptocurrencies in financial systems.

The existence of international and national rules and regulations in the field of blockchain and cryptocurrencies in order to create formal and legal frameworks for the development and action of financial systems is an undeniable requirement. Technology growth in hardware/software platform has an important impact on the stability, proper performance, efficiency and energy consumption of blockchain systems. The development of blockchain technology in the field of consensus system, scalability and support for the number of Transactions per Second (TPS) is great importance in the global application of this technology.

In addition to legislation, another important parameter in technology development and building public trust is appropriate cybersecurity. Cybersecurity is an important component of online financial systems. Legislation and cybersecurity require development of appropriate regulatory methods to monitor the implementation of blockchain and cryptocurrencies regulations. Regulatory systems are trying to establish customer monitoring and identification systems in the field of blockchain technology. It should be noted that the development of appropriate regulatory methods in the field of money laundering, terrorist financing, tax collection and trade monitoring is very important for governments and will have important effects on the development of this technology in the future. Awareness of people and organizations with the advantages of blockchain technology and cryptocurrencies, and promoting the use of cryptocurrencies in payment and financial systems will gradually build trust and public acceptance. With increasing public acceptance and the use of technology by the people, governments and organizations, investment in blockchain technology will also be increased.

It should be noted that due to face-to-face interview we were geographically limited to utilize more experts' opinions. Maybe, the indicators and related elements of each indicator are changed when more experts are used in the Delphi study.

In future research, each of the obtained indicators, including technology growth, legislation, development of cybersecurity, development of regulatory methods, public acceptance, and increasing investment, should be investigated to determine the technical and specialized dimensions and their development models in financial systems should be presented. Using the expertise of different countries in future research, the comprehensiveness of the results in identifying the indicators affecting the expansion of blockchain use in financial systems will increase. Research on the requirements for developing trade relations with other countries based on blockchain technology will help to develop the use of e-commerce in international trade.

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A Numerical Solution for the Fractional Ideal Equation of Thermoelectric Coolers

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Abstract

One of the fields studied in the science of heat physics is the thermoelectric phenomenon. This phenomenon is in fact the interaction between the current of electricity and the thermal properties of a system. In simpler terms, it is a phenomenon in which the direct conversion of a temperature difference to voltage occurs. In this paper, we introduced a method based on the finite difference technique for solving a fractional differential equation in the field of thermal physics which describes the thermoelectric phenomena, numerically. For this purpose, we used fractional order derivatives with the definitions of Caputo, finite differences with the second order central finite-difference approach, and the first order central finite-difference. By using this method, we translate the desired differential equation to a system of nonlinear differential equations which can be solved. Finally, some numerical are used to demonstrate the effective and accuracy of the scheme. The obtained numerical results show that our proposed method is highly accurate.

Keywords: Thermal physics, Thermoelectric phenomenon, Finite difference, Fractional order.

1 | Introduction

One of the ways to study the behavior of physical phenomena is to model them using the equations governing these phenomena by mathematical tools, in which differential equations are undoubtedly one of the most powerful tools in this regard [1]-[3]. Differential equations as a branch of mathematics are powerful tools in many scientific fields such as geology, chemistry, physics, engineering and other sciences [4].

One method of solving differential equations is the finite difference method [5]. The first application of finite difference methods was published in the second decade of the 20^{th} century by Richardson on fluid dynamics. In recent years, many researchers have developed numerical models to solve problems in various fields of science using this method.

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One of the fields studied in the science of heat physics is the thermoelectric phenomenon [6]. This phenomenon is in fact the interaction between the current of electricity and the thermal properties of a system. In simpler terms, it is a phenomenon in which the direct conversion of a temperature difference to voltage occurs. One of the most famous classical equations in this phenomenon is the heat flux equation (heat flow density vector) and is as follows:

$$\vec{q} = -k\vec{\nabla}T + S\vec{Tj}, \tag{1}$$

where S is Seebeck coefficient, T is the absolute temperature, j is the current density and k is the thermal conductivity. In fact, *Eq. (1)* expresses the net cooling power in terms of heat flux vector [7]. Ones can write the steady-state of heat diffusion equation as follows [7]:

$$\nabla.\left(k\vec{\nabla}T\right) + j^2\varphi - T\frac{dS}{dT}\vec{j}.\vec{\nabla}T = 0, \tag{2}$$

where the φ is the electrical resistivity and as we can see it is a nonlinear differential equation. In *Eq. (2)* the first, second and the third terms are the thermal conduction, the Joule heating and the Thomson heat, respectively [7]. It is usually assumed that the Thomson effect does not exist or can be ignored [8]-[10].

The fractional calculus raised in the 18th century. It is a branch of mathematics that orders of derivatives and integrals are arbitrary. In fact, it is a natural extension of classical mathematics. Really, this matter has recently become an increasingly important topic in the literature of many sciences such as applied mathematics, engineering, and so on. It has attracted the notice of many scientists in different fields of sciences [2], [11], [12]. Different methods have been used to solve this type of equation [13]-[15].

The *Eq. (2)* has been transformed into an ordinary nonlinear differential equation by using dimensionless variables as follows [7]:

$$y'' - abyy' + a(b-1)y' + c = 0. \quad y(0) = 0, \quad y(1) = 1 \tag{3}$$

Eq. (2) of the fractional order is as follows:

$$y^{(\alpha)} - abyy' + a(b-1)y' + c = 0, y(0) = 0. \quad y(1) = 1, \quad 1 < \alpha \le 2 \tag{4}$$

In this paper, we intend to solve the *Eq. (4)* by the finite difference method and then observe the effect of the fractional order of the derivative of the equation through the change in the order of the derivative. Finally, we compare the obtained solutions by drawing their graphs.

2 | Definitions, Basic Concepts and Formulas

In this section, we present some basic concepts, definitions, formulas, block pulse functions and the fractional calculations.

Definition 1. When $z(t) \in L_1[0, b]$ we will have the fractional derivative in Caputo sense as follows [4]:

$$D^{\alpha}z(t) = \begin{cases} I^{n-\alpha}D_t^n z(t), \ n-1 < \alpha \le n, \ n \in \mathbb{N}, t > 0 \\ \dfrac{d^n}{dt^n}z(t). \qquad \alpha = n \end{cases} \tag{5}$$

For a constant value, the derivative by means of Caputo is 0, and we have:

$$D_x^{\alpha}t^n = \begin{cases} 0, & n \in \mathbb{N}, n < \lceil\alpha\rceil \\ \dfrac{\Gamma(n+1)}{\Gamma(n+1-\alpha)}t^{n-\alpha}, & n \in \mathbb{N}, n > \lceil\alpha\rceil \end{cases} \tag{6}$$

where $\lceil\alpha\rceil$ is the smallest integer number larger from α [4].

Definition 2 ([4]). The Riemann-Liouville fractional derivative of order α where with respect to the variable t and with the starting point $t = a$ is

$$D^{\alpha}z(t)=\begin{cases}\frac{1}{\Gamma(n-\alpha)}\frac{d^n}{dt^n}\int_a^t(t-\tau)^{n-1-\alpha}z(\tau)d\tau, & \circ\le n-1\le\alpha<n\\ \frac{d^n}{dt^n}z(t), & \alpha=n\in\mathbb{N}\end{cases} \quad (7)$$

By means of the Riemann-Liouville sense, the fractional integral of order α is defined as [4]

$$I^{\alpha}\big(z(t)\big)={}_aD_t^{-\alpha}z(t)=\frac{1}{\Gamma(\alpha)}\int_a^t(t-\tau)^{\alpha-1}z(\tau)d\tau. \qquad \alpha>\circ \quad (8)$$

The relation between the Caputo operator and Riemann-Liouville is as follows [4]

$${}_aD_t^{\alpha}I^{\alpha}z(t)=z(t). \quad (9)$$

$$I^{\alpha}\,{}_aD^{\alpha}z(t)=z(t)-\sum_{k=\circ}^{n-1}z^{(k)}(a^+)\frac{(t-a)^k}{k!}. \qquad t>\circ \quad (10)$$

Lemma 1 ([4]). Let $\alpha,\beta\ge\circ, d_1,d_2\in\mathbb{R}$ and $k(t),g(t)\in L_1[\circ,p]$, and then

$$D^{\alpha}\big(d_1g(t)+d_2k(t)\big)=d_1D^{\alpha}g(t)+d_2D^{\alpha}k(t). \quad (11)$$

$$I^{\alpha}I^{\beta}g(t)=I^{\beta}I^{\alpha}g(t), I^{\alpha}I^{\beta}g(t)=I^{\alpha+\beta}g(t). \quad (12)$$

The basic concepts of finite differences are described in detail in various books [5]. Finite differences were introduced by Brook Taylor in 1715 and have also been studied as abstract self-standing mathematical objects in works by George Boole in 1860, Milne-Thomson in 1933, and Karoly Jordan in 1939. Finite differences trace their origins back to one of Jost Burgi's algorithms in 1592 and work by others including Isaac Newton [16]. A finite difference is a mathematical expression of the form $f(x+b)-f(x+a)$. If a finite difference is divided by $b-a$, one gets a difference quotient. The approximation of derivatives by finite differences plays a central role in finite difference methods for the numerical solution of differential equations, especially boundary value problems.

The difference operator, commonly denoted Δ is the operator that maps a function f to the function $\Delta[f]$ defined by $\Delta[f](x)=f(x+1)-f(x)$. A difference equation is a functional equation that involves the finite difference operator in the same way as a differential equation involves derivatives. There are many similarities between difference equations and differential equations, especially in the solving methods. Certain recurrence relations can be written as difference equations by replacing iteration notation with finite differences. In numerical analysis, finite differences are widely used for approximating derivatives, and the term "finite difference" is often used as an abbreviation of "finite difference approximation of derivatives" [17]-[19]. Finite difference approximations are finite difference quotients in the terminology employed above. Three basic types are commonly considered: forward, backward, and central finite differences [17]-[19].

A forward difference, denoted $\Delta_h[f]$ of a function f is a function defined as $\Delta_h[f](x)=f(x+h)-f(x)$. Depending on the application, the spacing h may be variable or constant. When omitted, h is taken to be 1; that is $\Delta_1[f](x)=\Delta[f](x)=f(x+1)-f(x)$.

A backward difference uses the function values at x and $x-h$, instead of the values at $x+h$ and x as $\nabla_h[f](x)=f(x)-f(x-h)$.

Finally, the central difference is given by $\delta_h[f](x)=f\left(x+\frac{h}{2}\right)-f(x-\frac{h}{2})$. So here are just a few definitions needed in this regard.

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Definition 3. The finite-difference grid can be defined as follows: the solutions region in the $x-y$ space is defined by a rectangular grid with dimensions Δx and Δy along the axes of x and y, respectively. *Fig. 1* shows this grid.

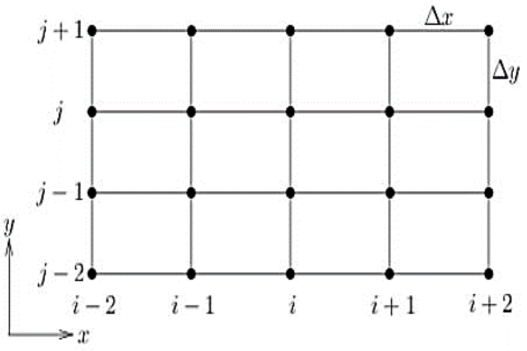

Fig. 1. Finite difference grid.

In this method, the function and its derivatives are approximated by finite differences. In this paper, we use two types of finite difference approximations, which we define below.

Definition 4. The approximation of the first-order derivative by centered difference is defined as follows:

$$y'(t_n) \simeq \frac{y_{n+1} - y_{n-1}}{2h}, \tag{13}$$

where y_{n+1} and y_{n-1} are the function values at points $(n + 1)$ and $(n-1)$ of the network, respectively.

Definition 5. The approximation of the second-order derivative by centered difference is defined as follows:

$$y''(t_n) \simeq \frac{y_{n+1} - 2y_n + y_{n-1}}{h^2}, \tag{14}$$

where y_{n+1} ,y_n and y_{n-1} are the function values at points $(n + 1)$, n and $(n-1)$ of the network, respectively.

3 | Numerical Method

In this section, we first solve the *Eq. (4)* with the finite difference method. Then, with the same method, we solve the mentioned equation with fractional derivative in Caputo sense.

Case1. Suppose $\alpha = 2$, so the *Eq. (4)* is as follows:

$$y'' - abyy' + a(b-1)y' + c = 0. \quad y(0) = 0, \qquad y(1) = 1 \tag{15}$$

Let $t_n = nh, n = 0, 1, \ldots, N, t_0 = 0, t_N = 1, y_0 = 0, y_N = 1$, then we approximate the derivatives in equation with finite differences as follows:

$$\begin{cases} y'(t_n) \approx \dfrac{y_{n+1} - y_{n-1}}{2h}, \\ y''(t_n) \approx \dfrac{y_{n+1} - 2y_n + y_{n-1}}{h^2}. \end{cases} \tag{16}$$

By replacing these approximations in the mentioned equation, we have

$$\frac{y_{n+1} - 2y_n + y_{n-1}}{h^2} - aby_n \frac{y_{n+1} - y_{n-1}}{2h} + a(b-1)\frac{y_{n+1} - y_{n-1}}{2h} + c = 0. \tag{17}$$

Now for $n = 1$ we get

$$\frac{y_2 - 2y_1}{h^2} - aby_1\frac{y_2}{2h} + a(b-1)\frac{y_2}{2h} + c = \circ. \tag{18}$$

And for $2 \le n \le N-2$ we have

$$\frac{y_{n+1} - 2y_n + y_{n-1}}{h^2} - aby_n\frac{y_{n+1} - y_{n-1}}{2h} + a(b-1)\frac{y_{n+1} - y_{n-1}}{2h} + c = \circ. \tag{19}$$

Finally, for $n = N-1$ we will have

$$\frac{1 - 2y_{N-1} + y_{N-2}}{h^2} - aby_{N-1}\frac{1 - y_{N-2}}{2h} + a(b-1)\frac{1 - y_{N-2}}{2h} + c = \circ. \tag{20}$$

As we can see, at any step we can obtain unknowns by using known values.

Case 2. Suppose $1 < \alpha \le 2$, so the *Eq. (4)* is as follows:

$$y^{(\alpha)} - abyy' + a(b-1)y' + c = \circ, y(\circ) = \circ, y(1) = 1. \tag{21}$$

By using definition of fractional derivative *Eq. (7)* we have

$$y^{(\alpha)}(t) = \frac{1}{\Gamma(2-\alpha)}\int_\circ^t (t-s)^{1-\alpha} y''(s)ds. \tag{22}$$

Now, we suppose $t_n = nh, n = \circ, 1, \dots, N, t_\circ = \circ, t_N = 1, y_\circ = \circ, y_N = 1$, then we calculate the fractional derivative in *Eq. (22)* for $t_{n+1/2}$ so we have

$$y^{(\alpha)}\left(t_{n+1/2}\right) = \frac{1}{\Gamma(2-\alpha)}\int_\circ^{t_{n+1/2}} \left(t_{n+1/2} - s\right)^{1-\alpha} y''(s)ds =$$

$$\frac{1}{\Gamma(2-\alpha)}\left(\begin{array}{c}\sum_{j=1}^{n}\int_{t_{j-\frac{1}{2}}}^{t_{j+\frac{1}{2}}}\left(t_{n+\frac{1}{2}} - s\right)^{1-\alpha} y''(s)ds + \\ \int_\circ^{t_{1/2}}\left(t_{n+1/2} - s\right)^{1-\alpha} y''(s)ds\end{array}\right). \tag{23}$$

By replacing the $y''(s) = \frac{y_{j+1} - 2y_j + y_{j-1}}{h^2}$ in *Eq. (23)* we have

$$y^{(\alpha)}\left(t_{n+1/2}\right) \simeq \frac{1}{\Gamma(2-\alpha)}\left(\begin{array}{c}\sum_{j=1}^{n}\int_{t_{j-\frac{1}{2}}}^{t_{j+\frac{1}{2}}}\left(t_{n+\frac{1}{2}} - s\right)^{1-\alpha} \frac{y_{j+1} - 2y_j + y_{j-1}}{h^2}ds \\ + \int_{t_{-\frac{1}{2}}}^{t_{\frac{1}{2}}}\left(t_{n+\frac{1}{2}} - s\right)^{1-\alpha} \frac{y_1 - 2y_\circ + y_{-1}}{h^2}ds\end{array}\right). \tag{24}$$

By applying the initials and simplifying we obtain

$$y^{(\alpha)}\left(t_{n+1/2}\right) = \frac{1}{h^2\Gamma(2-\alpha)}\left(\begin{array}{c}\sum_{j=1}^{n}\left(y_{j+1} - 2y_j + y_{j-1}\right)\int_{t_{j-\frac{1}{2}}}^{t_{j+\frac{1}{2}}}\left(t_{n+\frac{1}{2}} - s\right)^{1-\alpha} ds + \\ y_1\int_{t_{-1/2}}^{t_{1/2}}\left(t_{n+1/2} - s\right)^{1-\alpha} ds\end{array}\right). \tag{25}$$

Now in *Eq. (25)* we assume the existing integral as follows:

$$d_{n,j,\alpha} = \int_{t_{j-1/2}}^{t_{j+1/2}}\left(t_{n+1/2} - s\right)^{1-\alpha} ds. \tag{26}$$

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Now by solving it we will have

$$d_{n,j,\alpha} = \int_{t_{j-1/2}}^{t_{j+1/2}} \left(t_{n+1/2} - s\right)^{1-\alpha} ds = \frac{1}{2-\alpha}\left((t_{n+1/2} - t_{j+1/2})^{2-\alpha} - (t_{n+1/2} - t_{j-1/2})^{2-\alpha}\right). \quad (27)$$

With simplification *Eq. (27)* we can write

$$d_{n,j,\alpha} = \frac{h^{2-\alpha}}{2-\alpha}\left((n-j+1)^{2-\alpha} - (n-j)^{2-\alpha}\right). \quad (28)$$

And for $j = 0$ we have

$$d_{n,0,\alpha} = \frac{h^{2-\alpha}}{2-\alpha}\left((n+1)^{2-\alpha} - (n)^{2-\alpha}\right). \quad (29)$$

By replacing *Eq. (28)* in *Eq. (25)* we get

$$y^{(\alpha)}\left(t_{n+1/2}\right) = \frac{1}{h^2\Gamma(2-\alpha)}\left(\sum_{j=1}^{n}\left(y_{j+1} - 2y_j + y_{j-1}\right)d_{n,j,\alpha} + y_1 d_{n,0,\alpha}\right). \quad (30)$$

In *Eq. (30)* on the right-hand side, we rewrite the first sentence according to its limits, so we have

$$\begin{aligned}\sum_{j=1}^{n}\left(y_{j+1} - 2y_j + y_{j-1}\right)d_{n,j,\alpha} &= d_{n,1,\alpha}y_0 + \left(-2d_{n,1,\alpha} + d_{n,2,\alpha}\right)y_1 \\ &+ \left(d_{n,1,\alpha} - 2d_{n,2,\alpha} + d_{n,3,\alpha}\right)y_2 \\ &+\left(d_{n,2,\alpha} - 2d_{n,3,\alpha} + d_{n,4,\alpha}\right)y_3 + \cdots \\ &+\left(d_{n,n-3,\alpha} - 2d_{n,n-2,\alpha} + d_{n,n-1,\alpha}\right)y_{n-2} \\ &+\left(d_{n,n-2,\alpha} - 2d_{n,n-1,\alpha} + d_{n,n,\alpha}\right)y_{n-1} + \left(d_{n,n-1,\alpha} - 2d_{n,n,\alpha}\right)y_n + d_{n,n,\alpha}y_{n+1}.\end{aligned} \quad (31)$$

With a little calculation and by simplifying *Eq. (31)* we have

$$\begin{aligned}\sum_{j=1}^{n}\left(y_{j+1} - 2y_j + y_{j-1}\right)d_{n,j,\alpha} &= d_{n,1,\alpha}y_0 + \left(-2d_{n,1,\alpha} + d_{n,2,\alpha}\right)y_1 + \\ &\sum_{j=2}^{n-1}\left(d_{n,j-1,\alpha} - 2d_{n,j,\alpha} + d_{n,j+1,\alpha}\right)y_j + \left(d_{n,n-1,\alpha} - 2d_{n,n,\alpha}\right)y_n + d_{n,n,\alpha}y_{n+1}.\end{aligned} \quad (32)$$

By replacing *Eq. (32)* in *Eq. (30)* we get

$$y^{(\alpha)}\left(t_{n+1/2}\right) \approx \frac{1}{h^2\Gamma(2-\alpha)}\left(\begin{array}{c}\sum_{j=1}^{n-1}\left(d_{n,j-1,\alpha} - 2d_{n,j,\alpha} + d_{n,j+1,\alpha}\right)y_j + \\ \left(d_{n,n-1,\alpha} - 2d_{n,n,\alpha}\right)y_n + d_{n,n,\alpha}y_{n+1}\end{array}\right). \quad (33)$$

By replacing $y'\left(t_{n+1/2}\right) \approx \frac{y_{n+1}-y_n}{h}$, $y\left(t_{n+1/2}\right) \approx \frac{y_{n+1}-y_n}{2}$ and *Eq. (33)* in *Eq. (21)* we obtain

$$\begin{aligned}&\frac{1}{h^2\Gamma(2-\alpha)}\left(\sum_{j=1}^{n-1}\left(d_{n,j-1,\alpha} - 2d_{n,j,\alpha} + d_{n,j+1,\alpha}\right)y_j + \left(d_{n,n-1,\alpha} - 2d_{n,n,\alpha}\right)y_n + d_{n,n,\alpha}y_{n+1}\right) \\ &-ab\frac{(y_{n+1} - y_n)^2}{2h} + a(b-1)\frac{y_{n+1} - y_n}{h} + c = 0.\end{aligned} \quad (34)$$

Now for $n = 1$ we have

$$\frac{1}{h^2\Gamma(2-\alpha)}\left(\left(d_{1,0,\alpha} - 2d_{1,1,\alpha}\right)y_1 + d_{1,1,\alpha}y_2\right) - ab\frac{(y_2-y_1)^2}{2h} + a(b-1)\frac{y_2-y_1}{h} + c = 0. \quad (35)$$

In the following for $2 \le n \le N-2$ we have

$$\frac{1}{h^2\Gamma(2-\alpha)}\left(\sum_{j=1}^{n-1}\left(d_{n,j-1,\alpha} - 2d_{n,j,\alpha} + d_{n,j+1,\alpha}\right)y_j + \left(d_{n,n-1,\alpha} - 2d_{n,n,\alpha}\right)y_n + d_{n,n,\alpha}y_{n+1}\right) - ab\frac{(y_{n+1}-y_n)^2}{2h} + a(b-1)\frac{y_{n+1}-y_n}{h} + c = 0. \quad (36)$$

Finally, for $n = N-1$ we will have as follows:

$$\frac{1}{h^2\Gamma(2-\alpha)}\left(\sum_{j=1}^{N-2}\left(d_{N-1,j-1,\alpha} - 2d_{N-1,j,\alpha} + d_{N-1,j+1,\alpha}\right)y_j + \left(d_{N-1,N-2,\alpha} - 2d_{N-1,N-1,\alpha}\right)y_{N-1} + d_{N-1,N-1,\alpha}\right) - ab\frac{(1-y_{N-1})^2}{2h} + a(b-1)\frac{1-y_{N-1}}{h} + c = 0. \quad (37)$$

Again, as we can see, at any step we can obtain unknowns by using known values.

4 | Stability

Let $\|.\|$ be the usual L^2 norm. Assume that $\tilde{y}_n$ and $\hat{y}_n$ are exact and approximation solutions of *Eq. (17)*, respectively. Hence,

$$\frac{\tilde{y}_{n+1}-2\tilde{y}_n+\tilde{y}_{n-1}}{h^2} - ab\tilde{y}_n\frac{\tilde{y}_{n+1}-\tilde{y}_{n-1}}{2h} + a(b-1)\frac{\tilde{y}_{n+1}-\tilde{y}_{n-1}}{h^2} + c = 0. \quad (38)$$

$$\frac{\hat{y}_{n+1}-2\hat{y}_n+\hat{y}_{n-1}}{h^2} - ab\hat{y}_n\frac{\hat{y}_{n+1}-\hat{y}_{n-1}}{2h} + a(b-1)\frac{\hat{y}_{n+1}-\hat{y}_{n-1}}{2h} + c = 0. \quad (39)$$

We define the roundoff error $e_n = \tilde{y}_n - \hat{y}_n$. From *Eq.* (17) the following relationship can be obtained

$$\frac{e_{n+1}-2e_n+e_{n-1}}{h^2} - \frac{ab}{2h}\left(\tilde{y}_n(\tilde{y}_{n+1}-\tilde{y}_{n-1}) - \hat{y}_n(\hat{y}_{n+1}-\hat{y}_{n-1})\right) + a(b-1)\frac{e_{n+1}-e_{n-1}}{2h} = 0,$$

Or

$$\left(1+\frac{1}{2}ha(b-1)\right)e_{n+1} = 2e_n - \left(1-\frac{1}{2}ha(b-1)\right)e_{n-1} + \frac{1}{2}abh\left(\tilde{y}_n(\tilde{y}_{n+1}-\tilde{y}_{n-1}) - \hat{y}_n(\hat{y}_{n+1}-\hat{y}_{n-1})\right). \quad (40)$$

Thus, we have

$$\left|1+\frac{1}{2}ha(b-1)\right|\|e_{n+1}\| \le 2\|e_n\| + \left|1-\frac{1}{2}ha(b-1)\right|\|e_{n-1}\| + \frac{1}{2}|ab|h\left\|\left(\tilde{y}_n(\tilde{y}_{n+1}-\tilde{y}_{n-1}) - \hat{y}_n(\hat{y}_{n+1}-\hat{y}_{n-1})\right)\right\|. \quad (41)$$

Theorem 1 ([20]). Suppose f maps a convex open set $E \subseteq \mathbb{R}^m$, f is differentiable in E, and there is a real nember M such that $\|f''\| \le M$ for every $x \in E$. Then

$$f(b) - f(a) \le M|b-a| \text{ for all } a \in E, b \in E.$$

Also, in this paper we have

$$|||e_n||| = \max\{\|e_{n-1}\|, \|e_n\|, \|e_{n+1}\|\}. \quad (42)$$

From *Eqs. (41), (42)* and theorem 1 we obtain

$$\left|1+\frac{1}{2}ha(b-1)\right|\|e_{n+1}\| \le 2\|e_n\| + \left|1-\frac{1}{2}ha(b-1)\right|\|e_{n-1}\| + \frac{1}{2}|ab|h|||e_n|||, \text{ or} \quad (43)$$

$$\left|1+\frac{1}{2}ha(b-1)\right| \|e_{n+1}\| \leq \left(2+\left|1-\frac{1}{2}ha(b-1)\right|+\frac{1}{2}|ab|h\right) \||e_n|\|,$$

Thus,

$$\|e_{n+1}\| \leq \frac{1}{\left|1+\frac{1}{2}ha(b-1)\right|}\left(2+\left|1-\frac{1}{2}ha(b-1)\right|+\frac{1}{2}|ab|h\right) \||e_n|\|.$$

According to *Eq. (42)* we know that there is a real number K such that $\||.\|| \leq K\|.\|$,

Therefore,

$$\|e_{n+1}\| \leq \frac{K_n}{\left|1+\frac{1}{2}ha(b-1)\right|}\left(2+\left|1-\frac{1}{2}ha(b-1)\right|+\frac{1}{2}|ab|h\right) \|e_n\|. \quad (44)$$

So,

$$\|e_{n+1}\| \leq C_n\|e_n\|. \quad (45)$$

Where $C_n = \frac{K_n}{\left|1+\frac{1}{2}ha(b-1)\right|}\left(2+\left|1-\frac{1}{2}ha(b-1)\right|+\frac{1}{2}|ab|h\right)$.

From *Eq. (45)* we have $\|e_{n+1}\| \leq D\|e_0\|$,

Where

$$D = C_nC_{n-1} \dots C_0. \quad (46)$$

Therefore, according to *Eq. (46)* the scheme in (17) is stable in L^2.

5 | Illustrative Examples

As we know, ones use numerical methods are used to approximate the solution of equations generally do not have an analytical and exact solution. *Eq. (21)* is also one of these equations, so in the following examples, first, we solve some cases with the method described in the previous section. Then we present its accuracy by drawing the graph of the solution and comparing it with the graph of the exact solution (by selecting the existing coefficients with specific values). Then we present the error graph resulting from using the method along with the error table. Then, by changing the coefficient values and also changing the order of the derivative from integer to fractional, we analyze the solutions based on the graphs.

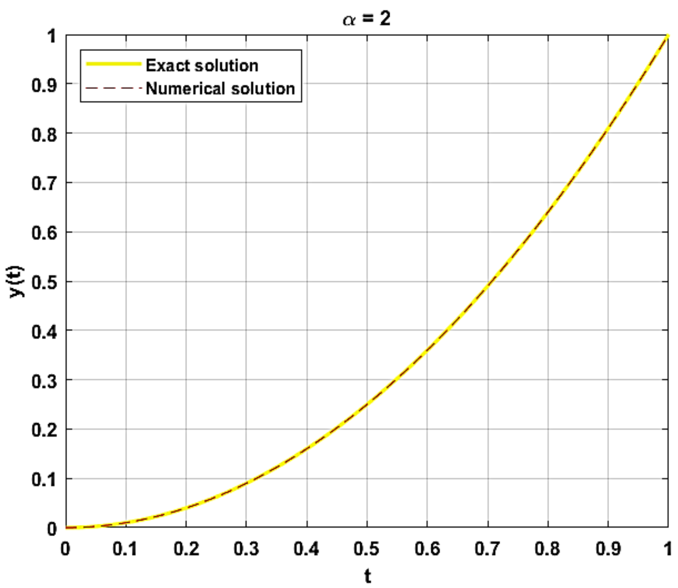

Fig. 2. Comparison between numerical and exact solution in example 1.

Example 1. In *Eq. (21)*, we set $\alpha = 2$, $a = \circ, b = \circ$ and $c = -2$ so, in this case we have $y'' - 2 = \circ$. As we know, the exact solution of this equation is $y(t) = t^2$. *Fig. 2* shows a comparison of the graph of the solution obtained from the numerical method and the exact solution of the equation.

As can be seen from *Fig. 2*, the method has acceptable accuracy. The *Table 1* shows the error of method at $t \in [0,1]$ and $h = 0.01$ Also, *Fig. 3* presents the graph of the error.

Table 1. Values of error for example 1.

Time	Exact Solution	Numerical Solution	Error
0	0.00000000000000000	0.00000000000000000	0
0.1	0.01000000000000000	0.00999999999999987	1.31839E-16
0.2	0.04000000000000000	0.03999999999999980	2.49800E-16
0.3	0.09000000000000000	0.08999999999999960	3.88578E-16
0.4	0.16000000000000000	0.16000000000000000	4.99600E-16
0.5	0.25000000000000000	0.25000000000000000	4.44089E-16
0.6	0.36000000000000000	0.36000000000000000	1.66533E-16
0.7	0.49000000000000000	0.49000000000000000	3.33067E-16
0.8	0.64000000000000000	0.64000000000000000	2.22045E-16
0.9	0.81000000000000000	0.81000000000000000	3.33067E-16
1	1.00000000000000000	1.00000000000000000	0

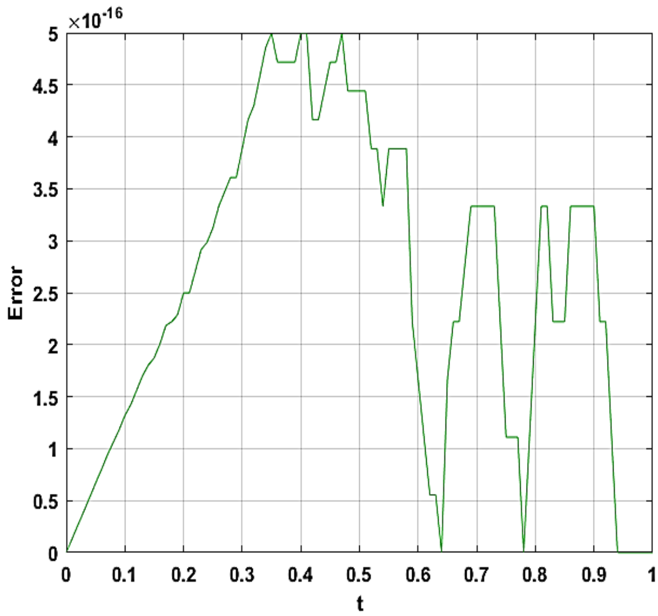

Fig. 3. The graph of error in example 1.

Now, by changing the order of the derivative from 2 to 1.8 and1.6, respectively, we draw the graphs of the solutions in *Fig. 4*. According to this Figure, the changes made in the graph of the solutions due to the change in the order of the derivatives from integer to fractional are quite obvious. From a mathematical point of view, the slope of the graph decreases with decreasing order, and in a part of the interval ($t < 0.3$), negative solutions are obtained. The convergence of the solutions is also easily visible.

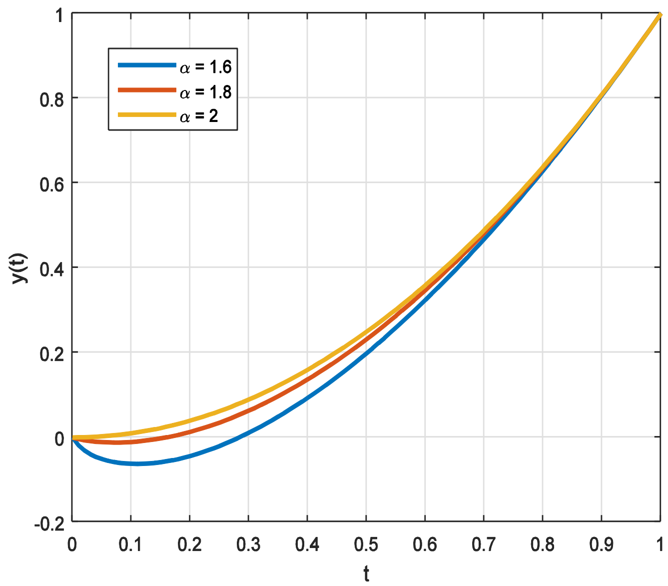

Fig. 4. Comparison of the graph of the solutions based on the order of derivatives.

From a physical point of view, the phase graph of a problem, in fact, is the drawing of solutions against the derivatives of the equation. So, it is of great importance. *Fig. 5* shows the phase diagram of this problem. As can be seen from this Figure, the critical points of the graphs are got away from the origin by decreasing the order of the derivative.

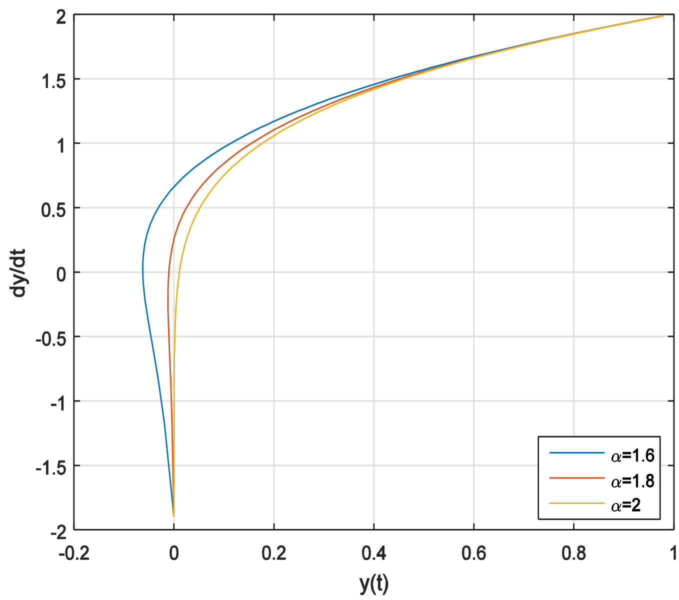

Fig. 5. The phase graph of example 1.

Example 2. In *Eq. (21)*, we set $\alpha = 2$, $a = 2$, $b = \circ$ and $c = 1$ so, in this case we know that the exact solution of this equation is $y(t) = \frac{1}{(2e^2-2)}(e^{2t}-1) + \frac{t}{2}$. *Fig.* 6 shows a comparison of the graph of the solution obtained from the numerical method and the exact solution of the equation. Again *Fig. 6* shows, the method has good and acceptable accuracy.

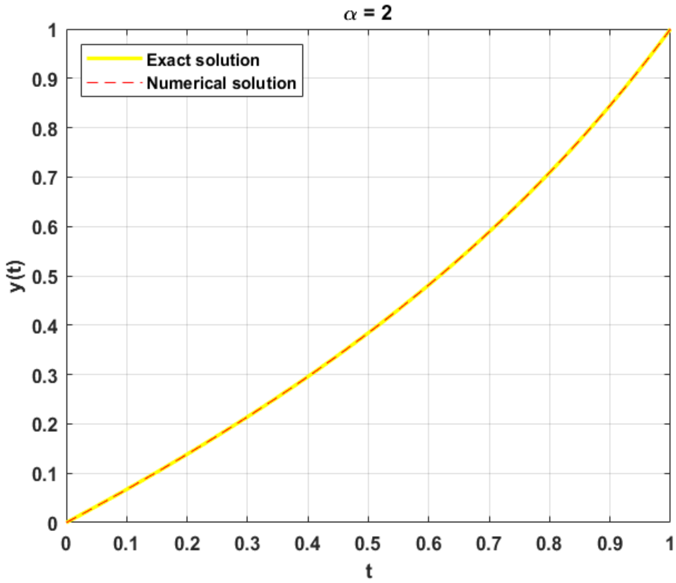

Fig. 6. Comparison between numerical and exact solution in example 2.

The *Table 2* shows the error of method at $t \in [0,1]$ and $h = 0.01$. Also, *Fig. 7* presents the graph of the error.

Table 2. Values of error for example 2.

Time	Exact Solution	Numerical Solution	Error
0	0	0	0
0.1	0.067326719	0.06732602	6.98703931E-07
0.2	0.138489621	0.13848821	1.41101358E-06
0.3	0.214338048	0.21433594	2.10870258E-06
0.4	0.295909389	0.295906638	2.75037861E-06
0.5	0.384470711	0.384467434	3.27703694E-06
0.6	0.481569616	0.48156601	3.60629057E-06
0.7	0.589096348	0.589092724	3.62490871E-06
0.8	0.709359658	0.709356479	3.17919737E-06
0.9	0.845179459	0.845177396	2.06263244E-06
1	1	1	0

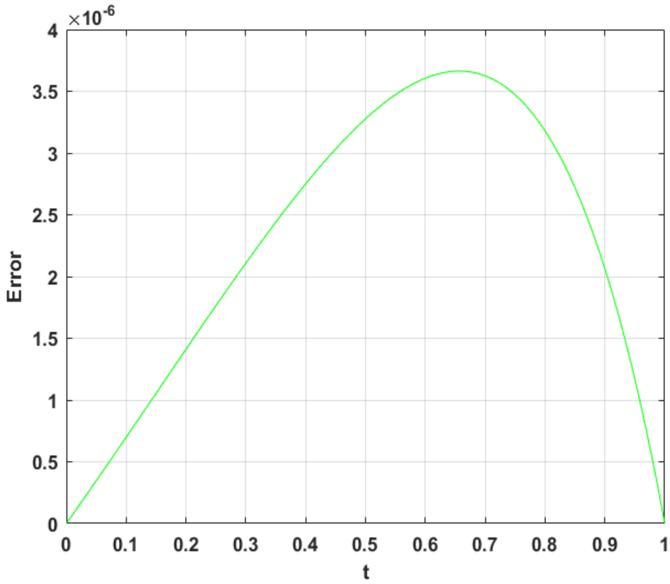

Fig. 7. The graph of error in example 2.

In the following, in *Example 2*, we change the derivative order from 2 to 1.9 and 1.7, respectively, and then plot the solutions in *Fig. 8*. It is clear that before the graph of the solutions converges, it can be said that with decreasing the order of the derivative, the slope of the related graphs increases.

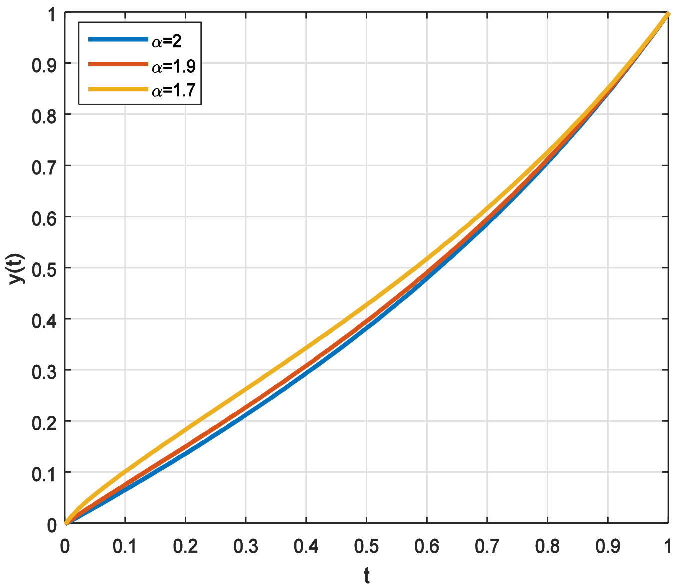

Fig. 8. Comparison of the graph of the solutions based on the order of derivatives.

The phase graph of *Example 2* is shown in *Fig. 9*. As can be seen from this Figure, the slope of the graphs decreases with decreasing order of the derivative, or in other words, the speed of the displacement or transfer reaction decreases

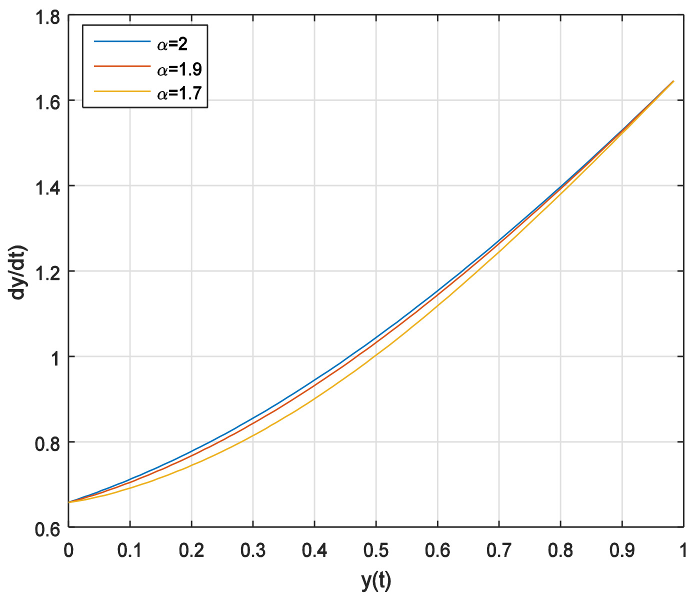

Fig. 9. The phase graph of example 2.

Example 3. In *Eq. (21)* we assume $a = 1$, $\boldsymbol{b} = \mathbf{2}$, $\boldsymbol{c} = \mathbf{3}$ and $\boldsymbol{\alpha} = \mathbf{2}$. With these assumptions, the mentioned equation does not have an exact solution, so we approximate the solution for the assumption coefficients. *Fig. 10* shows the result.

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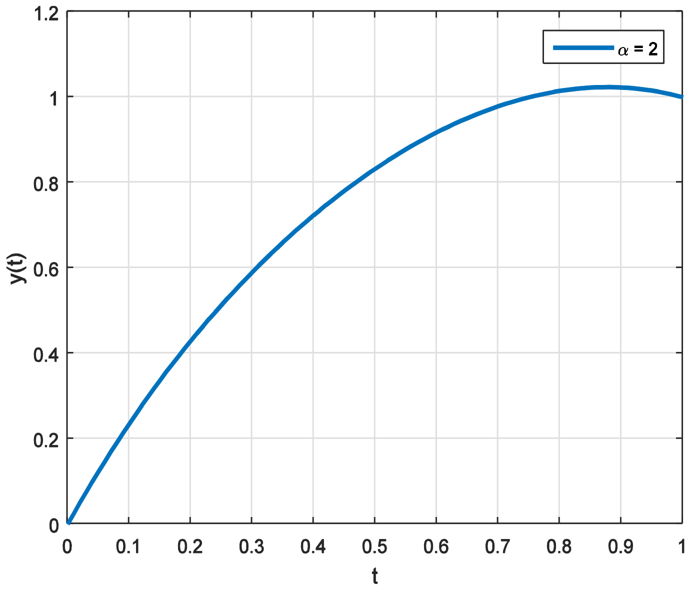

Fig. 10. The approximated solutions in example 3.

By keeping the coefficients of the equation constant, we change the order of the derivative in the equation from 2 to 1.9 and 1.7, respectively. *Fig. 11* shows the graph of the solutions of the equation with the mentioned derivatives. As can be seen from this Figure, the slope of the graph is shown by a significant increase with decreasing order. At the beginning of the interval, the rate of increase of this slope is very high, but as we move towards the end of the interval, this speed decreases, and in addition, at the end of the mentioned interval, the graphs converge around $t = 1$. The phase graph of this example is shown in *Fig. 12*.

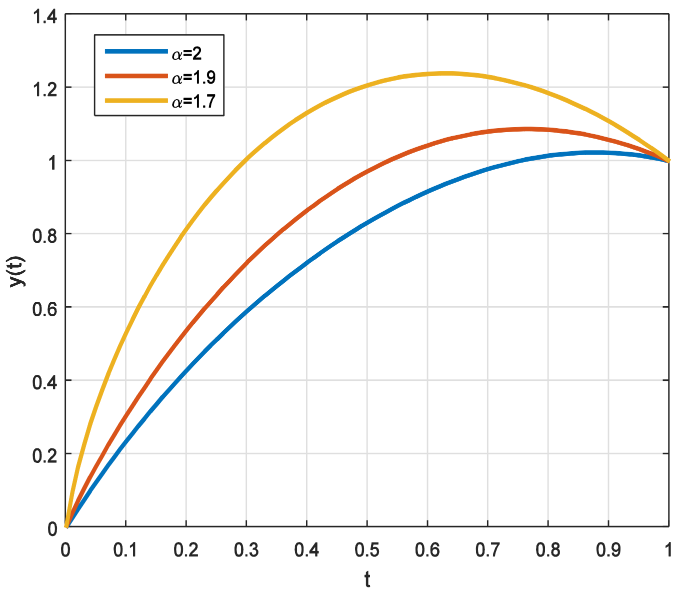

Fig. 11. Comparison of the graph of the solutions based on the order of derivatives.

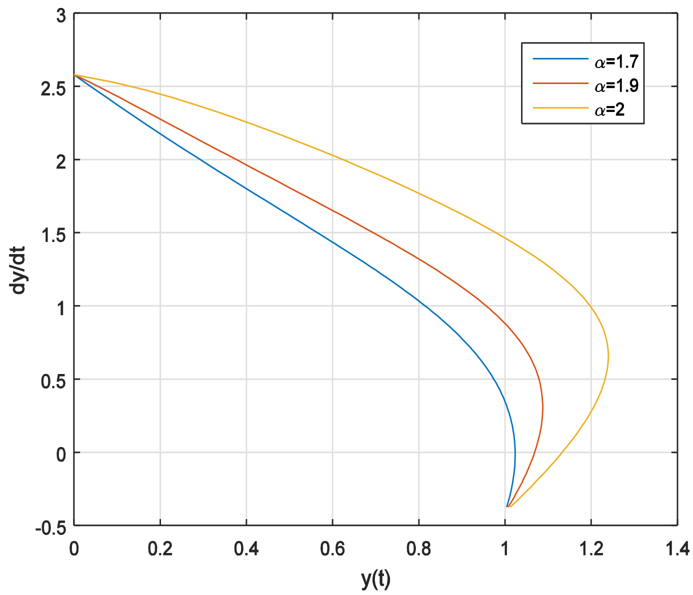

Fig. 12. The phase graph of example 3.

6 | Conclusion

In the presented work, we studied the Fractional Ideal Equation of Thermoelectric Coolers by finite difference method, numerically. First, we described the method in this paper. This method translated the fractional differential equation to a nonlinear algebraic equations system and then we solved it. We showed the efficiency and accuracy of the method with a few examples and by plotting the obtained solutions. In each of these examples, we presented the error graph and the table of error values and also examined the graph of the changes in the order of the equation from the integer to the fractional, as well as the phase graph of the equations. Then we solved the main equation and again examined the results by drawing the changes in the order of the equation from the integer to the fractional. The Phase graphs were also examined for the main equation of the fractional order. The obtained results show some behaviors of the system that can be seen only in the case where the order of equations is fractional.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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Paper Type: Research Paper

A Two-Stage Uncertain Model to Arrange and Locate Vehicle Routing with Simultaneous Pickup and Delivery

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Abstract

In this paper, a two-stage model is designed for arranging and locating vehicle routes with simultaneous pickup and delivery. The model developed in the first stage optimizes the arrangement of products in packages and thus optimizes packages' length, width, and height for delivery to customers. In the second stage, the goal is to provide customers with vehicle in simultaneous pickup and delivery. In this part of the model, the location of distribution centers is potentially considered, and the demand and cost parameters are considered uncertain. To solve the problem, precise methods and meta-heuristic algorithms of PSO for the first stage and multi-objective meta-heuristic algorithms NSGA II and MOALO for the set have been used. The results of examining the efficiency of the algorithms in the second stage show the high efficiency of the MOALO algorithm with a valuable weight of 0.8388. Therefore, to implement the model in the real problem (Golrang Broadcasting Company), the MOLAO algorithm has been used, the management results include obtaining 15 efficient answers.

Keywords: Vehicle routing location, Pickup and delivery, Product arrangement, Meta-heuristics algorithm, Fuzzy uncertainty.

1 | Introduction

The competition of organizations in the supply of goods and services has been an undeniable fact of the last two decades worldwide. Today, one of the approaches to creating a competitive advantage for companies and success in this environment is the regular integration in all production processes from raw material to the final consumer, which leads to flexibility in supply, production, and distribution of products. A supply chain is a suitable approach for quick and efficient response in this business environment [21]. One of the most critical issues in the supply chain is the design of distribution networks, which can significantly reduce system costs with careful design. The issue of multi-warehouse vehicle routing is one of the issues in distribution chain distribution and support systems. It includes two critical components of logistics systems, namely warehouse location and vehicle routing [47].

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The Vehicle Routing Problem (VRP) and Facility Location Problem (FLP) are two of the most difficult problems in Supply Chain Management (SCM), each of which requires a separate analysis, increasing planning time and costs. As a result, the Location-Routing Problem (LRP) is presented by combining the VRP and FLP in SCM [30]. Coordination between these two aspects is a crucial prerequisite for developing an effective distribution network in such problems [38]. Furthermore, in the real world, aspects such as shipping costs, customer demand and delivery time are not deterministic, and customers face shortages as a result of out-of-stock or late deliveries, as well as minor aspects, such as load capacity restrictions or refueling times, which result in reordering or lost sales [39]. The problem of vehicle routing with simultaneous pickup and delivery is an extension of the classic VRP in which customers have two types of demand for delivery and receipt of goods. These issues are divided into three main categories [29]. In the first category, called "first delivery-then pickup," it is assumed that customers are divided into two groups; customers with mere receipt requests and customers with mere delivery requests. And the satisfaction of the second type of customers will be possible only after the delivery of the needs of all the first type of customers [4]. The second category is called "mixed delivery and pickup" [20] unlike the previous class, customer groups with the demand of receiving or delivery goods can be simultaneously in the path of vehicle. Therefore, the amount of cargo fleet can be increased or decreased by referring to each node and, unlike the fundamental routing issues, will not have a decreasing trend [24]. The third category is VRPSPD; in this case, customers can receive and deliver goods simultaneously. Over the last decade, VRPSPD has attracted the attention of many researchers due to its high application in direct and reverse logistics systems, including goods collection and distribution processes [5], [42].

A two-stage model is designed in this article for arranging and locating vehicle routes with simultaneous pickup and delivery. The model developed in the first stage optimizes the arrangement of products in packages and thus optimizes packages' length, width, and height for delivery to customers. In the second stage, the goal is to provide customers with vehicle in simultaneous pickup and delivery. In this part of the model, the location of distribution centers is potentially considered, and the demand and cost parameters are considered uncertain. To solve the problem, precise methods and meta-heuristic algorithms of PSO for the first stage and multi-objective meta-heuristic algorithms NSGA II and MOALO for the set have been used. The results of examining the efficiency of the algorithms in the second stage show the high efficiency of the MOALO algorithm with a valuable weight. Therefore, to implement the model in the real Golrang Broadcasting Company, the MOLAO algorithm has been used, the management results obtaining efficient.

2 | Literature Review

The importance of vehicle routing has been extensively studied in recent decades with various developments and solutions due to the extent of vehicle routing. One of the areas that have recently been considered in the issue of routing is the routing of green vehicle. The goal is to route vehicle taking into account the effects of the environment and fuel consumption. Green vehicle routing issues fall into the general category of routing with optimized fuel consumption, routing considering environmental pollution, and routing in reverse logistics. In the field of routing with optimization of fuel consumption, a model called minimization of energy consumption in the problem of vehicle routing was presented [19]. The objective function explained in this study was the product of the distance traveled in terms of the vehicle's total weight, including the vehicle's weight and the cargo's weight. In addition to the displacement traveled and the total weight, the vehicle speed was studied to calculate the fuel consumption in the time-dependent VRP and was solved using the refrigeration simulation algorithm. However, a mathematical model for the problem was not presented [22]. Liu et al. [28] presented a linear mathematical model of a complex integer in terms of confidence. The proposed model was modeled on a single cycle and considering a product that used a new innovative method to solve the problem and route warehouses to demand points.

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The issue of capacity routing in the distribution of goods to minimize fuel consumption was raised by Xiao et al. [45]. Using regression analysis of fuel consumption related to mileage and vehicle load, they presented a fuel consumption optimization model and used a refrigeration simulation algorithm to solve the problem model. A routing model was proposed by Erdoğan and Miller-Hooks [11] in which vehicle have limited fuel tank capacity, considering the possibility of re-refueling. Then, by multiplying the objective function in a parameter called the carbon dioxide expulsion rate, the objective function of pollution minimization was presented. The problem was investigated as a two-objective one where the first objective function was to minimize the distance, and they designed artificial multiple bee colony algorithms [49].

Numerous recently published studies have introduced the issue of cross-warehouse vehicle routing as a type of classic vehicle routing issue. In another study, a variety of this model has been considered that combines the simultaneous arrival of goods with constant demand [26].

Routing and location scheduling issues with cross-docking were proposed to design the location of a cross-warehouse and the vehicle routing scheduling model [31]. The problem of cross-docking two-tier vehicle routing in a three-tier supply chain, including suppliers, cross-warehouses, and retailers, includes two levels of network routing, the first of which provides for suppliers and cross-warehouses, and the second of which provides for cross-docking. It is a crossover warehouse and retailer and linking the genetic algorithm to the local search method solved the problem [1]. Moreover, in another study, Vincent et al. [44] presented the issue of open vehicle routing using a cross-warehouse by proposing comparing the CPLEX solution with the refrigeration simulation algorithm. Lalla-Ruiz et al. [25] proposed a new mathematical model for the problem of open multi-warehouse routing by adding some further limitations to previous papers.

Kalayci and Kaya [18] researched the ant colony algorithm to find the optimal VRP with simultaneous delivery and harvesting solution. The purpose of this study is to minimize the total distance traveled by freight vehicle. Numerical results confirm that the developed method is robust and very efficient in solution quality and CPU time. Du et al. [10] and Hoseini et al. [13] developed a fuzzy linear programming model to minimize the risk of expected transportation when preparing hazardous materials and transporting products from different warehouses to customers. Four meta-innovative algorithms, including Particle Swarm Optimization (PSO), genetics, refrigeration simulation, and ant colony optimization, were used, and by providing numerical examples, comparisons were made between the proposed algorithms. Brandão [6] designed an open VRP with a time window in mind and used an iterative local search algorithm to solve it. This algorithm was used for more extensive size data and was implemented on 418 sample problems. The results showed the high efficiency of this algorithm in solving more significant size problems. In an article, Polyakovskiy and M'Hallah [35] examined and modeled the issue of product layout in two-dimensional space. For this purpose, they presented a complex integer linear programming model and solved the model in small sizes with CPLEX software. They also used innovative algorithms to solve the problem in larger sizes. Kumar-Das [23] and Ulmer et al. [43] presented a VRP with simultaneous delivery and withdrawal for food orders from a set of restaurants. The purpose of their study is to dynamically control the drivers' fleet to avoid delays in customers' regulations.

There are two sources of uncertainty; first, customers are not identified until they place an order. Second, the time of food preparation in the restaurant is unknown. To address these challenges, an ACA is proposed. Curtois et al. [7] presented a local search method for the problem of vehicle routing with simultaneous delivery and picking and time window consideration. This paper aims to determine the number of depots and vehicle routing with the distance minimization function.

Furthermore, experiments have been performed to analyze the benefits of components and meta-innovative methods and to use a combination of them to understand better how to solve the problem. In a dissertation, Dambakk [8] modeled a naval routing problem by considering simultaneous delivery and withdrawal and applying time-window and cost constraints. Given the NP-Hard nature of the problem, he proposed an efficient algorithm to solve his model. The results showed the high efficiency of the algorithm proposed by him to solve the problem. Golsefidi and Jokar [16] presented a different integer linear programming problem for a vehicle location-routing model with simultaneous delivery and harvesting. The model also considers the reverse flow of products. To reduce the cost of the entire system, the proposed model also plans decisions about reproduction settings, reproduction quantities, retailer visits, supplier inventory management, and retail inventory management under vendor management.

Qin et al. [36] designed an issue of vehicle routing with simultaneous delivery and withdrawal to reduce transportation costs and tax carbon dioxide. They also used the developed genetic algorithm to solve the problem. The results also showed that under the carbon tax mechanism, the effect of vehicle speed on total costs increases with an increasing carbon tax. Nadizadeh and Kafash [33] designed the problem of vehicle routing with simultaneous delivery and withdrawal, assuming demand is uncertain. Numerical experiments were performed to obtain the best value of model parameters, called "vehicle indices" and "warehouse indices," and to analyze their effects on the final solution. Li et al. [27] determined the optimal location of warehouses and vehicle routing. They used the firewall algorithm to solve the problem. Sadati et al. [37] presented a skeleton game to determine the optimal location of warehouses and vehicle routing to reduce costs. In the first level, the decision-maker as the leader chooses the optimal location of the facility. In the second level, as the leader, the second decision-maker determines the optimal route of the vehicle. Zhang et al. [48] considered the issue of Multi-Depot Green Vehicle Routing (MDGVR). They proposed an ant colony algorithm to solve the problem. In this paper, a significant constraint, vehicle capacity, is added to the model to make it more meaningful and closer to the case in the real world. Dell'Amico et al. [9] modeled the problem of arranging two-dimensional goods to reduce the number of packages used. Spencer et al. [41] modeled an arrangement of goods in packages for cold objects. Their primary purpose in this article was to reduce the number of packages used, reduce the average initial temperature of each package and reduce the minimum delivery time of the package to the customer. Table 1 examines the research gap of the two-stage modeling of vehicle routing for simultaneous pickup and delivery and the optimal arrangement of items in conveyors.

Moghdani et al. [32] classified VRPs into six groups considering the objective of the problems:

I. Vehicle routing problem.
II. Pollution-routing problem.
III. Heterogeneous vehicle routing problem.
IV. Energy minimizing vehicle routing problem.
V. Time-dependent vehicle routing problem.
VI. Fuel consumption in vehicle routing problem.

Anuar et al. [3] matheuristic approach based on a reduced two-stage Stochastic Integer Linear Programming model is presented. The proposed approach is suitable for obtaining a policy constructed dynamically on the go during the rollout algorithm. The rollout algorithm is part of the Approximate Dynamic Programming lookahead solution approach for a Markov Decision Processes framed Multi-Depot Dynamic Vehicle Routing Problem with Stochastic Road Capacity.

Fakhrzad et al. [14] and Engin and İşler [12] develops a new model for the VRP with simultaneous pickup and delivery under demand uncertainty. Due to the problem's complexity, the standard solvers are only able to solve small-scale instances. To solve the large-scale problems, a two-stage algorithm based on the modified AVNS is proposed. Extensive computational experiments are conducted using modified versions of Solomon's benchmark instances to show the performance of the algorithm.

The main objectives of this paper are formed in two opposing objective functions. The first objective function is to reduce the cost of selecting potential warehouses and the costs associated with transporting vehicle. The second objective function, which forms the basis of VRPs, reduces greenhouse gas emissions from vehicle traffic. Therefore, the correct selection of potential warehouses and determining the right vehicle traffic route to meet demand will achieve the two objectives. On the other hand, the arrangement of items requested by the customer in vehicle is also considered in-vehicle navigation. The performance of items ordered by customers in a package can be delivered so that any vehicle visiting the customer can quickly provide the package requested by him and pick up the second-hand package. The package deliverable to the first customer must be more accessible than the package deliverable to the second customer furthermore, besides the issue of vehicle routing with simultaneous pickup and delivery. This paper discusses how to deliver items and delivery to the customer in vehicle.

The model studied in this research can be expressed in two stages as follows:

I. In the first stage. Optimal arrangement of items that can be delivered and picked up to customers to give priority to customers.
II. In the second stage. Locating potential warehouses and optimal routing of vehicle for delivery and withdrawal simultaneously with the objectives of reducing the total cost of the problem and reducing greenhouse gas emissions.

Table 1. An overview of the most important papers in the field of VRP and product arrangement.

The Author	Year	The Objective Function	Certain/Uncertain	Multi-Warehouses /Single-Warehouse	Solving Method	Simultaneous Delivery and Pickup	Product Arrangement	Case Study
Kalayci and Kaya [18]	2016	Reduce distance	certain	-	Metahiuristics	*	-	-
Sethanan and Pitakaso [40]	2016	Reduce shipping costs	certain	-	Exact	-	-	-
Hadian et al. [17]	2019	1. Cost reduction	certain	multi-warehouses	Metahiuristics	-	-	-
Polyakovskiy and M'Hallah [35]	2018	Reduce the number of packages	certain	-	Exact	-	*	-
Curtois et al. [7]	2018	Total delay reduction	certain	-	Hiuristics	*	-	-
Li et al. [27]	2019	Reduce distance	certain	multi-warehouses	Metahiuristics	-	-	-
Spencer et al. [41]	2019	Reduce transportation and location costs	certain	-	Metahiuristics	-	*	-
Qin et al. [36]	2019	1. Reduce the number of packages	certain	-	Metahiuristics	*	-	-
Zhang et al. [48]	2019	2. Reduce the average initial temperature of each package	certain	multi-warehouses	Metahiuristics	-	-	-
Ulmer et al. [43]	2020	3- Reducing the maximum delivery time of goods to the customer	Uncertain (production time)	-	Metahiuristics	*	-	Collection of restaurants
Nadizadeh and Kafash [33]	2019	Reduce transfer time	Uncertain (demand)	multi-warehouses	Exact	*	-	-

Table 1. Continued.

The Author	Year	The Objective Function	Certain/Uncertain	Multi-Warehouses /Single-Warehouse	Solving Method	Simultaneous Delivery and Pickup	Product Arrangement	Case Study
Dell'Amico et al. [9]	2020	Reduce distance	certain	-	Exact	-	*	-
Fu and Banerjee [15]	2020	Reduce transportation and location costs	certain	-	Metahiuristics	-	*	-
Anuar et al. [3]	2021	Reduce transportation and location costs	Uncertain (demand)	-	Metahiuristics	*	*	-
Moghdani et al. [32]	2021	Reduce transportation and location costs	Uncertain (demand)	-	Metahiuristics	*	*	-
Fakhrzad et al. [14]	2022	Reduce transportation and location costs	Uncertain (demand)	-	Metahiuristics	*	*	-
The present study	-	Reduce transportation and location costs	Uncertain (demand)	multi-warehouses	Metahiuristics	*	*	Golrang Broadcasting Company

According to the literature on the subject and the study of the research gap, it can be stated that there is no comprehensive model that includes the two topics of vehicle routing with simultaneous picking and delivery and optimal arrangement of goods. Therefore, this research will discuss two-stage modeling of vehicle routing with simultaneous pickup and delivery besides product layout. Since the proposed model is an NP-Hard model, NSGA II, MOALO, and PSO algorithms will solve the problem in a larger size (Case study: Golrang Distribution Company). The PSO algorithm in this paper is to achieve the proper arrangement of goods in the vehicle (first stage) and NSGA II and MOALO algorithms to determine the optimal route of vehicle with simultaneous delivery and withdrawal (second stage).

3 | Problem Definition and Modeling

Fig. 1 shows an example of the problem of vehicle routing with simultaneous delivery and pickup, which is the primary basis of the present study. In this Figure, there are several potential warehouses and many customers with two types of demand. Vehicle should start moving from each of the selected warehouses. After delivery the desired application, each product will take second-hand or spoiled products from that customer after visiting the customer. Therefore, there are two strategic and tactical decisions simultaneously in the above issue. In the strategic decision, the main goal is to select the required warehouses from several potential warehouses at the study level and pick up second-hand or corrupt items

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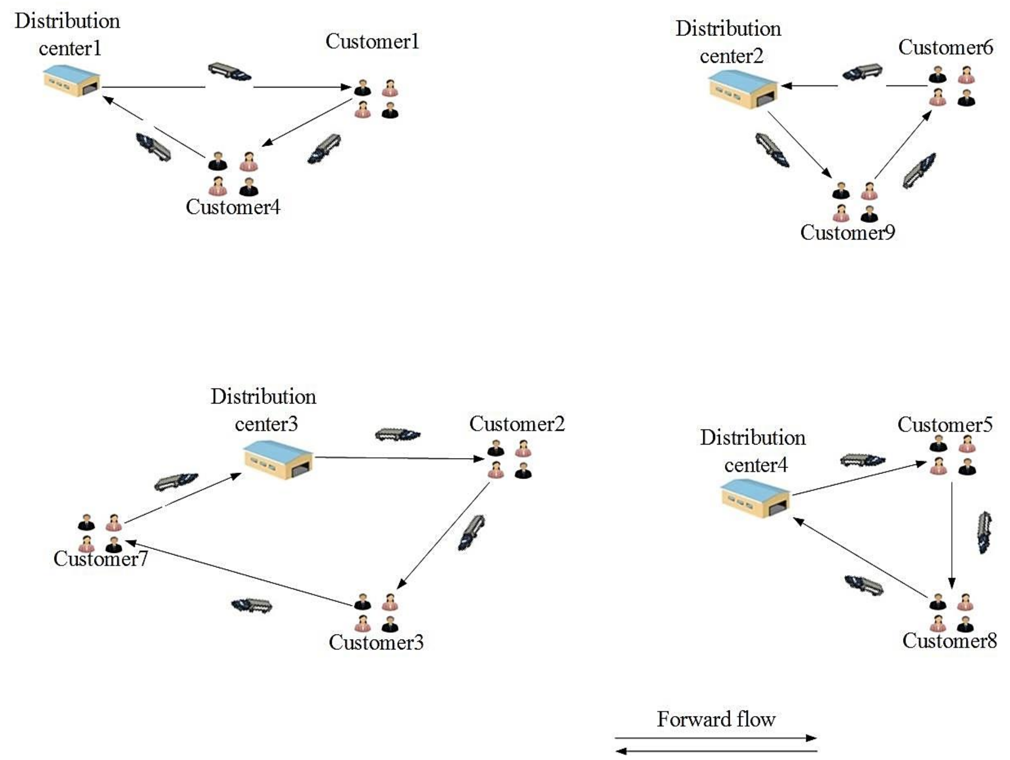

Fig. 1. The problem of vehicle routing with multiple warehouses.

Therefore, this paper develops and analyzes a two-stage vehicle layout and location model with modeling and simultaneous delivery. In the following sections, the background of relevant research and problem modeling are presented. Therefore, the framework of the article is as follows; the second part reviews the literature on the issue and examines the research gap. The third part presents a two-stage model of arrangement and location of vehicle routing with simultaneous pickup and delivery. In the fourth section, the solution methods used in the problem and the initial chromosome of the problem are presented. The fifth part includes solving the problem in small sizes and a real case study in Golrang Broadcasting Company. Finally, the sixth section concludes and proposes future research proposals.

Given the research gap, a two-stage model of the layout and location of the vehicle navigation with simultaneous pickup and delivery is presented in this section. Therefore, the main goal in the first stage is the optimal arrangement of goods to be delivered to customers in vehicle. On the other hand, the main goal in the second stage is to determine the number of potential warehouses and determine the optimal route of vehicle. According to *Fig. 2*, there are several likely warehouses of various products that different vehicle from these places load customers' demand in this model. Based on the request of the customer for each product, the optimal transportation route is determined. The vehicle delivers their first-hand goods at the customer's visit and load the second-hand or returned goods. Also, the arrangement of goods in vehicle based on length, width, and height is another issue that vehicle in selected warehouses should pay ttention to. Thus, due to the limitation of the vehicle's size, the chosen customers' goods must be arranged on it.

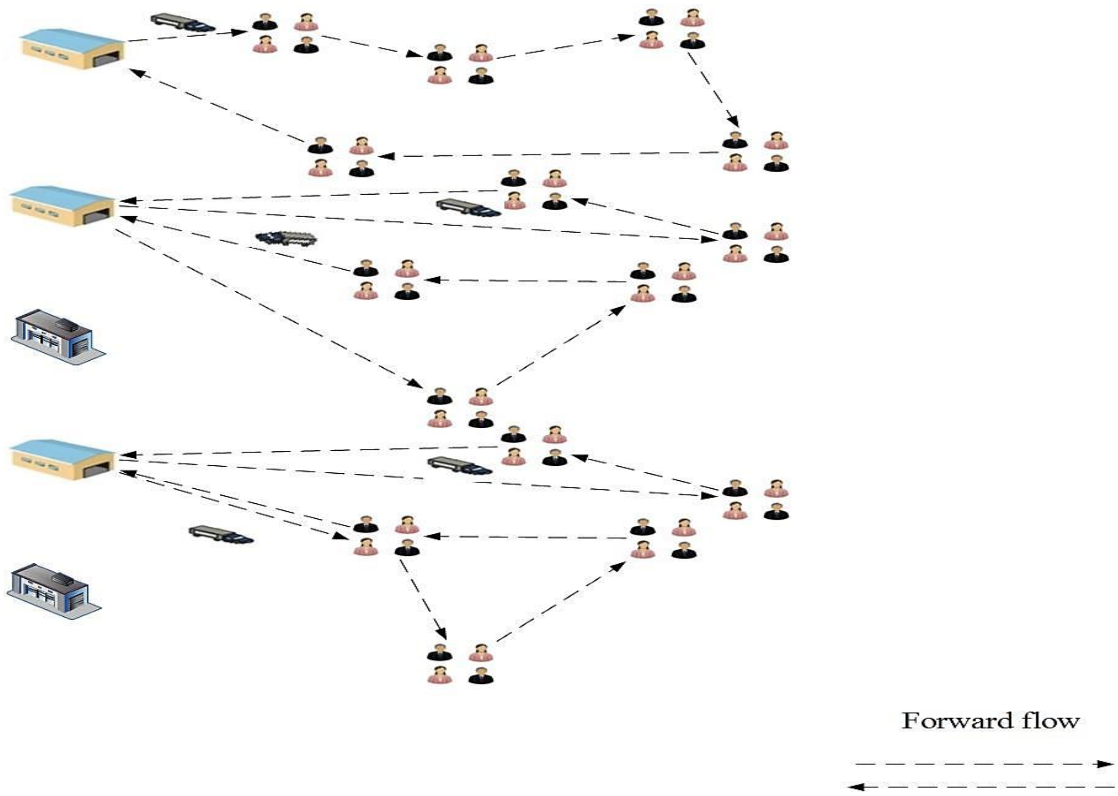

Fig. 2. Schematic of the problem of vehicle routing location with simultaneous pickup and delivery.

Therefore, the two-stage model of arrangement and locating of vehicle routing with pickup and delivery can be done simultaneously with the following assumptions:

- *The issue under consideration includes several products.*
- *The dimensions of the vehicle for the transfer of goods are already known.*
- *The size of the packages of goods for transfer is known in advance.*
- *The number of warehouses is unknown, and the location of warehouses is known.*
- *Uncertainty control of demand parameter is a fuzzy method.*

Based on the above assumptions and the definition of the problem, the first stage model of the problem, including the one-objective model of product layout in loadable packages in vehicle, is expressed as follows.

Sets in the first stage model

C	Fixed customer collections,	$m, c = \{1, \dots, C\}$.
P	Collection of products,	$p, p' = \{1, \dots, P\}$.

Parameters in the first stage model

W_{cp}	The width of the product can be delivered to the customer c.
L_{cp}	Product length pm deliverable to customer c.
H_{cp}	The height of the product can be delivered to the customer c.
M	Negative large number.

Decision variables in the first stage model

$Wmax_c$	Optimal package width for customer c.
$Lmax_c$	Optimal package length for customer c.
$Hmax_c$	Optimal closed height for the customer$c$.
X_{cp}	The starting point for the product layout of the customer's c at package's length.
Y_{cp}	The starting point of the product layout is the customer's c at package's width.
Z_{cp}	The starting point of the product layout of the customer's c at package's height.
$a_{cpp'}$	If product p is placed in front of the product p' for customer package c, value 1; Otherwise, it gets 0.
$b_{cpp'}$	If product p is to the right of the product p' for client package c, value 1; Otherwise, it gets 0.
$c_{cpp'}$	If product p is placed on top of the product p' for customer package c, value 1; Otherwise, it gets 0.
Xl_{cp}	If the product length p is parallel to the X-axis for the customer package c, the value is 1; Otherwise, it gets 0.
Zl_{cp}	If the product length p is parallel to the Z-axis for the client package c, the value is 1; Otherwise, it gets 0.
Yw_{cp}	If the product width p is parallel to the Y-axis for the customer package c, the value is 1; Otherwise, it gets 0.
$Zh_{r,i}$	If the product height p is parallel to the Z-axis for the customer package c, the value is 1; Otherwise, it gets 0.

3.1 | Model of Arrangement of Goods in Vehicle

$$\text{MinZ} = \sum_{c=1}^{C} (\text{Wmax}_c + \text{Hmax}_c + \text{Lmax}_c). \tag{1}$$

s. t.

$$X_{cp} + L_{cp}.Xl_{cp} + W_{cp}(Zl_{cp} - Yw_{cp} + Zh_{cp}) + H_{cp}(1 - Xl_{cp} - Zl_{cp} + Yw_{cp} - Zh_{cp}) \le X_{cp'} + M.(1 - a_{cpp'}). \quad \forall c, p \neq p' \tag{2}$$

$$Y_{cp} + W_{cp}.Yw_{cp} + L_{cp}(1 - Xl_{cp} - Zl_{cp}) + H_{cp}(Xl_{cp} + Zl_{cp} - Yw_{cp}) \le Y_{cp'} + M.(1 - b_{cpp'}). \quad \forall c, p \neq p' \tag{3}$$

$$Z_{cp} + H_{cp}.Zh_{cp} + W_{cp}(1 - Zl_{cp} - Zh_{cp}) + L_{cp}Zl_{cp} \le Z_{cp'} + M.(1 - c_{cpp'}). \quad \forall c, p \neq p' \tag{4}$$

$$X_{cp} + L_{cp}.Xl_{cp} + W_{cp}(Zl_{cp} - Yw_{cp} + Zh_{cp}) + H_{cp}(1 - Xl_{cp} - Zl_{cp} + Yw_{cp} - Zh_{cp}) \le \text{Lmax}_c. \quad \forall c, p \tag{5}$$

$$Y_{cp} + W_{cp}.Yw_{cp} + L_{cp}(1 - Xl_{cp} - Zl_{cp}) + H_{cp}(Xl_{cp} + Zl_{cp} - Yw_{cp}) \le \text{Wmax}_c. \quad \forall c, p \tag{6}$$

$$Z_{cp} + H_{cp}.Zh_{cp} + W_{cp}(1 - Zl_{cp} - Zh_{cp}) + L_{cp}.Zl_{cp} \le \text{Hmax}_c. \quad \forall c, p \tag{7}$$

$$a_{cpp'} + a_{cp'p} + b_{cpp'} + b_{cp'p} + c_{cpp'} + c_{cp'p} \ge 1. \quad \forall c, p \neq p' \tag{8}$$

$$Xl_{cp} + Zl_{cp} \le 1. \quad \forall c, p \tag{9}$$

$$Zl_{cp} + Zh_{cp} \le 1. \quad \forall c, p \tag{10}$$

$$Zl_{cp} - Yw_{cp} + Zh_{cp} \le 1. \quad \forall c, p \tag{11}$$

$$Zl_{cp} - Yw_{cp} + Zh_{cp} \geq 0. \quad \forall c, p \tag{12}$$

$$1 - Xl_{cp} - Zl_{cp} + Yw_{cp} - Zh_{cp} \leq 1. \quad \forall c, p \tag{13}$$

$$1 - Xl_{cp} - Zl_{cp} + Yw_{cp} - Zh_{cp} \geq 0. \quad \forall c, p \tag{14}$$

$$Xl_{cp} + Zl_{cp} - Yw_{cp} \leq 1. \quad \forall c, p \tag{15}$$

$$Xl_{cp} + Zl_{cp} - Yw_{cp} \geq 0. \quad \forall c, p \tag{16}$$

$$Wmax_c, Lmax_c, Hmax_c, X_{cp}, Y_{cp}, Z_{cp} \geq 0. \quad \forall c, p \tag{17}$$

$$a_{cpp'}, b_{cpp'}, c_{cpp'}, Xl_{cp}, Zl_{cp}, Yw_{cp}, Zh_{cp} \in \{0,1\}. \quad \forall c, p, p' \tag{18}$$

Eq. (1) shows the objective function of the problem in the first step and includes minimizing the package dimensions designed for the layout of the customer's products. *Eqs. (2)* to *(4)* ensures that the two products i and j do not overlap and do not overlap. *Constraints (5)-(7)* keep the dimensions of the products constant and only move their direction for the ideal arrangement. *Constraint (8)* indicates the position of each product relative to other adjacent products. *Relations (9)-(16)* ensure that the role of each product in the package remains constant according to the intended dimensions. *Constraints (17)* and *(18)* indicate the type and gender of decision variables. The model's output is the classification of products provided to customers besides arranging packages with customers' names. Therefore, each box that can be presented to the customer includes a set of products arranged in the best way inside the package. Based on the above results, the second stage model will consist of vehicle routing location with simultaneous pickup and delivery as follows:

Sets in the second stage model

L	Distribution centers (warehouses).	$l = \{1, \dots, L\}$.
C	Fixed customer collections.	$m, c = \{1, \dots, C\}$.
P	Collection of products.	$p, p' = \{1, \dots, P\}$.
V	Vehicle collection.	$v = \{1, \dots, V\}$.
N	The total set of nodes (distribution centers and customers).	$n, n' = \{1, \dots, L, L+1, \dots L+C\}$.

Parameters in the second stage model

U_l	Cost of establishing a distribution center$l$.
F_v	Fixed cost of using the vehicle v.
$\widetilde{D}_{cp}$	The amount of product delivery p to the customer c.
R_{cp}	The amount of product p harvested from the customer c.
$CapV_v$	Vehicle capacity v.
$CapL_{lp}$	Maximum capacity of distribution center l of product distribution p.
$Dis_{nn'}$	Distance between nodes n and n'.
$\widetilde{Tr}_{nn'}$	Shipping cost between nodes n and n'.
$T_{nn'}$	Transport time between nodes n and n'.
S_c	Unloading and loading time of the vehicle in the node c.
C_{lp}	Distribution cost per unit of product p by the distribution center l.
$[AS_c, BS_c]$	The soft time window for delivery and withdrawal of customer products$c$.
α	Cost of fines for exceeding the soft time window.
H	Product-dependent greenhouse gas emissions.
$Wmax_c$	The optimal package width determined from the first step for the customer c.

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$Lmax_c$	The optimal package length determined from the first step for the customer c.
$Hmax_c$	The optimal package height determined from the first step for the customer c.
WK_v	Vehicle width v.
LK_v	Vehicle length$v$.
Hk_v	Vehicle height$v$.
M	Negative large number.

Decision variables in the second stage model

V_{lpv}	The total amount of product p that can be distributed from the distribution center l by vehicle v.
Z_l	If distribution center l is established/selected, the value is 1 and otherwise 0.
Z_{lcv}	If the distribution center l is assigned to customer c and the vehicle v is given, the value is 1 and otherwise 0.
$X_{nn'v}$	If node n' is visited by vehicle v after node n, it takes 1 and otherwise 0. l, $c \in L \cup C$.
U_{cv}	Auxiliary variable for sub-tour deletion limit.
Tc_{lcv}	Time of arrival of vehicle v to customer c and out of distribution center l.
Lc_{lcpv}	The amount of product p present in the vehicle load v in the customer node c and out of the distribution center l.
Te_{cv}	Time exceeds the vehicle time window v at the client node c.
Y'_{cpv}	If the customer's product set c is carried by vehicle v value 1; Otherwise, it gets 0.
Al_{cv}	If customer c's package is allocated by vehicle v value 1; Otherwise, it gets 0.
$Xl1_c$	If the length of the client pack c is parallel to the X-axis, the value is 1; Otherwise, it gets 0.
$Yl1_c$	If the length of the client pack c is parallel to the Y-axis, the value is 1; Otherwise, it gets 0.
$Xw1_c$	If the width of the client pack c is parallel to the X-axis, the value is 1; Otherwise, it gets 0.
$Yw1_c$	If the width of the client pack c is parallel to the Y-axis, the value is 1; Otherwise, it gets 0.
O_v	If vehicle v is used value 1; otherwise, it takes the value 0.
$X1_c$	The starting point for the layout of the client package along with the vehicle.
$Y1_c$	The starting point for the layout of thec's client package across the width of the vehicle.
$Z1_c$	The starting point of the package layout of the customer at the height of the vehicle.
a'_{cm}	If pack c is to the left of pack m, the value is 1; Otherwise, it gets 0.
b'_{cm}	If packet c is to the right of packet m, the value is 1; Otherwise, it gets 0.
c'_{cm}	If pack c is placed behind pack m, the value is 1; Otherwise, it gets 0.
d'_{cm}	If packet c is placed in front of packet m, the value is 1; Otherwise, it gets 0.
e'_{cm}	If package c is below package m, the value is 1; Otherwise, it gets 0.
f'_{cm}	If packet c is placed on top of packet m, the value is 1; Otherwise, it gets 0.

3.2. | Vehicle Navigation Location Model with Simultaneous Pickup and Delivery

$$\text{Min}\omega 1 = \sum_{l=1}^{L} U_l Z_l + \sum_{n=1}^{N} \sum_{n'=1}^{N} \sum_{v=1}^{V} \widetilde{Tr}_{nn'} X_{nn'v} + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{v=1}^{V} C_{lp} V_{lpv} + \sum_{v=1}^{V} F_v O_v + \sum_{c=1}^{C} \sum_{v=1}^{V} \alpha Te_{cv}. \quad (19)$$

$$\text{Min}\omega 2 = \sum_{n=1}^{N}\sum_{n'=1}^{N}\sum_{v=1}^{V}\sum_{p=1}^{P} H.\,Dis_{nn'}Lc_{nn'pv}. \tag{20}$$

s. t.:

$$\sum_{v=1}^{V}\sum_{n=1}^{N} X_{lcv} = 1. \quad \forall c \tag{21}$$

$$\sum_{c=1}^{C}\sum_{n=1}^{N}\sum_{p=1}^{P} \widetilde{D}_{cp}X_{ncv} \leq CapV_vO_v. \quad \forall v \tag{22}$$

$$U_{cv} - U_{mv} + C.\,X_{cmv} \leq C - 1. \quad \forall m, c, v \tag{23}$$

$$\sum_{n=1}^{N} X_{ncv} = \sum_{n=1}^{N} X_{cnv}. \quad \forall v, n \tag{24}$$

$$\sum_{l=1}^{L}\sum_{c=1}^{C} X_{lcv} \leq 1. \quad \forall v \tag{25}$$

$$-Z_{lcv} + \sum_{n=1}^{N}(X_{lnv} + X_{ncv}) \leq 1. \quad \forall l, c, v \tag{26}$$

$$V_{lpv} = \sum_{c=1}^{C} \widetilde{D}_{cp}\, Z_{lcv}. \quad \forall l, p, v \tag{27}$$

$$\sum_{v=1}^{V} V_{lpv} \leq CapL_{lp}. \quad \forall l, p \tag{28}$$

$$Lc_{lcpv} \geq V_{lpv} - \widetilde{D}_{cp} + R_{cp} - M.\,(1 - X_{lcv}). \quad \forall l, p, c, v \tag{29}$$

$$Lc_{lmpv} \geq Lc_{lcpv} - \widetilde{D}_{mp} + R_{mp} - M.\,(1 - X_{cmv}). \quad \forall l, p, c, m, v \tag{30}$$

$$Tc_{lcv} \geq T_{lc} - M.\,(1 - X_{lcv}). \quad \forall l, c, v \tag{31}$$

$$Tc_{lmv} \geq Tc_{lcv} + T_{cm} + S_m - M.\,(2 - X_{cmv} - Z_{lcv}). \quad \forall l, c, m, v \tag{32}$$

$$Te_{cv} \geq AS_c.\,Z_{lcv} - Tc_{lcv}. \quad \forall l, c, v \tag{33}$$

$$Te_{cv} \geq Tc_{lcv} - BS_c.\,Z_{lcv}. \quad \forall l, c, v \tag{34}$$

$$\sum_{l=1}^{L} Lc_{lcpv} = Y'_{cpv}. \quad \forall c, p, v \tag{35}$$

$$\sum_{p=1}^{P} Y'_{cpv} \leq M * Al_{cv}. \quad \forall c, v \tag{36}$$

$$X1_c + Lmax_cXl1_c + Wmax_c(1 - Xl1_c) \leq X1_m + M.\,(1 - a'_{cm}). \quad \forall c < m \tag{37}$$

$$X1_m + Lmax_mXl1_m + Wmax_m(1 - Xl1_m) \leq X1_c + M.\,(1 - b'_{cm}) \quad \forall c < m \tag{38}$$

$$Y1_c + Wmax_cXl1_c + Lmax_c(1 - Xl1_c) \leq Y1_m + M.\,(1 - c'_{cm}). \quad \forall c < m \tag{39}$$

$$Y1_m + Wmax_mXl1_m + Lmax_m(1 - Xl1_m) \leq Y1_c + M.\,(1 - d'_{cm}). \quad \forall c < m \tag{40}$$

$$Z1_c + Hmax_c \leq Z1_m + M.\,(1 - e'_{cm}). \quad \forall c < m \tag{41}$$

$$Z1_m + Hmax_m \leq Z1_c + M.\,(1 - f'_{cm}). \quad \forall c < m \tag{42}$$

$$a'_{cm} + b'_{cm} + c'_{cm} + d'_{cm} + e'_{cm} + f'_{cm} \geq Al_{cv} + Al_{mc} - 1. \quad \forall v, c < m \tag{43}$$

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$$\sum_{v=1}^{V} Al_{cv} = 1. \quad \forall c \tag{44}$$

$$X1_c + Lmax_c . Xl1_c + Wmax_c . Xw1_c \leq Lk_v + M.(1 - Al_{cv}). \quad \forall c, v \tag{45}$$

$$Y1_c + Wmax_c . Yw1_c + Lmax_c . Yl1_c \leq WK_v + M.(1 - Al_{cv}). \quad \forall c, v \tag{46}$$

$$Z1_c + Hmax_c \leq HK_v + M.(1 - Al_{cv}). \quad \forall c, v \tag{47}$$

$$\sum_{c=1}^{C} Al_{cv} \leq M.O_v. \quad \forall v \tag{48}$$

$$Yl1_c = 1 - Xl1_c. \quad \forall c \tag{49}$$

$$Xw1_c = 1 - Xl1_c. \quad \forall c \tag{50}$$

$$Yw1_c = Xl1_r. \quad \forall c \tag{51}$$

$$V_{lpv}, U_{cv}, Tc_{lcv}, Lc_{lcpv}, Te_{cv}, X1_c, Y1_c, Z1_c \geq 0. \tag{52}$$

$$Z_l, Z_{lcv}, X_{nn'v}, Al_{cv}, Yl1_c, Xl1_c, Xw1_c, Yw1_c, O_v, Y'_{cpv}, a'_{cm}, b'_{cm}, c'_{cm}, d'_{cm}, e'_{cm}, f'_{cm} \in \{0,1\}. \tag{53}$$

Eq. (19) shows the value of the first objective function of the problem and involves minimizing the total costs of designing the vehicle routing network in the supply chain. These costs include fees 1) construction of the distribution center, 2) costs of transportation of products, 3) the cost of distribution of products by the distribution center, fixed costs of starting and operating the vehicle, and the cost of fines for exceeding the time window). *Eq. (20)* shows the second objective function of the problem and involves minimizing the amount of greenhouse gas emissions due to the amount of load in the vehicle. *Eq. (21)* ensures that each distribution center can only be assigned to one customer; *Eq. (22)* shows the maximum product transport capacity available by the vehicle. *Eq. (23)* represents the restriction related to the removal of the net below. Restriction *Eq. (24)* ensures that the vehicle can enter and exit each client node only once. *Eq. (25)* provides that a maximum of one vehicle can be assigned to each route created.

Eq. (26) shows the assignment of the customer to each distribution center. Also, it indicates that the vehicle must return to the distribution center after completing the visit to the customer nodes. *Eq. (27)* demonstrates the total amount of distribution performed by each distribution center and each vehicle. *Eq. (28)* guarantees that the maximum distribution capacity of that center cannot be used until the distribution center is constructed. *Eq. (29)* shows each vehicle's load leaving each distribution center on the first customer visit. *Eq. (30)* specifies the amount of cargo in each vehicle (balance of delivery and withdrawal) in visiting customer nodes and returning to the distribution center. *Eq. (31)* illustrates the vehicle's arrival time to the first customer node exited from the distribution center. *Eq. (32)* shows the time of arrival of the vehicle to the customer node based on the loading and unloading time as well as the traffic between the nodes. *Eqs. (33)* and *(34)* show the amount of time the vehicle is exceeding when visiting each client node in the soft timeline. *Eqs. (35)* and *(36)* calculate the allocation of each package to each vehicle. *Eqs. (37)* to *(42)* ensures that none of the packets overlap and do not fit inside. *Eq. (43)* provides that each package can only be next to the other package in one of the 6 available directions. *Eq. (44)* shows that each package can only fit in one vehicle. *Eqs. (45)* to *(47)* show that the packages' dimensions cannot be greater than the length, width, and height of the vehicle. *Eq. (48)* shows the type of vehicle loaded. *Eqs. (49) to (51)* ensures that the dimensions of the packages do not change during loading and only the placement type changes. *Eqs. (52)* and *(53)* indicate the type and gender of decision variables.

Due to the uncertainty of demand parameters and transportation costs in this model, the fuzzy programming method to control uncertainty parameters is described in the following. Linear mathematical programming model with fuzzy parameters is given by Pishvaee and Razmi [34]:

$$\text{Min } Z = \tilde{c}^t x$$

$$\text{s. t.:} \tag{54}$$

$$x \in N(\tilde{A}, \tilde{B}) = \{x \in R^n | \tilde{a}_i x \geq \tilde{b}_i. \quad i \in m \quad x \geq 0\}$$

Where $\tilde{c} = (\tilde{c}_1, \tilde{c}_2, \dots, \tilde{c}_n)$, $A = [\tilde{a}_{ij}]_{m\times n}$, $\tilde{b} = (\tilde{b}_1, \tilde{b}_2, \dots, \tilde{b}_n)^t$ are the fuzzy parameters used in the objective function of the problem are the vector coefficient and the parameter to the right of the constraint. The probabilistic distribution function of fuzzy parameters is assumed based on the properties of fuzzy numbers. Finally, $x = (x_1, x_2, \dots, x_n)$ represents the decision vector. For the feasibility and optimization of the problem presented in the above model, controlling the uncertain parameters shown in the objective and constraint function is necessary. Therefore, assuming the β parameter as the minimum degree of limitation, the controlled model is as follows:

$$\text{Min } Z = EV(\tilde{c})x$$

$$\text{s. t.:} \tag{55}$$

$$[(1-\beta)E_2^{a_i} + \alpha E_1^{a_i}]x \geq (1-\beta)E_1^{b_i} + \beta E_2^{b_i}, \quad i \in m$$

$$x \geq 0. \quad \beta \in [0,1]$$

In the above relation $EV(\tilde{c})$ is the expected value of the fuzzy number used in the objective function of the model, which is calculated as follows:

$$EV(\tilde{c}) = \frac{E_1^c + E_2^c}{2}. \tag{56}$$

In this paper, fuzzy parameters are considered as triangular fuzzy as shown in *Fig. 3*. This figure shows the possible distribution of the fuzzy parameter of $\tilde{C} = (C^1, C^2, C^3)$, where C^1, C^2, C^3 represent the optimistic, probable, and pessimistic values of the fuzzy number $\tilde{C}$ are determined by the decision-maker.

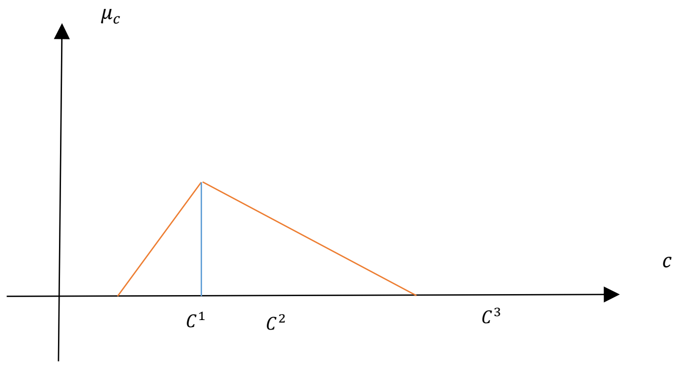

Fig. 3. Possible triangular distribution of the fuzzy parameter $\tilde{C}$.

Therefore, the mathematical expectation (expected value of the fuzzy parameter of the objective function) can be calculated as follows:

$$EI(\tilde{c}) = [E_1^c, E_2^c] = \left[\frac{c^1 + c^2}{2}, \frac{c^2 + c^3}{2}\right]. \tag{57}$$

Considering the triangular distribution of uncertain parameters as follows, the designed model can be controlled using the *Eq. (57)*. Therefore, the demand and transfer cost parameters are considered as $\tilde{D}_{cp} = (D_{cp}^1, D_{cp}^2, D_{cp}^3)$ and $\tilde{Tr}_{nn'} = (Tr_{nn'}^1, Tr_{nn'}^2, Tr_{nn'}^3)$. Finally, the definitive and controlled model of the problem is as follows:

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$$Min\omega 1 = \sum_{l=1}^{L} U_l Z_l + \sum_{n=1}^{N}\sum_{n'=1}^{N}\sum_{v=1}^{V}\left[\frac{Tr_{nn'}^{1} + 2Tr_{nn'}^{2} + Tr_{nn'}^{3}}{4}\right] X_{nn'v} + \sum_{l=1}^{L}\sum_{p=1}^{P}\sum_{v=1}^{V} C_{lp} V_{lpv} \tag{58}$$

$$+ \sum_{v=1}^{V} F_v O_v + \sum_{c=1}^{C}\sum_{v=1}^{V} \alpha Te_{cv}.$$

$$Min\omega 2 = \sum_{n=1}^{N}\sum_{n'=1}^{N}\sum_{v=1}^{V}\sum_{p=1}^{P} H.\, Dis_{nn'} Lc_{nn'pv}. \tag{59}$$

s. t.:

$$\sum_{c=1}^{C}\sum_{n=1}^{N}\sum_{p=1}^{P}\left[(1-\beta)\left(\frac{D_{cp}^{1}+D_{cp}^{2}}{2}\right)+\beta\left(\frac{D_{cp}^{2}+D_{cp}^{3}}{2}\right)\right] X_{ncv} \le CapV_v O_v. \quad \forall v \tag{60}$$

$$V_{lpv} = \sum_{c=1}^{C}\left[(1-\beta)\left(\frac{D_{cp}^{1}+D_{cp}^{2}}{2}\right)+\beta\left(\frac{D_{cp}^{2}+D_{cp}^{3}}{2}\right)\right] Z_{lcv}. \quad \forall l, p, v \tag{61}$$

$$Lc_{lcpv} \ge V_{lpv} - \left[(1-\beta)\left(\frac{D_{cp}^{1}+D_{cp}^{2}}{2}\right)+\beta\left(\frac{D_{cp}^{2}+D_{cp}^{3}}{2}\right)\right] + R_{cp} - M.(1 - X_{lcv}). \quad \forall l, p, c, v \tag{62}$$

$$Lc_{lmpv} \ge Lc_{lcpv} - \left[(1-\beta)\left(\frac{D_{cp}^{1}+D_{cp}^{2}}{2}\right)+\beta\left(\frac{D_{cp}^{2}+D_{cp}^{3}}{2}\right)\right] + R_{mp} - M.(1 - X_{cmv}). \quad \forall l, p, c, m, v \tag{63}$$

According to the above model, the output of modeling in the second stage is to determine the number of warehouses and the vehicle assigned to the customer. In this issue, the optimal transportation route of vehicle for simultaneous delivery and collection is also determined.

4 | Methodology

In this part of the article, the problem-solving methods are presented. Considering the two-stage nature of the developed model, in the first stage, to achieve optimal dimensions of packages that can be sent to the customers, GAMS software and Cplex solver for small size problems besides PSO algorithm for large size problems (a case study of Golrang company) has been used. Also, after achieving the optimal dimensions of the packages that can be sent to customers, the primary key in the second stage is to achieve efficient solutions of the two-objective model to reduce transportation costs and reduce greenhouse gas emissions. Therefore, to form the Pareto front, the LP-Metrics method for the small size problem and NSGA II and MOALO algorithms have been used to solve the case study. The following is a complete benchmarking method and chromosome design for the two stages of the developed model.

4.1 | LP-Metrics Method

According to multiple purpose of the designed model, the multi-objective decision-making method should be used to solve the model, as utilized in this paper. In LP-Metrics method, the particular optimization method must obtain the best value of each objective function. The software must first get the value of each objective function without considering the other objective function to be used in the calculations. Eq. 65 shows a LP-Metrics method [46].

$$L_p = \left\{ \sum_{i=1}^{n} W_i \left[\frac{(f_i - f_i^*)}{(f_i^*)} \right]^p \right\}^{\frac{1}{p}}. \qquad p \geq 1 \tag{64}$$

In the above relation W_i is the weight assigned to each objective function, f_i is the objective function i of the problem, and f_i^* is the best value of the objective function obtained from the indivisual optimization method. Also, in this article, linear softness, i.e., $p = 1$, is used.

4.2 | Chromosome Design (First Step)

In this article, the problem under study consists of two stages. The first step is to optimize the dimensions of the customer package (including the proper arrangement of the customer's orders within a package); the PSO algorithm is used to optimize the packet dimensions. To illustrate the chromosome and how it is decoded, consider a hypothetical example involving two customers and three products. Table 2 shows the dimensions of each product requested by the customer.

Table 2. Dimensions of products requested by the customer to define chromosomes.

	Product 1	Product 2	Product 3
Customer 1	(1,2,1)	(2,1,3)	(3,2,2)
Customer 2	(3,1,3)	(2,1,2)	(2,1,3)

Considering the arrangement of products in six different dimensions inside the package, the first part of the chromosome deals with the arrangement of products in each package. Thus, the customer produces three random numbers (1, 2, and 3). The number 1 means the x-axis, the number 2 represents the y-axis, and the number 3 means the z-axis. For example, the dimensions of product 2 for the customer are 1 (2, 1, 3); that is, the length of the product is two units, the product's width is 1 unit, and the height of the product is three units. Consider a random chromosome designed for this product 3-1-2. This chromosome is interpreted that the product's length must be along the y-axis because the number 1 chromosome is registered on the y-axis. The product's width should be along the x-axis; because the number 2 chromosome is recorded on the x-axis, and finally, the height of the product should be along the z-axis. Thus, the chromosome designed for *Table 2* can be defined as *Table 3*.

Table 3. The chromosome description of the first step for arranging the products inside the package.

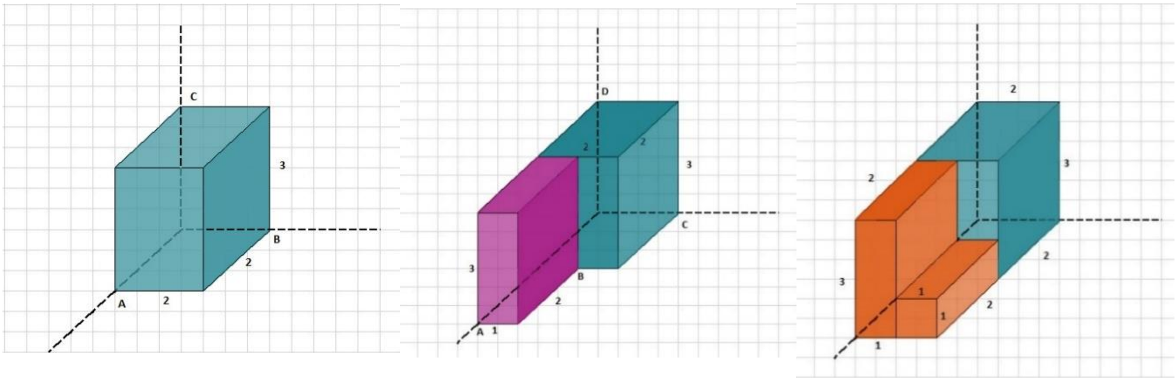
	Product 1	Product 2	Product 3
Customer 1	1-2-3	2-1-3	3-2-1
Customer 2	1-3-2	1-3-2	1-2-3
		⇩ Sorting	
Customer 1	(1,2,1)	(1,2,3)	(2,2,3)
Customer 2	(3,3,1)	(2,2,1)	(2,1,3)

The same must be done in the chromosome decoding step. First, the customer's products are sorted based on the maximum volume. For example, *Table 4* shows how to sort products by total volume.

Table 4. How to sort the volume of products in the chromosome of the first step.

Product volume	Product 1	Product 2	Product 3
Customer 1	2	4	12
Customer 2	9	4	6
		⇩ Sorting	
Customer 1	3	2	1
Customer 2	1	3	2

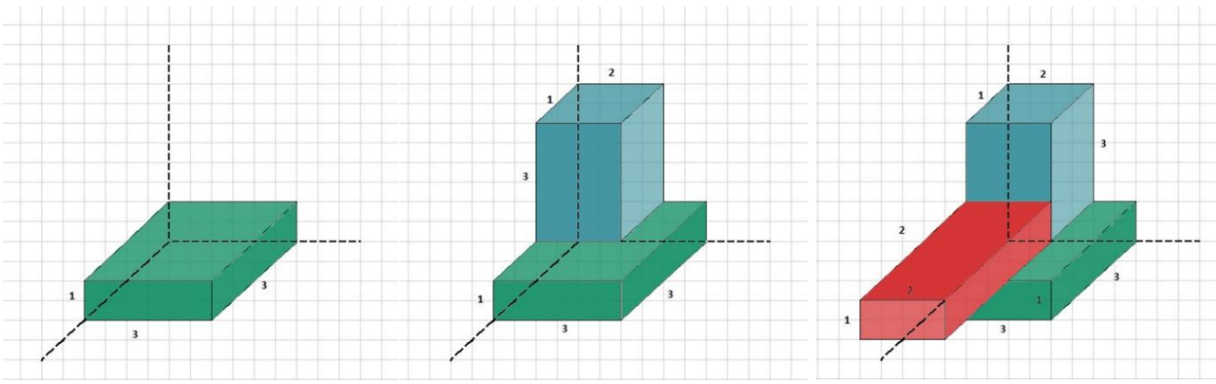
After sorting, first, the priority of customer 1, i.e., product 3, is placed in the lower-left corner of the package based on the modified dimensions of *Table 4*. *Fig. 4* shows how the first product is placed in package number 1.



a b c

Fig. 4. Arrangement of the first product based on the chromosome of the first step.

According to *Fig. 4.a,* it is observed that 3 points A, B, and C are eligible for the following product, i.e., product number 2, based on the priority of *Table 4*. Therefore, the PSO algorithm randomly selects one of the eligible points and arranges the second product inside the package. *Fig. 4.b*, shows how product 2 is positioned (for example, the PSO algorithm selects point A). After placing the second product on the length of the y-axis, four new points A, B, C, and D, will be eligible for the following product. In this section, the PSO algorithm selects a random point from 4 suitable points (such as B) and arranges the third product. *Fig. 4.c*, shows the arrangement of the third product in package number 1. After placing all the products inside the package, the optimal length, width, and height values are determined, e.g., the optimal closed dimensions for customer 1 are 3 * 4 * 2 longitudinal units. *Fig. 5* also shows how the second customer's products are arranged in package 2.



a b c

Fig. 5. Arrangement of second customer products based on the first stage chromosome.

Also, according to *Fig. 5*, it is observed that the dimensions of Jupiter package 2, 4 * 3 * 3 longitudinal units are obtained. The PSO algorithm based on mutation and combination operators will improve the dimensions of the customer's packages and determine precisely how the products are placed in each package.

4.3 | Chromosome Design (Second Step)

After achieving the optimal dimensions of packages to be delivered to the customer, the goal is to determine potential distribution centers and vehicle routing in the second modeling stage. In this section, two algorithms, NSGA II and MOALO are used to form the Pareto front. Therefore, in this section, assuming five customers, three central warehouses, and one central warehouse, the primary chromosome is presented according to *Fig. 6*. Depending on the problem, the designed chromosome also consists of two parts of the duct. In the supply chain network's first level, the substitution of natural numbers is produced for the total number of customers, and in the second level, natural numbers are substituted for the total number of distribution centers.

The Primary Answer of The First Level	5	3	4	2	1
The Primary Answer of The Second Level	1		3		2

Fig. 6. The primary chromosome of the problem.

The next part of chromosome design is the turn of assigning customers to each of the distribution centers. Therefore, the customers' total number is randomly assigned to the total number of distribution centers, and the routing of the vehicle is based on the numbers generated in the initial answer of the first level of the chromosome. *Fig. 7* shows how customers are assigned to distribution centers and vehicle routing on the chromosome in *Fig. 8*.

The primary answer of the first level	5	3	4	2	1
The primary answer of the second level	1		3		2

Fig. 7. Decoding of the primary chromosome of the problem.

According to *Fig. 7*, it is observed that customers 5 and 3 are allocated to distribution center 1, customer number 2 is assigned to distribution center 3, and customers 2 and 1 are earmarked for distribution center 2. Also, vehicle routing from distribution center 1 as $L1 \rightarrow C5 \rightarrow C3 \rightarrow L1$, vehicle routing from distribution center 3 as $L1 \rightarrow C5 \rightarrow C3 \rightarrow L1$, and vehicle routing from distribution center 2 as $L2 \rightarrow C2 \rightarrow C1 \rightarrow L2$. After assigning customers to distribution centers, other restrictions of the issue are examined in order. If a specific condition does not apply to the problem, the penalty function controls the limitation.

4.4 | Comparison Indicators of Meta-Heuristic Algorithms

Convergence to Pareto optimal solutions and providing density and variability among the obtained keys are the two main goals of any multi-objective evolutionary algorithm. Since these two goals are somewhat at odds, the criterion can alone, and there is no absolute way to decide on the performance of algorithms. Therefore, to evaluate the performance of the proposed algorithms, the following criteria are used:

Computing time (CPU Time): An algorithm with less computing time will be more desirable.

Number of answers in Pareto: This shows the number of undefeated solutions in the Pareto set obtained for each problem. The higher the number of points, the more efficient the algorithm.

Maximum Expansion: This criterion shows how many of the answers of a Pareto set are distributed in the answer space, which is calculated from the following equation (*Eq. (65)*). The larger the value of this criterion, the more appropriate the diversity of Pareto set answers.

$$\text{MSI} = \sqrt{\sum_{m=1}^{M}\left(\max_{i=1:|Q|}f_m^i - \max_{i=1:|Q|}f_m^i\right)^2}. \tag{65}$$

Spacing (SM): This indicates the extent to which the answers are evenly spaced, calculated from the *Eq. (66)*.

$$\text{SM} = \sqrt{\frac{1}{|Q|}\sum_{i=1}^{|Q|}(d_i - \bar{d})^2}. \tag{66}$$

In the above relation, |Q| indicates the size of the Pareto archive and the values d_i and $\bar{d}$ can be calculated from *Eqs. 67* and *68*, respectively. An algorithm that is less than this criterion will be more desirable.

$$d_i = \min_{k\in Q\cap k\neq i}\sum_{m=1}^{M}\left|f_m^i - f_m^k\right|. \tag{67}$$

$$\bar{d} = \sum_{i=1}^{|Q|}\frac{d_i}{|Q|}. \tag{68}$$

Distance from the ideal point (MID): This criterion is used to measure the degree of proximity to the optimal level of the real Pareto and written as *Eq. (70)*.

$$\text{MID} = \frac{\sum_{i=1}^{n} c_i}{n}. \tag{69}$$

In this relation, n is the number of answers in the optimal Pareto set, and c_i is the Euclidean distance of each member of the Pareto set from the ideal point, which is defined as *Eq. (70)*.

$$c_i = \sqrt{(f_{1i} - f_1^*)^2 + (f_{2i} - f_2^*)^2 + \cdots + (f_{mi} - f_m^*)^2}. \tag{70}$$

5 | Analysis of Results

In this section, computational analyzes performed using case samples and analyzes using metaheuristic methods are presented.

5.1 | Solving the Sample Problem in Small Size

In this section, to evaluate the designed model, a sample problem with three distribution centers, six end customers, two products, and four vehicles are considered. Also, some intervals of the problem parameters are regarded according to *Table 5*. The lower and upper bounds of the generated data are uniformly distributed based on the range of intervals used in the base papers.

Table 5. Limits of problem parameters based on uniform distribution.

Parameter	Parameter Range Limits	Parameter	Parameter Range Limits
U_l	~U(10000,12000)	$Tr_{nn'}$	~U(30,40)
F_v	~U(300,400)	$T_{nn'}$	~U(15,20)
D_{cp}	~U(20,30)	S_c	~U(2,5)
R_{cp}	~U(10,15)	C_{lp}	~U(2,3)
$CapV_v$	~U(100,120)	$[AS_c, BS_c]$	~U(20,50)
$CapL_{lp}$	~U(200,220)	α	6
$Dis_{nn'}$	~U(10,100)	H	3

After designing the problem and solving the model using GAMS software, Cplex solver, and the LP-Metrics method, the receiving table and the efficient answer obtained from solving the problem are described in *Table 6*. The receiving table contains the best values of the objective functions without considering other objective functions.

Table 6. Receipt table and an efficient answer obtained from solving the sample problem in small size.

Efficient Answer	The Value of the First Objective Function	The Value of the Second Objective Function
The first objective function	12541	-
The second objective function	-	22209
Efficient answer 1	12913	59640
Efficient answer 2	12916	51330
Efficient answer 3	12922	44079
Efficient answer 4	13512	39168
Efficient answer 5	13518	38892
Efficient answer 6	13530	38418
Efficient answer 7	14266	33495
Efficient answer 8	14270	31944

According to *Table 6*, it can be seen that the best value of the first objective function is equal to 12541 units, without considering the second objective function, and the best deal of the second objective function without considering the first objective function is equivalent to 22209 units. Also, the LP-Metrics method obtained eight different efficient answers by limiting the value of the first objective function. The Pareto front obtained from problem-solving is as shown in *Fig. 8*.

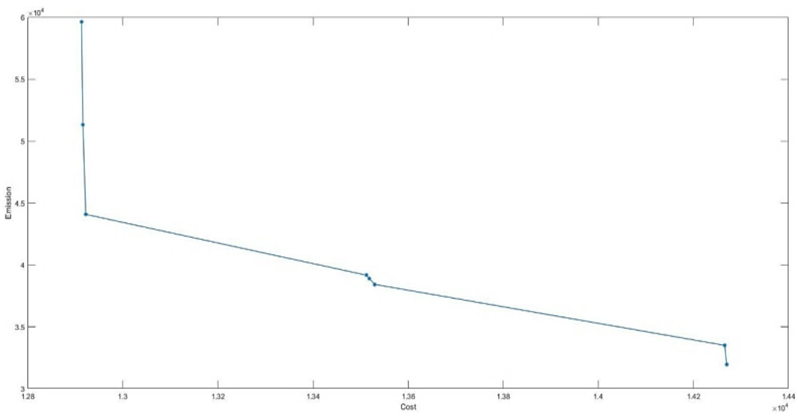


Fig. 8. Pareto front obtained by solving a small sample problem with a LP-Metrics method.

To examine the output variables of the problem, one of the efficient answers (Efficient answer 8) is selected. The location of the distribution centers is determined, and the exact routing of the vehicle is shown in *Fig. 9*.

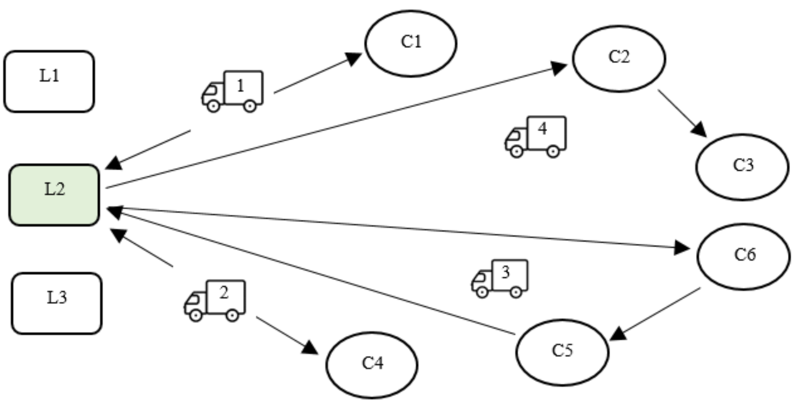


Fig. 9. Vehicle routing in the case of small sample size with a LP-Metrics method.

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According to *Fig. 9*, it can be seen that among the three distribution centers, distribution center No. 2 is selected, and four vehicles are responsible for delivery and picking up products to/from customer points. *Table 7* demonstrates the delivery and pickup of the product beside the time of vehicle arrival to demand points.

Table 7. The amount of delivery and withdrawal of goods and the time of arrival of the vehicle to the demand points.

Customer	The Amount of Load Accumulated When Entering the Customer Demand Point	The Time When the Vehicle Reaches the End of Customer Demand
Customer 1	12 units of product 1 12 units of product 2	23
Customer 2	38 units of product 1 40 units of product 2	23
Customer 3	22 units of product 1 23 units of product 2	94
Customer 4	14 units of product 1 11 units of product 2	24
Customer 5	24 units of product 1 24 units of product 2	92
Customer 6	38 units of product 1 31 units of product 2	27

After examining the problem's output variables, the issue's sensitivity under different parameters and its effect on the values of the objective functions of the problem is analyzed.

5.2 | Sensitivity Analysis of Small Sample Size Problem

This section analyzes the problem sensitivity under various parameters and its effect on the values of the objective functions of the problem. This sensitivity analysis selects the efficient answer number 8, and all calculations are performed on that efficient answer. First, in *Table 8*, the changes in the values of the objective functions in exchange for changes in the cost of transporting products in the study network are investigated.

Table 8. Sensitivity analysis on transportation cost in small sample problem.

Transportation Cost	The Value of the First Objective Function	The Value of the Second Objective Function
-20%	14200.2	31944
-10%	14235.1	31944
Basic	14270	31944
+10%	14304.9	31944
+20%	14339.8	31944

According to *Table 8*, the value of the first objective function has increased with increasing transportation costs, and the second objective function has not changed. The lack of transportation costs affects the number of goods accumulated on the vehicle and the increase/decrease in the amount of the second objective function. In the following, Table 9 examines the changes in the values of the target functions in exchange for changes in the amount of product-dependent greenhouse gas emissions in the study network.

According to *Table 9*, with increasing the amount of greenhouse gas emissions related to the product, the value of the second objective function has improved. Due to the ineffectiveness of this parameter on the value of the first objective function, the total network costs have not changed. *Table 10* examines the changes in the importance of the aim functions in exchange for changes in the rate of uncertainty in the study network.

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Table 9. Sensitivity analysis on the amount of greenhouse gas emissions depending on the product in the small sample size problem.

Product Greenhouse Gas Emissions	The Value of the First Objective Function	The Value of the Second Objective Function
1	14270	10648
2	14270	21296
3	14270	31944
4	14270	42592
5	14270	53240

Table 10. Sensitivity analysis on the rate of uncertainty in the problem of small sample size.

Delivery Request	The Value of the First Objective Function	The Value of The Second Objective Function
-20%	14086	31200
-10%	14178.2	31572
Basic	14270	31944
+10%	14362.8	33829
+20%	Unjustified	Unjustified

According to *Table 10*, it is observed that with increasing the amount of uncertainty rate, the total network costs increase. Consequently, due to the accumulation of vehicle load, greenhouse gas emissions have also increased. It is also observed that the problem does not have a valid answer by increasing the uncertainty rate by 20%. After performing the problem sensitivity analysis, NSGA II and MOALO algorithms were used to solve the problem in a larger size (Golrang case study).

5.3 | Problem-Solving in a Larger Size (Case Study)

To evaluate the efficiency of the algorithms used in the paper, the sample problem designed in the previous section was assessed and solved by NSGA II and MOALO algorithms. Therefore, the efficient solutions obtained from solving the small-size sample problem with metaheuristic algorithms and the LP-Metrics method are shown in *Table 11*.

Table 11. A set of efficient answers obtained from solving various sample problems in small size.

Efficient Answer	LP-Metrics		NSGA II		MOLAO	
	The Value of the First Objective Function	The Value of the Second Objective Function	The Value of the First Objective Function	The Value of the Second Objective Function	The Value of the First Objective Function	The Value of the Second Objective Function
1	12913	59640	13275	60751	13269	60751
2	12916	51330	13334	57555	13299	58882
3	12922	44079	13373	55617	13313	56544
4	13512	39168	13777	43245	13339	56151
5	13518	38892	14481	35320	13608	55963
6	13530	38418	14540	32740	13717	48028
7	14266	33495	14768	27774	13758	46311
8	14270	31944	15864	25284	14491	38184
9	-	-	15912	23047	14496	33471
10	-	-	-	-	14576	33078
11	-	-	-	-	14772	27838
12	-	-	-	-	14785	27534
13	-	-	-	-	15868	25711
14	-	-	-	-	15872	25284
15	-	-	-	-	15894	24432
16	-	-	-	-	15910	23313

According to the *Table 11*, the NSGA II algorithm has obtained nine efficient answers in solving the problem of a small size sample, and the MOALO algorithm has received 16 efficient responses. Other indicators for comparing efficient solutions between different solution methods are shown in *Table 12*.

Table 12. Comparisons of efficient solutions between different solution methods in the small sample problem.

Indicator	LP-Metrics	NSGA II	MOALO
The average of the first objective function	13480.87	14369.33	14419.81
The average of the second objective function	421120.75	40148.33	40092.37
Number of efficient answers	8	9	16
The most spread	27729.224	37796.10	37531.33
Metric distance	0.979	0.401	0.81
Distance from the ideal point	10419.82	17567.46	17250.33
Computational time	15.03	60.34	7.29

Table 12 shows that the LP-Metrics method has been more efficient in obtaining the mean indices of the first objective function and the distance from the ideal point. The NSGA II algorithm has shown its performance metric distance in getting maximum expansion indices. Finally, the MOALO algorithm has been more efficient than other methods in obtaining the mean index of the second objective function and computational time. To examine the Pareto front, *Fig. 10* shows the value of the first objective function of the problem for the dual objective function of the problem with different solution methods.

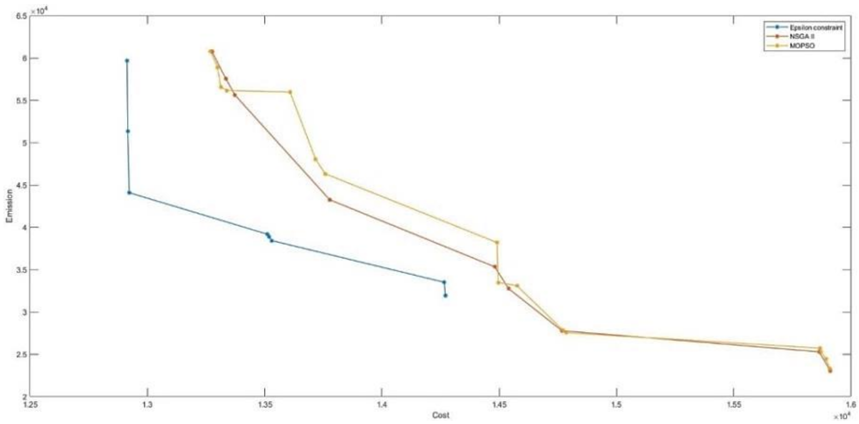

Fig. 10. Pareto front obtained by solving a small sample problem with solution methods.

Considering that each solution method has shown efficiency in obtaining different indicators, the TOPSIS multi-criteria decision-making method has been used to select the most efficient way for solving small-size sample problems. This method showed a score of 0.8388 by MOALO algorithm, 0.5865 by LP-Metrics method, and 0.2057 by NSGA II algorithm. Therefore, the MOALO algorithm has achieved the desired efficient solutions more efficiently than the complete standard method furthermore, due to the inability of the LP-Metrics method to solve large-size problems, the MOALO meta-innovative algorithm has been used due to its higher efficiency in solving the real study problem.

Golrang Holding is one of the largest economic groups in Iran, which consists of a group of manufacturing and distribution companies. Among these companies, each of which has a mission, Golrang Distribution Company plays a vital role as a liaison between the manufacturing companies and the retailers of Golrang Group. Implementing this study results in a reliable and complete optimization in the set of processes related to this company. This optimization will lead to the transparency of operations and the current situation and ultimately increase efficiency and reduce costs. Given the current sensitive competitive conditions, which are becoming more sensitive day by day with the opening of economic borders, the results of the article can empower this company, which plays an essential role in the whole complex, and due to the newness of this project in the country, the situation is better. Provide the organization with domestic and foreign competitors. *Tables 13* to *17* show the information needed to solve the problem in a real case study.

Table 13. Dimensions and size of Golrang Distribution Company supply chain network model.

Number of Time Periods	The number of periods for solving the problem includes 12 months from 1398.
Number of Suppliers	The number of suppliers of Golrang Broadcasting Company products is 47 companies.
Number of Distribution Canters	The number of distribution canters of Golrang Broadcasting Company in the country includes 12 main canters in the country's provinces. In this plan, only the sales distribution canter of Tehran has been studied.
Number of Customer Clusters	Due to the limitation of the sales distribution canter, the demand areas are selected in 10 clusters close to each other.
Number of Products	Due to the excessive range of products of Golrang Broadcasting Company, in this project, 76 products in 27 groups have been selected based on the maximum sales (90%) and have been used in solving the model.
Number of Transport Fleets	According to the information of 1396, 2 Isuzu units, 2 Alvand units are owned by the company, and 6 Nissan units and 1 Isuzu unit have been used as leases in the distribution and sale of products in the Tehran region.

Table 14. Major suppliers of Golrang Broadcasting Company.

Cod e	Title	Product Group	Code	Title	Product Group
10	Sehat products	Detergent	45	Money Man Pars	Other (chewing gum) - logistics
11	Pusan salt	Other	46	Anil Teb Azaran	Detergent - Logistics
12	Paniz Fam	sugar	50	Kerman	Other (dates)
13	Darougar	Detergent	51	Setareh Momtaz	Other (matches)
15	Khoramshar	Oil	57	Pegah Bazar Gostar	Other (dairy)
15	Nemuneh Farm	olive oil	58	Pegah Bazar Gostar	Other (noodles and dates)
16	Nemuneh Farm	Rice	61	Iman-Amin	Sesame oil - logistics
17	Ansarifar	Other (rose and liqueurs)	68	Kowsar Electronics	Other (electrical protector)
16	Bihamta Industry	beans	71	Paddy plain of Tabaristan Eliassi plain	Rice
17	Bihamta Industry	Paste, and tuna	72	Akbar Gerzin (well cooked(	Rice
18	Bihamta Industry	Other (olives and other canned food)	73	Vesta Polymer Nick	Other (Nylex)
19	Debsh	Other (toothbrush) - Logistic	78	Shams Azar	Other (Pasta)
20	Atieh Iranian Kish Development Company	Other	79	Ershad Talebi	Rice
24	Ideal	Other (Halva Ardeh)	82	Mihan	Other (dairy)

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Table 14. Continued.

Code	Title	Product Group	Code	Title	Product Group
27	Touba	Rice	86	Green Barg-Chin of Tehran	Other (tea)
30	Sepahan Noor Sugar Company	sugar	87	Mahan of Persian Gulf	Paste and tuna
31	Narges Gol Tafresh Company	Other (spice) logistics	90	Saf Noosh Iranian Company	Other (dates)
33	Padamira Mehr Pasargad Company	Other (chewing gum)	91	Mahvand Company	Fish paste and tuna
35	Behdis Tadbir Atieh Company	Other (toothpaste)	95	Qorbanpour	Rice
37	Fadishe Products	Detergent - Logistics	96	Ala Sabz Kavir Shahroud	Other (fried onions)
40	Targol Bayzeh	Other (spice) logistics	99	Novin Pakhsh Toos Javedan	Paste and tuna
41	Abrokh	Other (Candy) - Logistics	101	Qolam Paydar	Fish
43	Kayer khazar Tejarat Gostar	Rice	103	Zarpash Venser	Olive and sesame oil
45	Money Man Pars	Other (chewing gum) - logistics	104	Koosha Sepehr Sabalan	beans
46	Anil Teb Azaran	Detergent - Logistics	71	Paddy plain of Tabaristan Eliassi plain	Rice
50	Kerman	Other (dates)	72	Akbar Gerzin (well cooked	Rice
51	Setareh Momtaz	Other (matches)	73	Vesta Polymer Nick	Other (Nylex)
57	Pegah Bazar Gostar	Other (dairy)	78	Shams Azar	Other (Pasta)
58	Chain Stores	Other (noodles, and dates)	79	Ershad talebi	Rice
61	Iman-Amin	Sesame oil - logistics	82	Mihan	Other (dairy)
68	Kowsar Electronics	Other (electrical protector)	86	Green Barg-Chin of Tehran	Other (tea)
90	Saf Noosh Iranian Company	Other (dates)	87	Mahan of Persian Gulf	Paste and tuna
91	Mahvand Company	Paste and tuna	99	Novin Pakhsh Toos Javedan	Paste and tuna
95	Qorbanpour	Rice	101	Qolam Paydar	Fish
96	Ala Sabz Kavir Shahroud	Other (fried onions)	103	Zarpash Venser	Olive and sesame oil
104	Koosha Sepehr Sabalan	beans			

Table 15. Customer clusters considered in the Tehran region.

No.	Customer Cluster (Route – Service)	Return Time Required (Hours)	The Estimated Distance Back and Forth	Areas Within the Cluster
1	Hashtgerd and Nazarabad	5	170	Hashtgerd and Nazarabad
2	south of Tehran	4	70	Shahre-ray 9 - 10 - 11 - 12 - 16 - 17 - 18 - 19
3	Karaj	5	130	Karaj
4	West of Tehran	4	60	2- 5- 6- 21- 22

Table 15. Continued.

No.	Customer Cluster (Route – Service)	Return Time Required (Hours)	The Estimated Distance Back and Forth	Areas Within the Cluster
5	East and north of Tehran	5	150	1- 3- 4- 8- 13- 14
6	Varamin and Qayam Dasht	5 hours and 30 minutes	170	Varamin Qarchak Uprising of Pakdasht plain, 15th and 20th districts of Tehran
7	Sar-e-Asyab and Marlik	4	100	Sar-e-Asyab, Marlik and Ferdis
8	Mehrshahr and Mahdasht	5	110	Flower of Mehrshahr Mahdasht
9	Andisheh and Shahriar	4	90	Shahriar and Andisheh
10	Islamshahr	4	90	Islamshahr - Chahardangeh - Parand

Table 16. Information on the size and volume of the transport fleet.

No.	Type	The Number	Capacity (kg)	Dimensions (Meters)			Capacity (Volume)	Assumed Capacity	Rental Number	Number of Properties
				Length	Width	Height				
1	Nissan	6	2000	2.55	1.65	1.6	6.732	0	0	0
2	Isuzu	3	3000	3	1.8	1.6	8.64	2	2	2
3	Alvand	2	4000	4.7	2	2	18.8	2	2	2

Table 17. Weight and volume information of products.

Title	Product Weight (kg)	Product Packaging Dimensions (Meters)			Product Volume in the Package	Package Weight (kg)
		Length	Width	Height		
Pet frying oil 2700 g (3 liters)	2.7	0.27	0.27	0.33	0.03	11
Liquid oil mixed 2700 g transparent	2.7	0.27	0.27	0.33	0.03	11
Sepidan Tarom rice 10 kg	10	0.4	0.22	0.25	0.03	10
Sepidan Tarom 10 kg installment rice	10	0.4	0.22	0.25	0.03	10
Sepidan Tarom rice 10 kg (farm)	10	0.4	0.22	0.25	0.03	10
10 kg rice 1121 Delfard	10	0.4	0.22	0.25	0.03	10
Mohsen 10 kg Indian rice 1121	10	0.4	0.22	0.25	0.03	10
Fajr 10 kg Iranian rice (Eliassy)	10	0.4	0.22	0.25	0.03	10
Fajr Iranian rice 10 kg Sepidan (sad)	10	0.4	0.22	0.25	0.03	10
Fajr Iranian rice (Kayer) 10 kg	10	0.4	0.22	0.25	0.03	10
Aleppo 16 kg semi-solid oil	16	0.24	0.24	0.35	0.03	16
Aleppo frying oil 16 kg	16	0.245	0.24	0.35	0.03	16
Aleppo soybean oil 16 kg	16	٠0.24	0.24	0.35	0.03	16
Aleppo frying oil 16 kg Varamin	16	0.24	0.24	0.35	0.03	16
Aleppo soybean oil 16 kg Varamin	16	0.24	0.24	0.35	0.03	16
Super shampoo (jar) 220 g Darougar	0.24	0.26	0.38	0.26	0.03	12

Table 17. Continued.

Title	Product Weight (kg)	Product Packaging Dimensions (Meters) Length	Width	Height	Product Volume in the Package	Package Weight (kg)
5 kg (omega) semi-solid oil	5	0.34	0.34	0.25	0.03	20
Aleppo 5 kg semi-solid oil	5	0.34	0.34	0.25	0.03	20
Palm soap 58-130 g with cellophane (green)	0.135	0.34	0.24	0.25	0.03	10
900 g beans (chains)	0.9	0.57	0.21	0.11	0.02	9
900 g Lentils (chains))	0.9	0.57	0.21	0.11	0.02	9
900 g chickpeas (chains))	0.9	0.57	0.21	0.11	0.02	9
900 g coke (chains)	0.9	0.57	0.21	0.11	0.02	9
900 g Red Beans (Chains)	0.9	0.57	0.21	0.11	0.02	9
900 g beetroot beans (chain)	0.9	0.57	0.21	0.11	0.02	9
Basket cotyledons (10 pieces)	0.9	0.57	0.21	0.11	0.02	9
Lentils (basket of goods)	0.9	0.57	0.21	0.11	0.02	9
900 g mung bean (chain)	0.9	0.57	0.21	0.11	0.02	9
900 g white beans (chains)	0.9	0.57	0.21	0.11	0.02	9
810 g Peta frying oil	0.8	0.3	0.24	0.28	0.03	10
810 g PET mixed oil	0.81	0.3	0.24	0.28	0.03	10
424108-PET 810 g sunflower oil	0.81	0.3	0.24	0.28	0.03	10
Sunflower oil (basket of goods)	0.81	0.3	0.24	0.28	0.03	10
Shouma Washing machine powder 500 g with activator	0.5	0.31	0.31	0.39	0.04	12
500 g Darya washing hand washing powder	0.5	0.31	0.31	0.39	0.04	12
500 cc olive oil refining	0.5	0.25	0.19	0.3	0.02	6
500 cc virgin olive oil	0.5	0.25	0.19	0.3	0.02	6
500 cc premium olive oil	0.5	0.25	0.19	0.3	0.02	6
500 cc Refined olive oil Mena	0.5	0.25	0.19	0.3	0.02	6
500 cc of virgin olive oil	0.5	0.25	0.19	0.3	0.02	6
4 kg solid omega (omega) oil	4	0.34	0.34	0.2	0.03	16
Aleppo butter semi-solid oil 4 kg	4	0.34	0.34	0.2	0.03	16
4 kg Jaam dishwashing liquid	4	0.4	0.13	0.29	0.03	16
4 kg Rica	4	0.4	0.23	0.29	0.03	16
1 kg Jaam dishwashing liquid	1	0.43	0.27	0.26	0.04	15
1 kg cylinder Rica	1	0.43	0.27	0.26	0.04	15
180 g tuna fish easy to open (48) (chains)	0.18	0.36	0.26	0.14	0.02	5
180 g Easy to open tuna (chain)	0.18	0.36	0.26	0.14	0.02	5
180 g tuna (basket of goods)	0.18	0.36	0.26	0.14	0.02	5
Premium rose 1 liter	1	0.3	0.24	0.28	0.03	6
1 liter of mint juice	1	0.3	0.24	0.28	0.03	6
Cold Sweat Potion 1 liter (6 pieces) (chain)	1	0.3	0.24	0.28	0.03	6
800 g Ordinary tomato paste sprouts (chains)	0.81	0.42	0.3	0.12	0.02	10
800 g easy to open tomato paste sprouts (chains)	0.81	0.42	0.3	0.12	0.02	10
4-piece simple tomato paste pack (reliance chains)	0.81	0.42	0.3	0.12	0.02	4

Table 17. Continued.

Title	Product Weight (kg)	Product Packaging Dimensions (Meters) Length	width	Height	Product Volume in the Package	Package Weight (kg)
900 g Refined sesame oil 20 foods	0.9	0.3	0.24	0.28	0.03	9
900 g Virgin sesame oil 20 foods	0.9	0.3	0.24	0.028	0.03	9
1 kg Towel and clothes softener for blue halo	1	0.43	0.27	0.26	0.04	12
50 kg of Dehkhoda sugar cane	50	0.85	0.4	0.25	0.09	50
50 kg bulk sugar Miandoab	50	0.85	0.4	0.25	0.09	50
Bulk sugar 50 kg Karun	50	0.85	0.4	0.25	0.09	50
50 kg bulk sugar Miandoab (Hosseinzadeh)	50	0.85	0.4	0.25	0.09	50
250 cc olive oil refining	0.25	0.3	0.21	0.35	0.03	3
250 cc virgin olive oil	0.25	0.3	0.21	0.35	0.03	3
250 cc premium olive oil	0.25	0.3	0.21	0.35	0.03	3
Large Nilex (Vesta Polymer Nick)	25	1	0.55	0.63	0.35	25
Medium Nilex (Vesta Polymer Nick)	25	1	0.55	0.63	0.35	25
400 g Iranian tea	0.4	0.43	0.25	0.26	0.03	13
Rica 3 kg, new design of 5 pieces	3	0.43	0.27	0.26	0.04	15
300 sheets of special cloth (chain)	0.2	0.86	0.44	0.3	0.12	10
680 g Ratab Mazafati first grade	0.68	0.17	0.11	0.09	0.01	1
200 sheets of special cloth (chain)	0.14	0.86	0.66	0.2	0.12	11
5 kg Dada carton broken sugar	5	0.2	0.2	0.2	0.01	5
70 gr Toothpaste 2 colors	0.07	0.26	0.16	0.17	0.01	6
Carrot jam, 900 g can, Easy Open sprout (chain)	0.9	0.8	0.6	0.25	0.12	11
Twin towel paper towels 24 pieces (chain)	0.3	0.86	0.44	0.3	0.12	8

After solving the above problem using MOALO multi-objective meta-heuristic algorithm, 15 efficient answers were obtained in 235.46 seconds. The Pareto front was obtained, and also the efficient answers are as *Table 18*.

Table 18. Efficient answers obtained from solving the real sample problem.

Efficient Answers	The Value of the First Objective Function (*100000)	The Value of the Second Objective Function
1	15107.60	125141.30
2	16393.54	121962.90
3	17177.72	115498.00
4	18717.57	110156.30
5	20442.85	103926.40
6	21449.82	97413.38
7	24592.54	92803.49
8	26600.77	88816.87
9	28240.71	84858.93
10	30305.94	78525.10
11	31813.67	72870.50
12	34445.84	69932.91
13	36038.83	65817.99
14	37805.33	60872.65
15	39224.3	58261.14

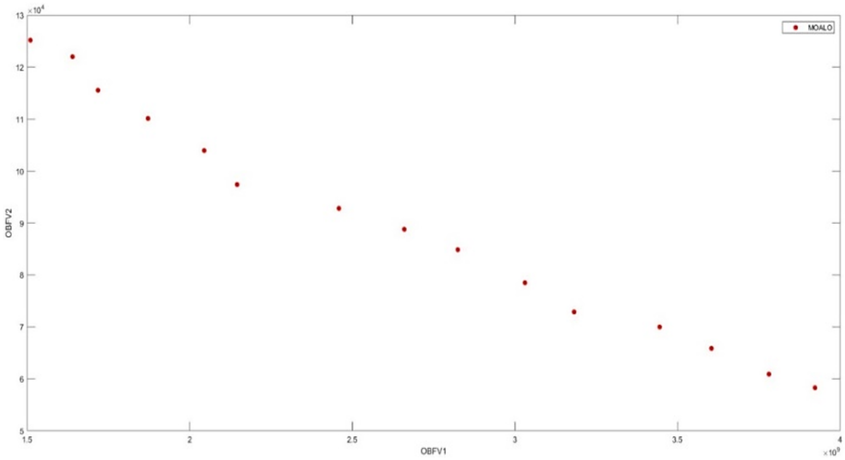

Fig. 11. Pareto front obtained from solving the sample problem in the actual study.

6 | Discussion

Many efficient algorithms have been developed to solve NP-hard problems and obtain reliable solutions [2]. This research fills in the gaps in the link between routing and location choices in a realistic manner, taking into account the actual restrictions of a distribution network. The model may reduce the uncertainty in vehicle performance while choosing a refueling strategy or dealing with diverse traffic scenarios, bringing it closer to certainty. In addition, modified NSGA II, MOALO and PSO meta-innovative algorithms are presented for solving the model. According to the opinion of the decision makers and management of the reviewed case study, the results of the proposed method in this article perform better in comparison to the exact approach for medium- and large-sized problems. The model presented in this study has many constraints and complex conditions. The use of new decision variables makes modeling attractive, but satisfying all related constraints would be difficult, concerning the models are designed for select location and routing simultaneously, and it becomes more complex when the model is optimized considering more echelons in the supply chain. Indeed, these additional constraints make the problem so complex than simply finding routes that respect all the constraints is a challenge in itself, even before considering optimization. They increase solving time, especially, when exact methods are chosen. In this research, not only does observing several conditions make the model more complex, using robust optimization to address uncertainty in traffic scenarios is time-consuming, especially when metaheuristic algorithms run to solve the model. This issue becomes highlighted when the size of the problem is increased.

7 | Conclusions

Today, vehicle routing plays a vital role in logistics and supply chain, both at the operational level and focusing on environmental issues and reducing fuel consumption as a fundamental goal for the global community. In some cases, the combination of some items, there is no history of integrated research regarding environmental issues and reducing fuel consumption on the subject of routing.

Holding is one of the largest economic groups in Iran, which consists of a group of manufacturing and distribution companies. Among these companies, each of which has a mission, Golrang Distribution Company plays a vital role as a liaison between the manufacturing companies and the retailers of Group. Conducting this research leads to a reliable and complete optimization in the set of processes related to this company in this company. This optimization will lead to the transparency of operations and the current situation, ultimately increasing efficiency and reducing costs. Given the current sensitive competitive conditions, which are becoming more sensitive day by day with the opening of economic borders, this plan can empower this company, which plays an essential role in the whole complex, and due to the newness of this plan in the country, the situation is better and better. Provide the organization with domestic and foreign competitors. Therefore, this paper proposes a mathematical model of vehicle routing with simultaneous delivery and withdrawal with several warehouses for Golrang Distribution Company.

The first stage discusses the location of potential warehouses that distribute products and the optimal routing of transportation of these products with different vehicle, and in the second stage, the arrangement of goods and products in vehicle. Finally, this paper discusses the NSGA II, MOALO and PSO meta-innovative algorithms for solving the model in a larger size (case study).

- *The research results show an increase in costs and the amount of greenhouse gas emissions due to increasing uncertainty rates. Since the demand is in a pessimistic state at its highest level, it leads to an increase in the number of vehicles for the distribution of goods and services, increasing the cost and the amount of greenhouse gas emissions.*
- *The results showed that the efficiency of the MOALO algorithm in solving small-size problems is higher than the NSGA II algorithm and LP-Metrics.*
- *This method was used to solve the large-size problem.*
- *The results of large-scale problem implementation (case study) showed that there were 15 efficient answers.*

For future research, a robust version of the sustainable and green VRP with delivery and uncertainty avoidance can be proposed. Due to the complexity of the problem, the robust adaptive model is only able to solve small samples using standard solutions. To solve large samples, it is suggested to design developed neural-fuzzy algorithms. The robustness of the solutions should be investigated by increasing the uncertainty and the comparison of the results with the modified version of the meta-heuristic algorithm with their data sets should be qualitatively evaluated.

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An Empirical Analysis of Exact Algorithms for Solving Non-Preemptive Flow Shop Scheduling Problem

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Abstract

Sequencing and scheduling are the forms of decision-making approach that play a vital role in the automation and services industries. Efficient scheduling can help the industries to achieve the full potential of their supply chains. Conversely, inefficient scheduling causes additional idle time for machines and reduces productivity, which may escalate the product price. This study aims to find the most effective algorithm for solving sequencing and scheduling problems in a non-preemptive flow shop environment where the objective functions are to reduce the total elapsed time and idle time. In this research, four prominent exact algorithms are considered and examined their efficiency by calculating the 'total completion time' and their goodness. In order to demonstrate the comparative analysis, numerical examples are illustrated. A Gantt chart is additionally conducted to exhibit the efficiency of these algorithms graphically. Eventually, a feasible outcome for each condition has been obtained by analyzing these four algorithms, which leads to getting a competent, time and cost-efficient algorithm.

Keywords: Exact algorithm, Flow shop, Makespan, Optimal sequence, Scheduling.

1 | Introduction

Job sequencing and scheduling problems are one of the elemental and essential applications of operations research [1], [2]. Scheduling problems frequently require the combination of several elements and it is an exceptionally perplexing one because of different limitations, for example, routing,and assignment [3]. However, significant assumptions that exist in real-world scheduling problem are constantly overlooked [4]. Job shop scheduling is an optimization process in which jobs are assigned to handle particular cpmplex sequence [5]. Furthermore, it is an optimization problem in which a collection of n jobs should be processed through a collection of m specific machines [6]. Each job contains a particular set of operations, that needs to be processed in keeping with a given order. When we have m number of machines and n number of jobs in production scheduling, then there are $n!)^m$ number of possible sequences. However, the most optimal sequence minimizes the

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total elapsed time (makespan) as well as the idle time. Consequently, the sequencing problems are concerned with the suitable choice of a sequence of jobs to be given a finite number of machines [7].

The integral elements in sequencing and scheduling models are resources (machines) and tasks (jobs). Here we are concerned to work with a static system in which the set of tasks available for scheduling does not change over time. We presume that each machine executes one job simultaneously, and each job is processed by a single machine with no pre-emption. That is, we are considering the non-preemptive flow-shop scheduling problem.

It is worth mentioning here that the terms Sequencing and Scheduling are both associated with the job shop (machine order varies) and flow shop (machine order is fixed) process. Sequencing is the serial, where the jobs (tasks) are executed through the machines (resources). On the contrary, scheduling is the process of allocating machines to accomplish a set of jobs over a timeframe. Several notations that we are going to use throughout this paper are given in *Table 1*.

Table 1. Mathematical notations used.

Notation	Description
J	Set of jobs, $J = \{1,2,3, \dots, n\}$, assigned by j
M	Set of machines, $M = \{1,2,3, \dots, m\}$, assigned by i
n	No. of jobs to be processed
m	No. of machines in a shop
p_{ij}	Job (j) processing time on machine (i)
C_{max}	Maximum completion time or makespan
UB	Upper bound at the beginning
LB	Lower Bound (LB) of the makespan C_{max}
|PS|	Partial sequence
|NPS|	Not part of the partial sequence |PS|

Review work with several existing exact algorithms is conducted here. Although the existing algorithms are not recent, the selected algorithms work pretty well in minimizing the makespan and the idle time in a flow shop environment. The minimum makespan and idle time are evaluated by applying the four prominent exact algorithms in this manuscript. Furthermore, the goodness of these existing algorithms is measured by calculating the Lower Bound (LB) which provides a clear idea of their applicability.

This paper will discuss several exact algorithms to solve flow shop sequencing and scheduling problem where the objective is to minimize the total elapsed time and the idle time. The remaining portion of this article is presented as follows: in the next section, the previous works have been summarized on the flow shop scheduling problem conducted by other authors. Section 3 represents a generic flow shop problem along with the mathematical statements. In the following section, the exact algorithm to solve the sequencing and scheduling problem has been discussed. An empirical comparison between these algorithms is documented in Section 5. Investigation of big data has been introduced as an advanced insightful innovation, including the considerable scope and complex applications [8]. A real-life problem has been adopted, where data is collected from a local Ready-Made Garments (RMG) manufacturing company. Finally, Section 6 represents the findings of the study and Section 7 shows the conclusion and future recommendations.

2 | Literature Review

Several studies on job sequencing and scheduling have been conducted so far. According to an analysis of relevant literature, most of the exact and heuristic algorithms have been developed for makespan minimization in a flow shop environment over the past fifty years. The earliest algorithm known as Johnson [9] considered the two-machine flow shop scheduling problem to minimize the total elapsed time [10].

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After that, the researchers developed different exact, heuristic, and meta-heuristic algorithms to minimize the total elapsed time for 'm' machine problems.

Palmer [11] utilized 'a single iteration' technique to minimize the total elapsed time. The sequencing was conducted depending on the 'Slope Index (SI)' estimation, which is then arranged in the decreasing order to get the optimal sequence by Palmer's heuristic technique. The objective was to prioritize the jobs so that jobs with processing times that increase from machine to machine can receive higher priority [11]. This approach can be used to solve m-machine and n-job flow shop scheduling problems. Ignall and Schrage [12] developed Branch and Bound (B&B) algorithms for the Permutation Flow Shop Problem (PFSP) with the objective of makespan minimization.

Campbell et al. [13] developed a makespan minimization heuristic for scheduling problems in a flow shop environment that augments Johnson's rule. It uses several iterations to arrive at the eventual solution, unlike the modified Johnson method [13]. This method is known as 'CDS heuristic' and is a widely used heuristic. A variety of distinct sequences are constructed here, among which the optimum sequence is the one that has the least makespan. Furthermore, Johnson's rule is followed at each iteration. Gupta [14] proposed a similar heuristic to Palmer's SI method. He described the SI differently by considering some interesting cases regarding the optimality of Johnson's algorithm for a three-machine scheduling problem [14]. Dannenbring [15] introduced the Rapid Access (RA) procedure which incorporates the benefits of both Palmer's SI method and the CDS method. Its objective is to generate a suitable solution as rapidly as feasible. Rather than solving $m-1$) fictitious two-machine problems, it uses Johnson's rule to solve only one fictitious problem, with processing times specified by a waiting strategy [15].

Muhammad et al. [16] designed a framework consisting of the sum of individual job processing times. According to this heuristic approach, jobs with a higher total processing time across all machines must be prioritized over the jobs with lower total processing times. This approach does not convert the initial m-machine scheduling problem into a two-machine fictitious problem. The algorithm constructs the eventual sequence, incorporating a new job at each stage and determining the optimal partial sequence [16]. They used this idea and proposed the NEH heuristics algorithm, which minimizes the total elapsed time.

Kusiak [17] implemented Johnson's method more efficiently for solving n-job & two-machine flow-shop scheduling problems. The suggested method is especially effective for scheduling problems involving a large number of jobs n).

Rajendran and Chaudhuri [18] devised a heuristic approach for the flow shop scheduling problem to minimize the elapsed time, the flow time, the idle time, and many other objectives. The initial sequence was derived from the CDS algorithm for this improved heuristic. The heuristic choice correlation is suggested and utilized to minimize the search for feasible improvements in various objectives. In scheduling, it appears that decision-making objectives are widespread [18].

Modrak et al. [19] compared various heuristic algorithms depending on the makespan. Palmer's SI method, CDS method, Gupta's algorithm, NEH algorithm, and MOD algorithm are among the heuristics that have been selected. Palmer used a single iteration to achieve the feasible solution, whereas the NEH approach utilized the maximum number of iterations. Palmer's method was relatively quick; however, it was inaccurate, and the solutions acquired from this method do not correspond to the optimal solution obtained by the other heuristics algorithms [19].

Rao et al. [20] demonstrated a deviation procedure to solve the flow shop scheduling problem. The time deviation method is a modified heuristic strategy for determining the optimum job sequence and the minimum makespan [20]. This heuristic method described the processing of n jobs on 2 machines, n jobs on 3 machines, and n jobs on m machines.

Gupta et al. [21] suggested an approach for generating the ideal job sequence for an n-job & m-machine scheduling problem with the minimum number of iterations. This recent technique is referred to as the SAI method. The method adopted for solving a huge variety of scheduling problems is the most effortless. It takes the fewest iterations to arrive at the best job sequence [22]. The SAI method finds the optimal job sequence by using mathematical reasoning.

3 | Representation of Flow Shop Problem

A mathematical statement of the flow shop problem can be made as follows:

Let $J = \{J_1, J_2, \dots, J_n\}$ and $M = \{M_1, M_2, \dots, M_m\}$ be two finite sets. On account of the industrial origins of the problem, the J_j are called *jobs* and the M_i are called machines. In a flow shop, processing all jobs require machines in the identical order and every job is done by every machine exactly once. An instance of a 3-job & 2-machine flow shop scheduling problem is illustrated in *Table 2*.

Table 2. A flow shop scheduling problem with 3 jobs and 2 machines.

P_{ij}	Machine (i)	
Job (j)	M_1	M_2
J_1	7	11
J_2	13	3
J_3	5	8

Without changing order, each job must first go to M_1 and then M_2. That is, the order of machines to process these jobs is the same $M_1 \rightarrow M_2$).

4 | Methodology

A flow shop problem assumption is considered during sequencing the jobs and is illustrated in *Table 3*.

Table 3. Assumptions in sequencing problems.

Hypotheses about jobs (job-related assumptions)	At any time, no more than one machine can process a job. Every job must go through the machines in a specific order. Depending on the machine order, a job is processed as early as possible. There are no priorities; therefore, all jobs are equally essential.
Hypotheses about machines (machine-related assumptions)	Each machine can process a maximum of one job at a time. After starting an operation, it has to be completed. From each category, there will be only one machine. Any machine does not process a job more than once.
Hypotheses about processing times (time-related assumptions)	Each job's processing time on each machine is independent of the sequence in which the jobs are processed. Each job on each machine has a predetermined and integer processing time. The amount of time required to transfer a job from one machine to another is nearly negligible. Transportation times and setup times are incorporated in the processing times.

4.1 | Johnson's Algorithm

Johnson's algorithm is a technique for scheduling tasks in two workstations. Its principal objective is to locate an optimum sequence of tasks to reduce 'makespan'. The technique minimizes the makespan and idle time in the case of two workstations. Moreover, the method determines the smallest makespan in the case of three or more workstations if additional constraints are met [9].

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4.1.1 | Johnson's algorithm for n jobs and 2 machines

Assume that jobs must be processed through machine 1 first, then through machine 2. The minimum makespan (or total elapsed time) is determined using Johnson's algorithm.

The steps involved in Johnson's method are as follows:

Let p_{ij} = Processing time for job j on machine i.

Find the job with the least p_{ij}.

If $i = 1$ (*machine* 1), the job turns into the first job.

If $i = 2$ (*machine* 2), the job turns into the final job.

Eliminate assigned job from the list and repeat (break ties arbitrarily).

Calculate the total elapsed time as per the sequence determined and calculate the idle time associated with machines.

4.1.2 | Johnson's algorithm for n jobs and 3 machines

Suppose now we have three machines namely, A, B, C and A_i, B_i, C_i are the processing times in machine A, B and C respectively. Johnson's Algorithm may be expanded to resolve the exceptional cases when at least one of the following conditions is met:

Min A $_i$) ≥ Max B_i).
Min C_i) ≥ Max B_i).

Then replace the problem with a similar problem, considering n jobs and two imaginary machines say, G and H and corresponding processing time as G_i and H_i are defined by $G_i = A_i + B_i$ and $H_i = B_i + C_i$.

4.1.3 | Johnson's algorithm for n jobs and m machines

Suppose that expected processing times for n Jobs and m machines are represented in *Table 4*.

Table 4. Processing times for n jobs and m machines.

Jobs \ Machines	M_1	M_2	M_3	…	M_{m-1}	M_m
1	p_{11}	p_{21}	p_{31}	…	$p_{(m-1)1}$	p_{m1}
2	p_{12}	p_{22}	p_{32}	…	$p_{(m-1)2}$	p_{m2}
3	p_{13}	p_{23}	p_{33}	…	$p_{(m-1)3}$	p_{m3}
…	…	…	…	…	…	…
n	p_{1n}	p_{2n}	p_{3n}	…	$p_{(m-1)n}$	p_{mn}

A result for this problem is achievable if and only if any of the following cases are fulfilled:

I. The least processing time on machine M_1 is greater or equal to the highest processing time among machines $M_2, M_3, \dots \dots \dots, M_{m-1}$.
II. The least processing time on machine M_m is greater or equal to the highest processing time among machines $M_2, M_3, \dots \dots \dots, M_{m-1}$.

That is,

Either, $min(p_{1j}) \geq max\{p_{2j}, p_{3j}, \dots \dots \dots, p_{\ m-1)j}\}$, Or, $min(p_{mj}) \geq max\{p_{2j}, p_{3j}, \dots \dots \dots , p_{m-1)j}\}$,

The following steps are involved in determining the optimal sequence:

Step 1. Investigate whether it fulfils the previously mentioned case.

Step 2. If the case is fulfilled, continue further, or else the technique fails.

Step 3. Convert the m machines problem into an identical two machines problem, say G and H, so that

$G: G_i = M_1 + M_2 + \cdots + M_{m-1}$ (Excluding the time of the last machine),

$H: H_i = M_2 + M_3 + \cdots + M_m$ (Excluding the time of the first machine).

Step 4. Using Johnson's method, find the optimal sequence of n jobs through twop machines.

4.2 | B&B Algorithm

B&B algorithm substitute the initial problem into a group of sub-problems and can be used in minimizing the total flow time [23]. As per Ignall and Schrage [12], the initial problem is reformulated into a 'solution tree', where every node indicates a LB of the desired 'objective function' [24].

The B&B algorithm was utilized and suggested by Kim [25], where every node indicates the partial sequence of the eventual outcome. This partial sequence is termed as $|PS|$, and the group of jobs that are not part of it is termed as $|NPS|$.

Once a node gets branched, the partial sequence corresponding to the branched node receives a new job from $|NPS|$, which generates a single sequence or several partial sequences [25]. For each node generated, one LB is determined for the total elapsed time [24].

Ronconi [26] used the 'depth-first search' algorithm to select the branching node, which chooses the node in the partial sequence with the most jobs. In the event of a tie, the node with the minimum LB for the 'makespan' is chosen [26].

Ronconi's successful implementation of the node selection algorithm in the permutation flow shop with a blocking problem was the reason for its selection [24]. *Fig. 1* presents the 'flow chart' of the B&B algorithm. A pseudo-code for this algorithm is shown below.

B&B Algorithm for the PFSP

Step 1. "Initialization" (setting the root node)

UB $\rightarrow$ Initial Upper Bound ;

$|PS| = \{\emptyset\}$;

$|NPS| = \{1, 2, 3, \dots, n\}$;

Nodes = 0 number of branching nodes) ;

Step 2. "First Level Branching Step"

for Node = 1: n do ;

$|PS|_{Node} = \{j\}$;

$|NPS|_{Node} = |NPS|_{Node} - |PS|_{Node}$;
$LB_{Node} =$ LB for $|PS|_{Node}$;

if $LB_{Node} < UB$;

Nodes = Nodes + 1 ;

end if ;

end for ;

Step 3. "Other Levels Branching Step"

while Nodes > 0 do ;

Nodes = 0 ;

for Node = 1: Nodes do ;

for $j \in |NPS|_{Node}$ do ;

$|PS|_{Node} = |PS|_{Node} + \{j\}$;

$|NPS|_{Node} = |NPS|_{Node} - \{j\}$;

$LB_{Node} =$ LB for $|PS|_{Node}$;

if $LB_{Node} < UB$;

if Level < n ;

Nodes = Nodes + 1 ;

else ;

$LB_{Node} = UB$;

end if ;

end if ;

end for ;

end for ;

end while ;

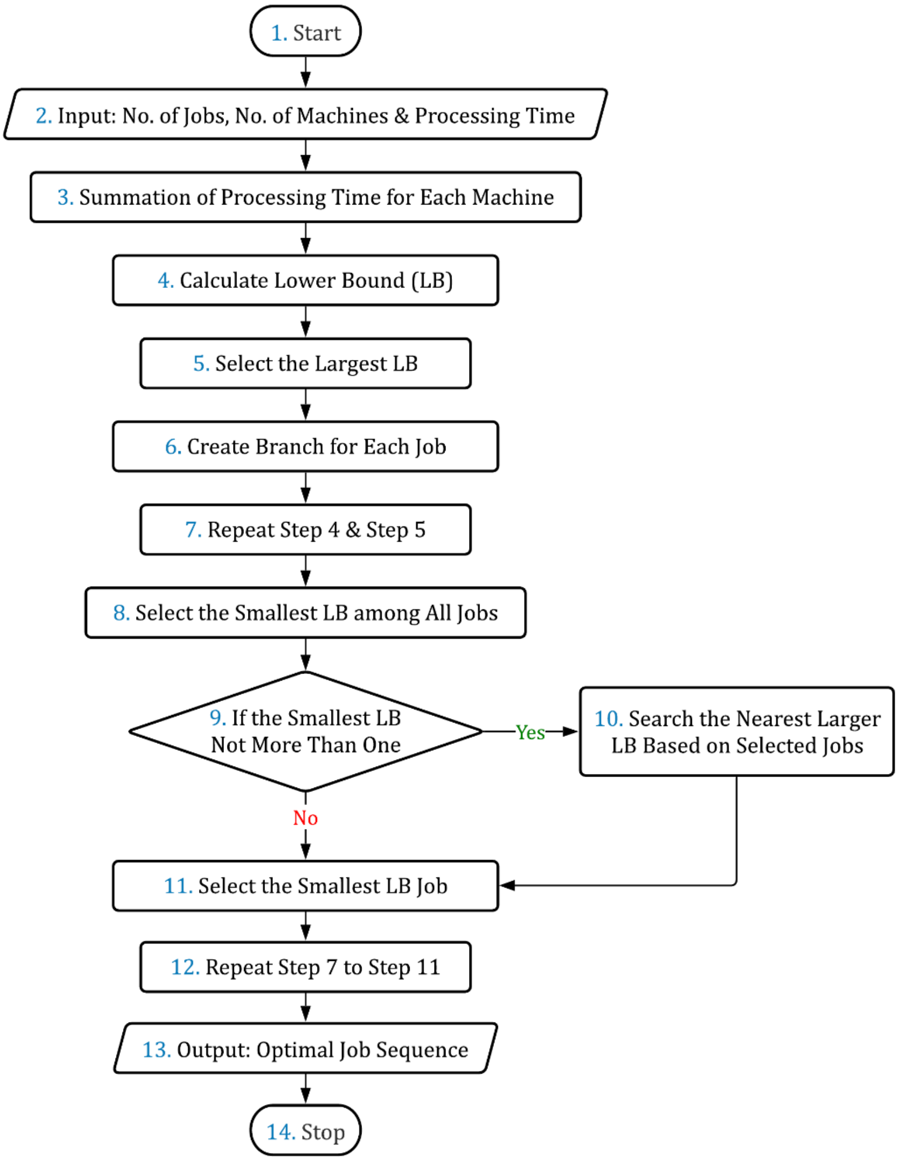

Fig. 1. Flow chart of B&B algorithm for the General Flow Shop Problem (GFSP).

4.3 | Kusiak's Algorithm

Andrew Kusiak introduces this algorithm, which is a more efficient implementation of Johnson's scheduling technique. The steps of the algorithm are as follows:

Step 1. Set $k = 1, l = n$.

Step 2. For each job, store the least processing time and the corresponding machine number.

Step 3. Arrange the resultant list with job number, time, or machine number in ascending order of processing time.

Step 4. For every entry in the arranged list:

If *machine number* $= 1$,
(*i*) Set the associated job number at the place of k,
(*ii*) $k = k + 1$.
Else
(*i*) Set the associated job number at the place of l,
(*ii*) $l = l - 1$.

End if

Step 5. Terminate when the complete list of jobs is filled.

4.4 | SAI Algorithm

The 'step-wise' iterative technique of SAI algorithm to find out the optimal sequence for 'n jobs' on 'm machines' are explained below:

Step 1. The processing time of n jobs (1 to n) on m machines (1 to m) is illustrated in *Table 5*.

Table 5. Processing time of n jobs on m machines.

Jobs \ Machines	1	2	3	...	j	...	n
1	p_{11}	p_{12}	p_{13}	...	p_{1j}	...	p_{1n}
2	p_{21}	p_{22}	p_{23}	...	p_{2j}	...	p_{2n}
3	p_{31}	p_{32}	p_{33}	...	p_{3j}	...	p_{3n}
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
i	p_{i1}	p_{i2}	p_{i3}	...	p_{ij}	...	p_{in}
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
m	p_{m1}	p_{m2}	p_{m3}	...	p_{mj}	...	p_{mn}

Step 2. Investigate the jobs and choose the least job processing time among all n jobs $j = 1\ to\ n$) for each machine and later checked it with −) sign. Suppose that the 'minimum processing time' is appeared at j^{th} job on i^{th} machine then mathematically, this can be illustrated as;

$$\underset{j}{\text{Min}}\ \{p_{i1}, p_{i2}, \cdots, p_{ij}, \cdots, p_{in}\} = p_{ij}.$$

Step 3. In a similar manner, choose the least processing time among all m machines $i = 1\ to\ m$) for each job and later checked it with +) sign. Suppose that the 'minimum processing time' is appeared at i^{th} machine for the j^{th} job then mathematically, this can be illustrated as;

$$\underset{i}{\text{Min}}\ \{p_{1j}, p_{2j}, \cdots, p_{ij}, \cdots, p_{mj}\} = p_{ij}.$$

Step 4. Investigate the rows and columns of the table once again, chose the cell with ∓) sign. Suppose that the ∓) sign has appeared at the cell that relates to the i^{th} machine and j^{th} job. Then the j^{th} job is eliminated from the table and is inserted in the optimal job sequence.

Step 5. Step 1 to 4 are continued until every one of the jobs are set in the optimal job sequence. There might be a circumstance when a tie has happened;

I. When ∓) appears at more than one cell, the job with 'least processing time' is chosen and is set in the optimal job sequence.

II. When ∓) appears at more than one cell, and the processing time for the assigned jobs is identical. After neglecting the other higher-order machines, the job that will process on the lower-order positional machine is chosen.

Step 6. Finally, we compute the idle time and makespan of machines.

5 | Numerical Experiments

A practical problem has been considered to minimize the makespan of the n-jobs and m-machines flow shop problem. The numerical data is illustrated in *Table 6*, gathered from a RMG manufacturing

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company. The manufacturer has to perform two operations: cutting and sewing on various jobs (products). The required time to execute these operations for each job is specified.

Table 6. 3-jobs and 3-machines flow shop problem.

Jobs	Cutting (Minutes)	Sewing (Minutes)	Packing (Minutes)
J1	3	4	7
J2	8	5	9
J3	7	1	5
Total processing time	18	10	21

Table 7 gives all the possible sequence and the corresponding makespan and idle time.

Table 7. All possible sequences (flow shop scheduling for three machines).

Sequence	Makespan (Mins)	Idle Time (Mins)
J1-J2-J3	30	41
J1-J3-J2	32	47
J2-J1-J3	34	53
J2-J3-J1	34	53
J3-J1-J2	32	47
J3-J2-J1	36	59

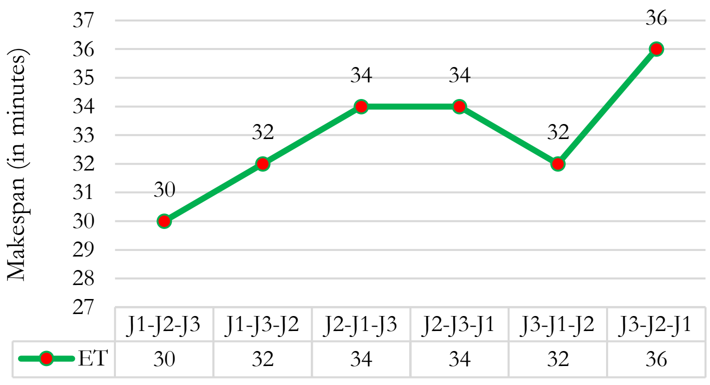

Fig. 2. Sequences and makespan.

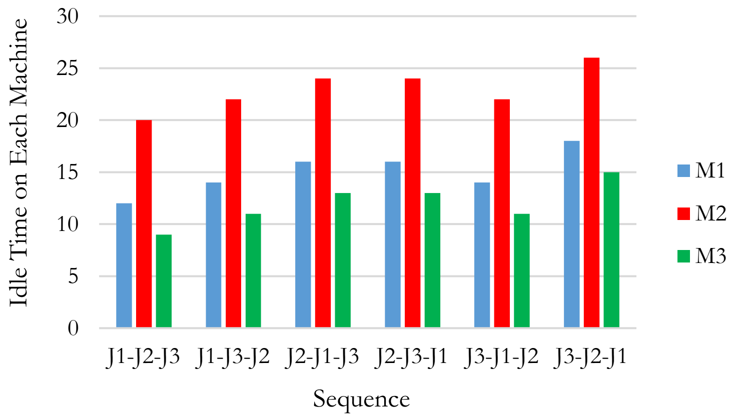

Fig. 3. Sequences and idle time.

A 4-jobs and 4-machines flow shop problem is illustrated in *Table 8*.

Table 8. 4-jobs and 4-machines flow shop problem.

Jobs	Cutting (Mins)	Sewing (Mins)	Pressing (Mins)	Packing (Mins)
J1	6	5	3	9
J2	7	6	5	7
J3	5	4	6	8
J4	8	3	4	6
Total processing time (in minutes)	26	18	18	30

All possible sequences and the corresponding elapsed time and idle time is tabulated in *Table 9*.

Table 9. All possible sequences (flow shop scheduling for four machines).

Sequence	Makespan (Minutes)	Idle Time (Minutes)	Sequence	Makespan (Minutes)	Idle Time (Minutes)
J1-J2-J3-J4	45	88	J3-J1-J2-J4	45	88
J1-J2-J4-J3	45	88	J3-J1-J4-J2	45	88
J1-J3-J2-J4	44	84	J3-J2-J1-J4	45	88
J1-J3-J4-J2	44	84	J3-J2-J4-J1	45	88
J1-J4-J2-J3	47	96	J3-J4-J1-J2	45	88
J1-J4-J3-J2	44	84	J3-J4-J2-J1	47	96
J2-J1-J3-J4	48	100	J4-J1-J2-J3	47	96
J2-J1-J4-J3	48	100	J4-J1-J3-J2	46	92
J2-J3-J1-J4	48	100	J4-J2-J1-J3	50	108
J2-J3-J4-J1	48	100	J4-J2-J3-J1	50	108
J2-J4-J1-J3	48	100	J4-J3-J1-J2	47	96
J2-J4-J3-J1	48	100	J4-J3-J2-J1	47	96

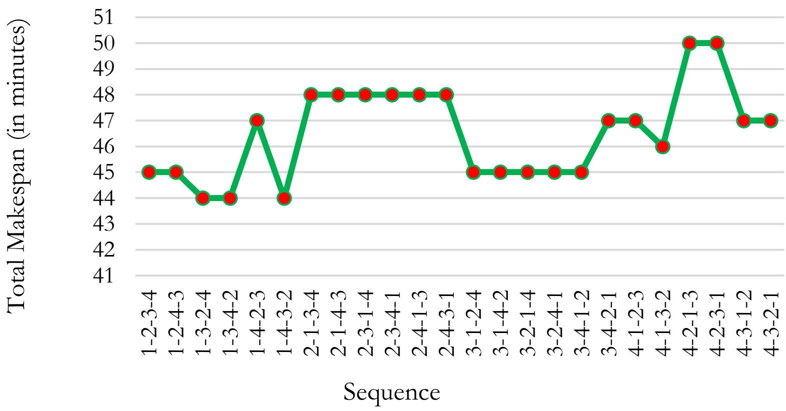

Fig. 4. Sequences and total makespan.

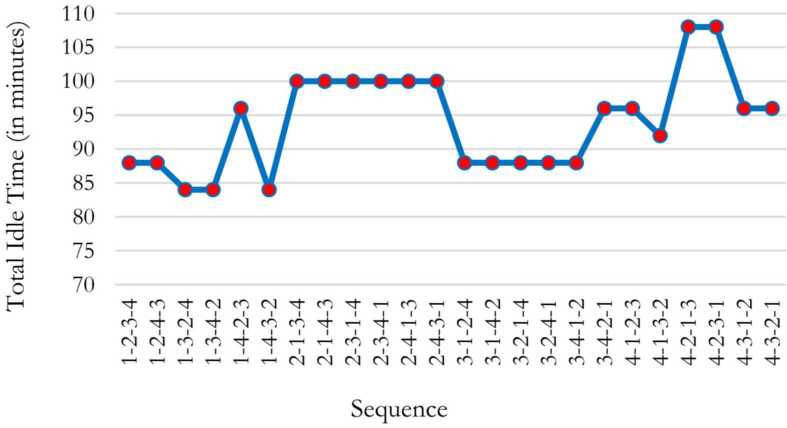

Fig. 5. Sequences and total idle time.

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In *Figs. 4* and *5*, we have shown how the total idle time and total elapsed time vary with sequences' choice. In *Table 10*, we will apply all four algorithms to determine an optimum or nearly optimum sequence.

Table 10. Consider following 5-jobs and 3-machines flow shop problem.

Jobs	Cutting (Minutes)	Sewing (Minutes)	Packing (Minutes)
J1	3	4	7
J2	8	5	9
J3	7	1	5
J4	5	2	6
J5	4	3	10
Total processing time	27	15	37

The minimum makespan obtained by the four algorithms are as follows,

1. Johnson's Algorithm=44.
2. B&B Algorithm=44.
3. Kusiak's Algorithm=44.
4. SAI Algorithm=46.

Goodness of an algorithm measures the error percentage of the algorithm shown in *Eq. (1)*.

$$\text{Goodness of Exact Algorithms} = \frac{\text{Makespan} - \text{LB}}{\text{LB}} \times 100\%. \tag{1}$$

In order to find out how good the algorithm is, we have to determine the LB for the makespan based on each of the machines. Now,

LB based on M1, $LB_{M1} = \sum p_{1j} + \min\{\sum(p_{2j}, p_{3j})\} = 27 + (1 + 5) = 33,$

LB based on M2, $LB_{M2} = min(p_{1j}) + \sum p_{2j} + min(p_{3j}) = 3 + 15 + 5 = 23,$

LB based on M3, $LB_{M3} = min\{\sum(p_{1j}, p_{2j})\} + \sum p_{3j} = \ 3 + 4) + 37 = 44.$

Now out of the 3 LBs the maximum one is the best bound.

$$\text{LB} \ = \ \text{Max}\ \{\text{LB}_{M1}, \text{LB}_{M2}, \text{LB}_{M3}\} = \text{Max}\ \{33, 23, 44\} \ = \ 44.$$

Based on the LB, now we know that the optimum makespan cannot be less than 44. So, the makespan can only be 44 or more. The goodness measure in *Table 11* shows that for this problem all the three methods except SAI give similar result and achieves the best possible sequence with 0% error. *Fig. 6* illustrates the Gantt chart for optimal sequence.

Table 11. Goodness measurement of the selected exact algorithms.

Algorithm/Method	Optimal Sequence	Makespan (Minutes)	Idle Time (Minutes)	Goodness $\left(\frac{MS-LB}{LB} \times 100\%\right)$
Johnson's Algorithm	J4-J1-J5-J2-J3	44	53	$\frac{44-44}{44} \times 100\% \approx 0\%$
B&B Algorithm	J1-J3-J4-J5-J2	44	53	$\frac{44-44}{44} \times 100\% \approx 0\%$
Kusiak's Algorithm	J1-J4-J5-J2-J3	44	53	$\frac{44-44}{44} \times 100\% \approx 0\%$
SAI Method	J3-J4-J1-J5-J2	46	59	$\frac{46-44}{44} \times 100\% \approx 4.54\%$

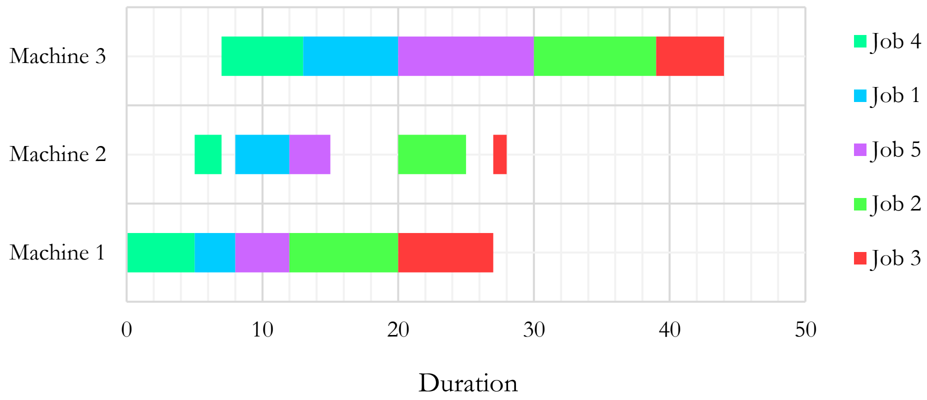

Fig. 6. Gantt chart for optimal sequence (4, 1, 5, 2, 3).

We further considered several problems and applied the algorithms to find the optimal sequence. In *Table 12*, we have documented some results when the system has identical number of jobs and machines, which can also be observed in *Fig. 7*.

Table 12. Results obtained by exact methods for identical number of jobs and machines.

Methods	Problem Size	Optimal Sequence	Elapsed Time (Minutes)
Johnson	(2×2)	$1 \rightarrow 2$	16
	(3×3)	$1 \rightarrow 2 \rightarrow 3$	30
	(4×4)	$1 \rightarrow 3 \rightarrow 2 \rightarrow 4$	47
	(5×5)	$1 \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow 4$	58
Branch & Bound	(2×2)	$1 \rightarrow 2$	16
	(3×3)	$1 \rightarrow 2 \rightarrow 3$	30
	(4×4)	$1 \rightarrow 2 \rightarrow 4 \rightarrow 3$	47
	(5×5)	$5 \rightarrow 4 \rightarrow 1 \rightarrow 3 \rightarrow 2$	62
Kusiak	(2×2)	$1 \rightarrow 2$	16
	(3×3)	$1 \rightarrow 2 \rightarrow 3$	30
	(4×4)	$1 \rightarrow 3 \rightarrow 2 \rightarrow 4$	47
	(5×5)	$1 \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow 4$	58
SAI	(2×2)	$1 \rightarrow 2$	16
	(3×3)	$3 \rightarrow 1 \rightarrow 2$	32
	(4×4)	$1 \rightarrow 4 \rightarrow 3 \rightarrow 2$	47
	(5×5)	$5 \rightarrow 1 \rightarrow 4 \rightarrow 3 \rightarrow 2$	62

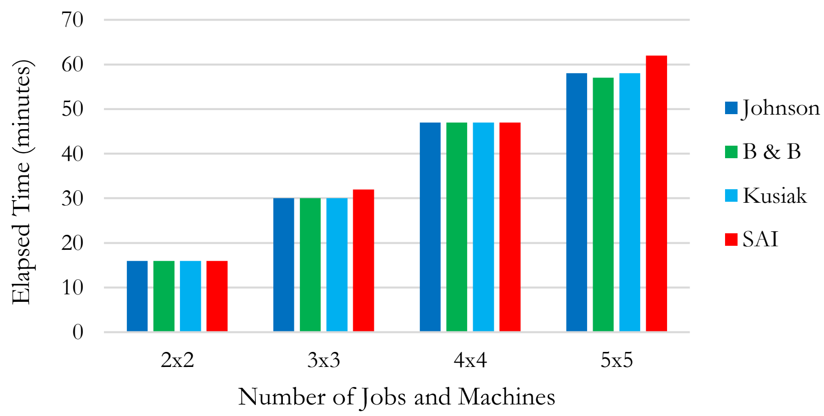

Fig. 7. Comparison diagram of the methods for identical number of jobs and machines.

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6 | Findings and Complexity Analysis

The following conclusions are made based on the objective of makespan minimization in flow shop scheduling problems:

I. Johnson's algorithm gives the best optimal sequences with minimum elapsed time for two machines and *n* jobs scheduling problem. In the case of three or more machines, if the condition of using Johnson's algorithm does not hold, then Branch & Bound gives the better solution.

II. One of the advantages of using the SAI algorithm over Johnson's method is that no conversion of machines is required in the SAI algorithm in the case of three or more machines.

III. Kusiak's algorithm works likewise to Johnson's algorithm. Due to frequent ties, both Johnson's and Kusiak's algorithms produce more than one sequence.

IV. The Kusiak algorithm is specifically helpful while dealing the scheduling problems involving a large number of jobs.

V. Though Branch & Bound gives better solutions in some cases but as the number of jobs and number of machines increases, the complexity of the B&B algorithm increases.

For a n job & m machine flow shop problem, number of sequences and computational complexity or time complexity evaluated by the exact algorithms are given in *Table 13*.

Table 13. Computational complexity of the algorithms for n jobs and m machine.

Exact Algorithms	Number of Sequence	Computational Complexity
Johnson's Algorithm	1	$O(n\log(n))$
B&B Algorithm	n! (at most)	$O(n^2)$
Kusiak's Algorithm	1	$O(n\log(n))$
SAI Algorithm	1	$O(n + m\log(n))$

7 | Conclusions

In this paper, several exact algorithms have been analyzed to solve the flow shop problem. The primary objective of this study is to identify the most efficient algorithm for solving sequencing and scheduling problems in a flow shop environment. The objective is to minimize the total elapsed time and the idle time. Four prominent exact algorithms are taken, including Johnson's Algorithm, B&B Algorithm, Kusiak's Algorithm, and SAI Algorithm, and examined their efficiency by calculating the total completion time and the goodness. Numerical results show that Johnson's Algorithm gives the best result in most cases, but when it fails, the B&B algorithm gives a better result than others. A comparison between a stochastic methods with the exact algorithms can be performed in future work. A modified and hybrid exact algorithm may also be proposed later. Unique 'tight LBs and meta-heuristic calculations, like the Genetic Algorithm (GA), and Tabu Search (TS) can be combined for further research.

Abbreviation and Nomenclature

B&B	B&B	GFSP	GFSP
UB	Initial Upper Bound	LB	LB
ET	Elapsed Time	IT	Idle Time

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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Industrial Engineering is a Mindset, not a Methodology

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Abstract

Mindset means mental attitude. Methodology means a system of methods used in particular area of study. If one studies any textbook in Industrial Engineering, one reads about various methods of optimisation. Hence it is natural to assume that Industrial Engineering is a methodology. However, this paper argues that Industrial Engineering is a mindset, geared for optimisation and methodology is just manifestation of that mindset.

Keywords: Industrial engineering, mindset, Methodology, Method, procedure.

1 | Introduction

For deeper scholars, it becomes apparent that engineering is a mindset. Of course this mindset is manifested through methodology. However, methodology is just symptom of mindset. And indeed, what an engineering education gives an engineer is not so much the methodology, but a mindset that views the world differently, not necessarily in a better manner or worse manner. It is in order that one understands the concept of mindset and methodology in a greater depth than just an understanding of meaning of these two words permits.

Mindset is an established set of attitudes, regarded as typical of group's values, frame of mind, disposition. A mindset causes one to adopt prior behaviour, choices or tools, a cognitive inertia of sorts, which makes it difficult to counteract its effect on analysis and decision making. Mindset represents mental processes activated in response to a task.

Methodology is frame work for research, a coherent, logical scheme, based on views, values that guides choices that researcher makes. Methodology is theoretical analysis of methods and principles associated with branch of knowledge.

In general methodology is same as method and proposes to provide solutions. Methodology provides a theoretical perspective for understanding which methods can be applied to question or a problem. Methodology can be viewed as a spectrum from quantitative approach to qualitative approach.

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Methodology may be understood to be:

I. Description of methods.
II. Study of methods.
III. Analysis of methods.

Method is a procedure, technique or manner of doing something. Essentially method is way of doing something in a systematic manner. Now let us understand what is engineering and what Industrial Engineering is by study of their definitions. Engineering is application of science and mathematical models to the innovation, design, construction and maintenance of structures, machines, materials, devices, systems, processes and organisations [1], [2].

Industrial Engineering is optimisation of complex processes, systems and organisations by developing, improving and implementing systems of people, money, knowledge, information and equipment [1], [2]. Basically, industrial engineering seems to be some sort of specialisation in engineering with focus on optimisation. Industrial Engineering is thus a set of mathematical and scientific methods geared for optimisation through improving and implementing money, machine and material. And optimisation means making best use of something. Let us just focus on specific case of Industrial Engineering rather than general case of engineering.

2 | Analysis

So industrial engineering we study methodology of optimisation, which is perhaps same as method, which again means a systematic procedure, technique or manner.

For instance here are some of the methods that an Introductory Textbook on Industrial Engineering may cover.

I. Economic order quantity: without getting into formulae or graphs, roughly economic rder quantity is calculated based on usage rate per year, cost of ordering, cost per commodity, inventory carrying costs etc.
II. Utilisation and capacity: capacity refers to maximum possible production, whereas utilisation means percentage use of capacity.
III. Quality control chart: these charts are used to calculate upper control limit, lower control limit, average, standard deviations and so on.

Of course, these examples of methods can be multiplied manifold times. And specialised text books on Industrial Engineering have more detailed and specific methods in various sub disciplines of industrial engineering such as supply chain management, production planning, work design, quality management, operation research and so on.

Nowhere in Industrial Engineering curriculum is a mindset imparted directly. Hence the argument that Industrial Engineering is a mindset and not a methodology will seem heretical, blasphemous and sacrilegious. However, here is what will give a reality check. After examinations, most people, including engineers, forget substantial amount of what was expected in exams. Hence while Industrial Engineering education does seem to focus on methods it would be safe to argue that some of methods, if not all of methods could face a degree, partial perhaps, of memory loss.

Nobel Laureate, Albert Einstein said "education is that which remains when one has forgotten everything one has learnt in school." Indeed Albert Einstein, the great genius, also said that "education is not learning of facts, but training of mind to think."

The purpose of education is not knowledge but imagination. Why is this hair splitting difference between facts and thinking so important? Because facts represents methods or methodology and thinking represents attitude or mindset. Thus at least as per Albert Einstein and many others one would presume, education

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is training in mindset and not methodology. Because it should be obvious that methodology experiences memory oblivion within certain duration. However a mindset is ingrained for longer duration. Thus while Industrial Engineering is training in methodology however Industrial Engineering shapes up a Mindset.

The definition of Industrial Engineering is optimisation of systems, processes and organisations, through development of men, material and machines. Now optimisation means making best use of something. Now this optimisation can be thought of as a methodology or optimisation can be thought of as a mindset. In education, optimisation is clearly taught in terms of methodology. However, as we have just discussed, most of this methodology quickly becomes vicitim of memory loss. However, as einstein said, education is what remains after facts have been forgotten and education is not learning of facts but training mind to think. Thus, it should be obvious that since methodology is forgotten, what remains is mindset. Thus, study of economics is not about methodology but a mindset.

Similarly study of psychology is as much about mindset as much as methodology. When people question the fallacy of business administration and management education, they forget that an MBA does not give you a methodolgy as much as it gives you a mindset. Hence it is safe to argue that Industrial Engineering is also about mindset rather than methodology. Why is this hair splitting, difference between methodology and mindset so important? Because by having a Mindset instead of methodology of optimisation, an Industrial Engineer is freed from boundaries, procedures and appropriateness in application of optimisation. Thus, an Industrial Engineer is free to apply optimisation, everywhere, everytime and everything, in any manner, any fashion, any way. Because though Industrial Engineers may forget methods, they are stuck with mindset. And Mindset is the thinking process triggered in response to a task. Thus, an Industrial Engineer will start thinking in terms of optimisation whenever and wherever and whatever situation one finds oneself in. That opens a pandora's box of optimisation where sky is the limit as far as optimisation is concerned. Hence Industrial Engineers mindset of optimisation can be applied in situations where Industrial Engineers were not meant to contribute.

3 | Examples

Let us consider some examples where mindset orientation of Industrial Engineering pays great dividends even as methodology orientation of Industrial Engineering comes up a cropper.

Consider crowded trains in Mumbai. The methodology orientation of Industrial Engineering has no solution for this. But a mindset orientation will quickly find various methods of optimisation such as:

I. Move offices to other side of town.
II. Make peak hour travel expensive.
III. Redesign seating spaces.
IV. Work from home.
V. Rotate holidays.
VI. Flexible timings.
VII. Double decker trains.

Honestly this sort of thing does not come from any methodology in Industrial Engineering education; however, the training in methods in Industrial Engineering education creates a mindset, inadvertently perhaps, which enables solutions without recourse to any method.

Similarly there is nothing in methodology of Industrial Engineering that trains students in political campaigning effectiveness. But the mindset of optimisation that is perfected through the methodology training can make it impossible for an Industrial Engineer not to see a more sane way of political campaigning.

A person with an Industrial Engineering mindset will quickly see that speeches and rallies are useless since they barely reach 1% of audience. Hence the optimisation mindset will compel an Industrial Engineer, to suggest press conferences instead of rallies, as newspapers are read by nearly 100% audience as opposed to 1% audience affected by speeches and rallies.

Similarly there is nothing in Industrial Engineering methodology that seeks to optimise stress level in academic system. However a person with Industrial Engineering mindset will quickly see that if students are given say 5 days holiday before exams, the stress levels are reduced to 1 month of exams rather than 4 months of semester without increasing semester duration substantially.

4 | Conclusions

There is need for greater discussion on mindset versus methodology orientation of education in general and in context of this journal, of Industrial Engineering in particular. Essentially it should be accepted that education and profession are largely about mindset not methodology, though it is through the alleys and grooves of methodology that mindset gets honed and shaped. Education is meant to create a mind set and not train in methodologies. After all it is obvious that what one crams and mugs for exams are forgotten immediately after exams. But what stays is a mind set. A Business and Management education creates a mind set for commerce. An engineering education create mindset for technology career. An education in liberal arts, helps in social work, politics, and other people professions. But these are not methodologies learnt in education that are put in practice. It is the mind set acquired in education that is useful in career.

Coming back to Industrial engineering. If Industrial Engineering is viewed as methodology then it will have limited application and utility. However if Industrial Engineering is viewed as a mindset, then its application areas get more broad. By limiting Industrial Engineering to methodology we are seriously constraining what Industrial Engineering is capable of. To unleash Industrial Engineering we need to free Industrial Engineering from the chains of Methodology and allow Industrial Engineering to blossom as a flower of Mindset.

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