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A Multidimensional Decision Making for Supplier Selection in the presence of Information Systems

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Abstract. Information Systems (IS) have turned into vital means for companies to survive in the contemporary technology-oriented environment. Subsequently, over the last decades, this has brought about the heavy investment of companies in ISs to guarantee high-quality products and services. Similarly, supplier selection (SS) plays an inescapable role in today's business. In addition, there are several studies published showing the importance of the ISs in the SS problem. However, there has not been any work evaluating the effectiveness of ISs on the SS problem, including a comprehensive and up-to-date SS model. Therefore, this study proposed a complete model including six criteria that are almost most important and shared in the literature: sustainability, reliability, resiliency, greenness, risk and cost, and 31 sub-criteria. Then the effectiveness of 10 ISs on the SS problem has been shown through using BWM in two consecutive stages, and then the model conducted in Emdadkhodro automotive company to show its practicality and accuracy.

Keywords: best-worst method, cost, information systems, greenness, risk, reliability, resiliency, supplier selection, sustainability

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1. Introduction

Information Systems (IS), as a scientific discipline, firstly grabbed the attention of researchers in the 1960s [20]. That was when applied computer science emerged, which aimed at designing and implementing data processing applications [5]. Information Systems (ISs) have turned into a vital factor so that all organizations should take it into account to survive in the current technology-oriented market. Accordingly, more organizations have invested widely in their IS infrastructures to provide better services and produce better value products. These fast-growing numbers result in the question of how much those systems add value to the business or the organization compared to their investment. The role of information systems (IS) in providing businesses with a competitive edge has recently been the topic of many discussions. Therefore, this reveals that the competitive advantages stem from the IS solution and its utilization [44]. Indeed, on account of the functions above and the importance of ISs, there are so many studies showing the significance of ISs regarding a wide range of different disciplines such as health and medicine [37, 31], transportation [7], energy [36], biology [27], education, environment [4], geography [42] and so many other ones. However, there are many studies about supplier selection in which different types of ISs play a significant role [35, 2].

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On the other hand, owing to the indispensable role of SS in supply chain management, over the recent years, so many studies have been published about the models based on which the best suppliers are selected. Nevertheless, because of several contributing factors such as time, discipline, and studies' purpose, each of these researches has followed various models with different priorities so that some studies have taken into account the sustainability factor in their SS problem [23, 34], someone emphasizes on resiliency [8], some other scholars have worked on reliability [45] and undoubtedly greenness has also been one of the most popular criteria in the SS models [23, 18, 15] so that a large number of researchers have considered varying aspects of the green suppliers selecting; specifically they have focused on the evaluation and ranking of the weighting factors critical in choosing of green suppliers [41]. In addition, in so many works, researchers have considered two terms of risk and cost in their studies regarding SS because of their undeniable significance in realistic situations. Further, these criteria have been integrated into the SS models [26, 3, 21, 40]. This undoubtedly illustrates the significance of SS models for companies' prosperity because of their adaptability and functionality in different circumstances.

Finally, when the heavy impact of ISs on SS is coupled with the undeniable role of SS in supply chain management, this is highly likely to be vital for firms to have a thorough cognition and understanding of the effectiveness and functionality of their ISs on their using SS model, regardless of what criteria it includes. Probably once [16] have considered IS as a contributing factor affecting supplier selection, was the first time when a study referred to a close correlation between green SS and IS.

As there are different types of information systems and each of them concentrates on various parts and targets in an organization, or generally a system, each of them impacts on selection process differently; the purpose of this study is the evaluation the effectiveness of various ISs not only on each of aforementioned primary criteria in SS models including sustainability, reliability, resiliency, greenness, cost, and risk but also on SS model including all of these criteria as a general model. Accordingly, this paper proposes a comprehensive framework to support its purposes. Initially, it examines other studies, literature, and experts' opinions to gather the most determining criteria and sub-criteria which affect the general supplier selection (by considering sustainability, reliability, resiliency, greenness, cost, and risk as criteria and their sub-criteria). Then, through the Best-Worst method (BWM), the local and global weights of criteria and sub-criteria will be calculated in accordance with the experts' opinions. The next step is computing the ISs' performance associated with sustainability, reliability, resiliency, greenness, cost, and risk separately and the general supplier selection in two different stages, based on the experts' opinions. Finally, firms could work on specific IS or ISs playing the most crucial role in their SS processes and manage them, if necessary. All of these steps are designed to answer this study's research questions:

How does each of the information systems affect the six main criteria of the SS model?

What is the most effective information system in supplier selection problem?

Aiming to address the research objective of this study, evaluating the effectiveness of 10 different information systems on supplier selection is proposed.

2. Literature review

This section investigates the literature to illustrate the significance of information systems in the supplier selection problem. To this end, this section includes four main parts in which four different pieces of this puzzle are clarified separately. Accordingly, in the first part, the studies illustrate the importance of ISs in supply chain or supplier selection. [17] used a Geographic Information System (GIS) to select the best location between some candidates aiming to design a high-resolution microalgae-based biofuel supply chain through three phases. Similarly, a Geographic Information System (GIS) software associated with a network analysis and vehicle routing problem was considered by [43] to design a green vehicle routing to evaluate and decrease the carbon footprint of the papaya supply chain in Thailand. [1] took into account information systems to support the business processes of the cocoa supply chain as one of the most important economic industries in Ghana to identify its downsides. [9] proposed a novel integrated MCDM model including 12 determining factors under the four divisions to select the most efficient Inter-Organizational Information Systems as the basis of the modern supply chain. [13] considered one of the information systems, E-commerce, to represent a criteria model for E-supplier in the mechanical manufacturing industry. [35] worked on the web-based information system, including five critical criteria for selecting the optimal supplier to address the problem of providing similar goods by various suppliers.

Finally, [2] propose a dynamic decision support system (DSS) as an information system to select a sustainable supplier in a circular supplier chain. These studies published in recent years show how important ISs are in the SS problems and the supply chain. In the next part, the studies represent the ISs as contributing factors in the six criteria (sustainability, reliability, resiliency, greenness, risk, and cost) in various fields. [12] considered information system integration associated with internal cost management and absorptive capacity as three effective criteria in inter-organizational cost management in the supply chain. [10] used geographical ISs to green areas' accessibility in Turkey. With the aim of the effectiveness of ISs on reliability criteria, this study inspired by research has been done by [19], adopted an ontological model of an IS for evaluating and ensuring transportation reliability. [6] illustrated that an appropriate decision support tool could guarantee the resiliency of a system such as a power distribution system.

As decision support systems are among the most important ISs, this shows the importance of this tool for enabling resiliency. [33] adopted a geographic IS to determine the risk of contracting some specific diseases in different areas in Thailand. [39] developed an integrated accounting and agricultural IS to guarantee sustainability and productivity in the farming sector. In these sections, the significance of ISs in SS problems and the six main criteria have been shown by citing recent studies.

However, in the next part of this section, the studies are presented in which the SS models include one, two or three numbers of those six criteria to show the significance of these criteria in the recent studies in the SS problems. Undoubtedly, greenness is one of the criteria playing a leading role in SS problems. Researchers [18, 23, 15] proposed three different methods, including Modified two-phase fuzzy goal programming integrated with IF-TOPSIS, a novel hybrid MCDM model including the support vector machine (SVM), the fuzzy BWM and the fuzzy TOPSIS approaches, and finally BWM and fuzzy TOPSIS, respectively, to select green suppliers. Some researcher considered transportation cost to be one of the essential criteria in SS problems based on an MCDA referring to the significance of cost factor in SS problem. [40], however, applied the Fuzzy FANP, DEMATEL, fuzzy TOPSIS, and finaly a Weighted Goal Programming (WGP) to select sustainable-reliable suppliers to increase three vital elements for customer satisfaction and environmental regulations. [22] proposed a hybrid method including AHP, TOPSIS, and finally, interval-valued intuitionistic fuzzy sets (IVIFSs) to select the sustainable supplier for water environment treatment Public-Private Partnership projects.

Some researcher took into account two critical criteria regarding risk including disruption risks and a risk-averse decision-maker to select the supplier selection and order allocation through the particle swarm optimization (PSO) algorithm in the centralized supply chain, which illustrates the strong influence of risk criteria in SS problem. Finally, [8] proposed a model to select the resilient supplier. To this end, they utilized an integrated efficiency measurement model consisting of Data Envelopment Analysis (DEA) and principal components analysis (PCA). And finally, in this part, first, it is mentioned why the BWM method is superior to other traditional MCDM techniques. then some recent studies are represented using this method in SS problems.

According to [29], BWM should be considered a powerful MCDM method to address complicated problems. What is more, in his study, he mentions four distinct benefits of this method, distinguishing that from other MCDM techniques such as AHP. And these superiorities are:

1. The number of pairwise comparisons needed in BWM is highly fewer than the figure for matrix-based MCDM methods.

2. Even though in a sizeable number of MCDM methods, consistency ratio is utilized to find out whether the comparisons are reliable or not, since the output of this method is always consistent, the consistency ratio is used to check the reliability level, thereby the results arising from BWM is highly more likely to be reliable.

3. One of the most practical advantages of BWM is that not only used independently but also integrated with other techniques.

4. Removing fractional numbers used in some of the other MCDM methods such as AHP and only using integer numbers makes BWM easier to use.

Nevertheless, in this situation, it should be mentioned that [28] referred to such weakness of BWM based on which in some realistic situations it is almost impossible to determine the best and the worst option, and it is possible to have two best options or two worst options. Accordingly, they proposed a modified BWM method to address this problem. However, several studies using BWM to select the suppliers are shown below. [25] proposed an integrated method including fuzzy BWM, fuzzy COPRAS, and fuzzy WASPAS to choose the excellent strategic supplier in accordance with their greenness capabilities. In another study, [15] have used BWM in addition to fuzzy TOPSIS to determine contributing factors of green supplier selection. And [38] have proposed an integrated method consisting of a fuzzy group BWM and a fuzzy combined compromise solution (CoCoSo), aiming to select the best supplier in reverse supply chains by taking four contributing factors, namely lean, agile, resilient, and green elements into account. As a result, in this section, it has been tried to cover all different aspects of the SS problem represented in this study, ranging from the importance of ISs on the SS problem and on the six main criteria to the importance of the six criteria on the SS problem to the significance of BWM technique.

3. Statement of the problem

As almost all companies in today's complicated market ought to have relationships with partners in different parts of their supply chain, especially supplier selection, the fast flow of thorough and practical information would be highly demanded to optimize the connection of all determining sectors of the supply chain that lead into competitive advantages. This significance of having a long-term relationship with partners in the contemporary market illustrates the necessity of the supplier selection problem as one of the essential parts of the supply chain [14]. This importance and necessity are the exact reason why companies should take a wide range of criteria and weighting factors into account in their SS problem. That is to say, undoubtedly, to minimize the risk and cost resulting from selecting the wrong suppliers as well as attaining the potential profits arising from the selection of a sustainable, reliable, resilient, and green supplier, SS plays a critical role for companies. Accordingly, there are extrinsic and intrinsic contributing factors such as environmental, economic and social performance, forcing companies to consider the critical criteria so as to fulfill their expectations [21]. On the other hand, mounting evidence has revealed the undeniable effectiveness of ISs in the supply chain, so that adoption of appropriate information systems not only impacts positively on the process of the supplier selection but also influences different significant criteria such as sustainability, reliability, resiliency, greenness, risk, and cost that are some of the most common contributing factors in SS problems. However, although there are several studies in the literature in which one information system or information system as a whole has been introduced as a weighting factor for SS problems, there is not any study evaluating the effectiveness of a wide range of information systems on different types of SS models.

Therefore, to address the problem mentioned above and to fill the mentioned gap in the literature, this study:

1. Proposes a comprehensive SS model that rarely is found in the literature: This model consists of six main criteria regarding the SS problem that are currently considered by scholars, including sustainability, reliability, resiliency, greenness, risk, and cost. Although all of these criteria have been used in a long list of studies published in the literature, there is not any paper in this field in which its SS model includes all of these six criteria, which are almost the most common, at the same time. That is to say, most of the studies which have proposed models for the SS problem take one, two, or three criteria. Therefore, a study takes all of them into account for the first time.

2. Takes 10 different types of ISs into account in order to evaluate their influence on SS. Usually, in the literature, the papers working on the SS problem mainly have taken information system alone as a contributing factor in the SS problem. However, these days almost all companies benefit from different types of ISs. Thus, it is almost for the first time that a study examines the effectiveness of 10 various ISs on the SS problem by considering those six major criteria.

3. Orders the ISs according to their effectiveness on SS. As just mentioned, until now, there has been no research examining the effectiveness of a wide range of ISs on a comprehensive SS model. As a result, this study shows the significance of each information system on a model, including all the primary criteria of the SS problem. In this way, managers and decision-makers in the company can gain an excellent understanding of the relationships between two integral parts of their company.

4. Orders the ISs according to their effectiveness on the six criteria individually. As some companies maybe have not all of these ISs or, on the other hand, give some of those six criteria, not all, priority, this study provides them with such facilities that they emphasize the effectiveness of each ISs on each criterion. for example, if in a company greenness is placed on the premium, they can use this model to find out the effectiveness of each ISs on the greenness factor.

To this end, initially, a general supplier selection model including six criteria and 31 sub-criteria is proposed, so that its criteria are the six main factors that a contemporary SS model would take into account, sustainability, reliability, resiliency, greenness, risk, and cost, in association with their own contributing factors as the sub-criteria. In the subsequent stage, this study employs the BWM method to find out the contribution or effectiveness of each of those criteria in supplier selection. Then, the BWM method is used again to compute the effectiveness of each of the predetermined information systems in each of those six criteria separately. In this way, two sets of weights are gained through two-stage use of the BWM method showing the effectiveness of different ISs on different criteria, and subsequently, the effectiveness of the criteria on SS (see Figure 1).

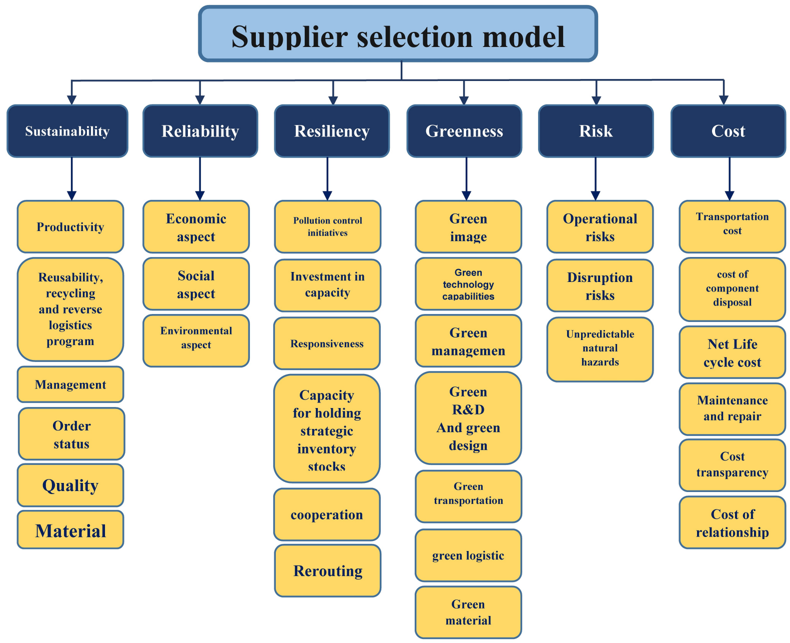

Figure 1: *The hierarchy of green supplier selection's criteria and sub-criteria.*

4. Methods and materials

As the purpose of this study is to evaluate the effectiveness of different information systems on a supplier selection problem in which six different criteria and their sub-criteria have been taken into account, the BWM as an MCDM method is adopted in two successive stages in order to deal with this problem. Accordingly, firstly the BWM is used to gain the weights of criteria and sub-criteria. Then, this method is used one more time to find out the weights of different ISs in accordance with their effectiveness on those sub-criteria.

4.1. Best Worst Method

There is a large number of MCDM methods applied in the published researches. However, BWM as a newly developed MCDM method is utilized in this study [29, 30]. Mounting evidence has revealed that this method possesses some unique features making this method superior to so many other MCDM methods. This method demands fewer data and does not require a full pairwise comparison matrix making this method the most appropriate one for this study- and ease of use for experts and decision-makers are some of those advantages. Nevertheless, in the following, different stages of this method have been represented:

Step 1 - Determine a set of decision criteria. In this study, the criteria are presented in two levels as criteria and sub-criteria.

Step 2 - Determine the best (B) (e.g., the most desirable, the most important) and the worst (W) (e.g., the least desirable, the least important) decision criteria based on the decision-maker(s)/expert(s) opinion.

Step 3 - Determine the preference of the best decision criterion (B) over all the other decision criteria, using a Linguistic 9-point scale for pairwise comparison for the best-worst method (Figure 2). The result is a best-to-others (BO) vector as follows;

$A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$

Whereas a_{Bj} represents the preference of B over j and as expected $a_{BB} = 1$.

Step 4 - Determine the preference of all the decision criteria over the worst criterion (W), using a Linguistic 9-point scale for pairwise comparison for best-worst method (Figure 2), Which results in the others-to-worst (OW) vector as follows;

$A_W = (a_{W1}, a_{W2}, ..., a_{Wn})^T$

Whereas a_{jW} represents the preference of j over W and as expected $a_{WW} = 1$.

Step 5 - Find the optimal weights$(W_1^*, W_2^*, \ldots, W_n^*)$. The optimal weights should be determined such that the maximum absolute differences $|W_B - a_{Bj}W_j|, |W_j - a_{jW}W_w|$ for all j is minimized, or equivalently;

$minmax|W_B - a_{Bj}W_j|, |W_j - a_{jW}W_w|$

$s.t.$

$\sum_j W_j = 1$

$$W_j \geq 0forallj \tag{1}$$

Problem (2) is equal to the following linear problem:

$min\xi^L$

$|W_B - a_{Bj}W_j| \leq xi^L forallj$

$|W_j - a_{jW}W_w| \leq xi^L forallj$

$\sum_j W_j = 1$

$$W_j \geq 0forallj \tag{2}$$

Solving the above model (2), optimized weights $(W_1^*, W_2^*, \ldots, W_n^*)$ and the optimal objective function value ξ^L will be gained. For this model, ξ^L can be directly considered as an indicator of the consistency of the comparisons (here, we do not use Consistency Index, so that values close to zero show a high level of consistency of the pairwise comparisons provided by the decision-maker(s)/expert(s). For MCDM problems with more than one level of criteria such as this study, first of all, the weights for different levels should be obtained through the BWM steps, then, the weights of different levels have to be multiplied to determine the global weights [32].

Linguistic scale	Equally important	Equal to moderately more important	Moderately more important	Moderately to strongly more important	Strongly more important
Equivalent number	1	2	3	4	5
Linguistic scale	Strongly to very strongly more important	Very strongly more important	Very strongly to extremely more important	Extremely more important	
Equivalent number	6	7	8	9	

Figure 2: *Linguistic scale for pairwise comparison for best worst.*

4.2. Evaluation of the effectiveness of ISs

SO far, by using the BWM method, the optimal weights of the criteria and sub-criteria have been calculated for supplier selection. Similarly, the same method has been adopted, aiming to calculate the optimal weights of ISs regarding those sub-criteria. Accordingly, in this stage, to calculate the final weights of information systems based on the BWM, these (ISs) should be considered the new sub-criteria for each of the main sub-criteria of the represented model. Then, the subsequent stage (calculation of the global weights of ISs) is the same as the operations done for calculation the global weights of sub-criteria in the last section. However, in this phase, the number of times BWM has been used for ISs is as many as those sub-criteria. Finally, all weights of each IS in different sub-criteria categories ought to be aggregated.

5. Case Study

The proposed model and method are conducted in Emdad-Khodro Company in Saipa automotive group as one of the two largest automotive companies in Iran, to evaluate the effectiveness of its information systems on the supplier selection problem in this company. In 2011, almost all ISs in this company were converted from windows-based ISs to web-based systems. Then, since 2014, all of them have been substituted with the mobile ISs covering almost all different sectors in the company. However, from the utilization of these information systems in the company, there has not been any study to evaluate these ISs on the Supplier selection process by considering the most contributing factors, including sustainability, reliability, resiliency, greenness, cost, and risk. Furthermore, there has not been any research showing what ISs should be focused on more and what ISs are using too many resources.

Currently, the using ISs of this company are; 1 - transaction processing system (TPS), 2 - customer relation management (CRM), 3 - management information system (MIS), 4 - office automation system (OAS), 5 - knowledge management (KM), 6 - supply chain management (SCM), and 7 - enterprise resource planning (ERP). To this end, in the following section, different steps of evaluating the effectiveness of 10 ISs (including 1 - transaction processing system (TPS), 2 - electronic commerce (EC), 3 - customer relation management (CRM), 4 - decision support system (DSS), 5 - management information system (MIS), 6 - office automation system (OAS), 7 - knowledge management (KM), 8 - supply chain management (SCM), 9 - enterprise resource planning (ERP) and 10 - business intelligence (BI)) on the SS problem by considering the six determining factors through the proposed method are represented. In order to create a balance among the experts' ideas, this study benefits from the opinions of 50 academics and industrial experts to determine the criteria, sub-criteria, and different stages of the BWM relying on the experts' opinions. Totally, all of the questionnaires had been sent to 87 experts, and finally, 50 of them have responded completely to all of those questionnaires. In the following, however, the figure gives more detailed information about the experts.

Experts information		Total Number (academicians)
Age	20-30	3(0)
	30-40	5(1)
	40-50	15(8)
	50-60	23(11)
	60+	4(3)
Seniority	1-10	2(1)
	10-20	16(7)
	20-30	28(12)
	30-40	4(3)
Educational level	bachelor	4(0)
	master	14(0)
	PhD	32(23)
Profession	engineering	9(5)
	management	19(7)
	IT	8(4)
	computer science	11(7)
	MBA	3(0)
Position	top managers	7(0)
	middle-level managers	14(0)
	low-level managers	6(0)
	full Professor	6(6)
	Assistant professor	11(11)
	Associate professor	6(6)

Figure 3: *Experts information.*

6. Discussion

6.1. Calculating the global weights of sub-criteria

Step 1- in this stage, based on the opinions of the company's experts and literature, six criteria, namely; stainability, reliability, resiliency, greenness, cost, and risk, have been determined to form the first level of the SS problem. Subsequently, several sub-criteria are first gathered and then selected according to the experts' opinion by considering the literature and published related studies.

As a result, a SS model is proposed, including six criteria and 31 sub-criteria (Figure 1). In order to select criteria and their sub-criteria, a questionnaire has been prepared, aiming to gather the experts' opinions through scoring them from 1 to 10 according to their importance (1; not effective to 10; perfectly effective). These selected criteria and sub-criteria are those factors that the accounting average of experts' opinions about them have been seven or more.

Criteria	Experts' scores
Sustainability	8.66
Reliability	7.33
management	5.01
control	3.76
demand	4.79
Cost	7.48
technology	5.11
quality	6.39
Resiliency	7.25
material	6.17
Risk	7.81
supplier	5.44
Greenness	8.22

Figure 4: *Determining criteria based on expert's opinion.*

Figure 1 illustrates the main list of criteria gathered from the literature (first column) and according to the experts' opinions (second column as the average score of experts), scoring them from 1 to 10, by considering their significance as the appropriate criteria for the supplier selection model. And after obtaining the criteria, their sub-criteria are gathered from the literature.

Similarly, the same procedures have been followed to find out the most appropriate sub-criteria for the SS model by the experts' opinions (Figure 4).

Selected criteria	Sub-criteria	Experts' scores
Sustainability	Productivity	7.91
	Reusability, recycling, and reverse logistics program	7.17
	Rejection ratio	6.12
	Order status	7.15
	quality	8.11
	recovery rate	6.16
	remanufacturing	5.35
	management	7.66
	purchasing volume	5.39
	material	7.65
Reliability	Economic aspect	8.35
	Social aspect	7.36
	Environmental aspect	7.82
Cost	Transportation cost	7.77
	Premium rate ($/unit)	5.69
	Net Life cycle cost	8.24
	Maintenance and repair cost	7.53
	Cost transparency	7.19
	Cost reduction capability	6.55
	cost of component disposal	7.33
	Logistics cost	6.12
	cost of relationship	7.08
Resiliency	Pollution control initiatives	7.33
	Investment in capacity buffers	7.45
	Responsiveness	7.71
	Capacity for holding strategic inventory stocks	7.35
	cooperation	7.87
	rerouting	7.66
Risk	operational risks	8.14
	disruption risks	8.28
	Unpredictable natural hazards	7.19
Greenness	Green packing	5.62
	Green R&D And green design	8.59
	Green management systems	7.86
	Green transportation	7.35
	Green purchasing	4.48
	green logistic	7.75
	Green material	7.44
	Green customers' market share	4.71
	Green technology capabilities	7.61
	Green image	7.20

Figure 5: *Determining sub-criteria based on expert's opinion.*

Step 2- in this stage, BWM has been used in order to calculate the global weights of sub-criteria. To this end, the following steps have been done;

Step 2-1- determining the best and the worst criteria based on the experts' opinion. Accordingly, sustainability and resiliency have been chosen as the best and the worst criteria, respectively. In the subsequent phase, the BO and OW stages of the BWM have been operated to calculate the optimal weights of criteria.

Step 2-2- The same operations have been used for sub-criteria to calculate their optimal weights in the next stage,

Step 2-3- Finally, for calculating the global weights of sub-criteria, the optimal weight of each sub-criterion multiples to the optimal weight of its criteria.

The results of these operations are shown in Figure 1. In the first column, the criteria are illustrated, and through green and yellow colors, the best and the worst criteria have been marked, respectively. In the second column, the local weights of those criteria are shown calculated through the BWM. The third and fourth columns represent the sub-criteria and their local weights. Finally, in the last column, the global weights of the sub-criteria are shown calculated by multiplying the numbers of the fourth column (local weights of sub-criteria) by the related numbers of the second column (local weights of their criteria).

Criteria	Local weights	Sub-criteria	Local weighs	Global weights of sub-criteria
Sustainability	0.3966376	Productivity	0.06945899	0.027550047
		Reusability, recycling, and reverse logistics program	0.1946962	0.077223833
		management	0.116198	0.046088496
		Order status	0.141769	0.056230916
		quality	0.3548255	0.140737135
		material	0.1230523	0.048807169
Reliability	0.09387256	Economic aspect	0.5742701	0.053908204
		Social aspect	0.147929	0.013886474
		Environmental aspect	0.2778009	0.026077882
Resiliency	0.0451701	Pollution control initiatives	0.04857282	0.002194039
		Investment in capacity buffers	0.09668633	0.004367331
		Responsiveness	0.1150814	0.005198238
		Capacity for holding strategic inventory stocks	0.09556857	0.004316842
		cooperation	0.4090194	0.018475447
		rerouting	0.2350715	0.010618203
Greenness	0.1259804	Green image	0.04448254	0.005603928
		Green technology capabilities	0.0855666	0.010779714
		Green management systems	0.07895062	0.009946231
		Green transportation	0.1172175	0.014767108
		Green R&D and design	0.3729801	0.046988182
		green logistic	0.09098864	0.011462785
		Green material	0.209814	0.026432452
Risk	0.1159868	operational risks	0.2069377	0.024002042
		disruption risks	0.702891	0.081526078
		Unpredictable natural hazards	0.09017133	0.010458684
Cost	0.2223525	Transportation cost	0.2308482	0.051329674
		cost of component disposal	0.0966025	0.021479807
		Net Life cycle cost	0.4045347	0.089949302
		Maintenance and repair cost	0.1235444	0.027470406
		Cost transparency	0.09295023	0.020667716
		cost of relationship	0.05151991	0.011455581

Figure 6: *Local weights of criteria and sub-criteria and the global weights of sub-criteria.*

6.2. Calculating the global weights of information systems

In this stage, it is time to calculate the weights of ISs regarding the SS problem. So far, the weights of two levels of factors (criteria and their sub-criteria) have been calculated. Then, the global weights of these sub-criteria have been gained to determine the effectiveness of each sub-criteria on the SS problem. Similarly, if it is going to evaluate the effectiveness of several ISs on the SS problem, the effectiveness of each single IS ought to be determined regarding those sub-criteria. This is just like a three-tier model including criteria, sub-criteria, and ISs. in this case, it is noticeable that all of the 10 ISs are considered as the new sub-criteria for the main sub-criteria of the SS model in this study. This means that the BWM method must be repeated as many as the number of sub-criteria (31 times in this study, on account of 31 sub-criteria) to calculate the weights of all ISs regarding every single sub-criterion.

Step 1- Using the BWM to find the local weights of ISs in accordance with 31 sub-criteria.

Step 2- In order to calculate the global weights of ISs regarding every sub-criterion, the local weight of each IS, is multiplied to the global weights of the related sub-criteria calculated in the last stage. As a result, the global weights of every single IS are computed in 31 different categories (the number of sub-criteria). That is to say, all different stages done in these steps for the calculation of the global weights of ISs are as similar as those of calculating the global weights of sub-criteria. However, the criteria and sub-criteria in this stage are different so that the criteria are the sub-criteria of the SS problem and the new sub-criteria are the ISs that are similar for all 31 new criteria (31 sub-criteria). In the following, Figure 4 and Figure 5 show the local weights and global weights of one criterion (sustainability) for instance. Firstly, in Figure 7, the local weights of all 10 ISs regarding every single sub-criterion (in this figure, the sub-criteria of sustainability) are shown, calculating through BWM. Then, in Figure 8, the global weights of all 10 ISs regarding each sub-criterion (in this figure, the sub-criteria of sustainability) are shown calculating through multiplying the local weights of ISs regarding each sub-criterion with the global weights of that sub-criterion calculated in the last stage.

		Sustainability					
		Productivity	Reusability, recycling and reverse logistics program	management	Order status	quality	material
ISs	TPS	0.07681445	0.05693335	0.06986654	0.0905076	0.07645691	0.05997823
	OAS	0.06659976	0.029177	0.03593363	0.07112547	0.0720267	0.03164432
	MIS	0.1200072	0.06515054	0.2673155	0.07765892	0.08078466	0.06565723
	DSS	0.08517521	0.06844334	0.1085824	0.06927118	0.06542323	0.0633424
	EC	0.06208639	0.07362643	0.07117928	0.03028742	0.06136033	0.07615733
	ERP	0.2909396	0.3014819	0.1092784	0.2930592	0.1120183	0.3104403
	SCM	0.1375907	0.124729	0.1192128	0.1215641	0.1371327	0.1372419
	CRM	0.02959204	0.1005772	0.06915796	0.1090869	0.3062841	0.1183403
	KM	0.06981834	0.08315266	0.08195883	0.06435748	0.05829695	0.07020543
	BI	0.06137625	0.0967286	0.0675146	0.07308177	0.03021614	0.06699264

Figure 7: *local weights of ISs regarding six sub-criteria of Sustainability criteria.*

		Sustainability					
		Productivity	Reusability, recycling and reverse logistics program	management	Order status	quality	material
ISs	TPS	0.002116242	0.004396612	0.003220044	0.005089325	0.010760326	0.002927368
	OAS	0.001834827	0.00225316	0.001656127	0.00399945	0.010136831	0.00154447
	MIS	0.003306204	0.005031174	0.012320169	0.004366832	0.011369402	0.003204544
	DSS	0.002346581	0.005285457	0.005004399	0.003895182	0.009207478	0.003091563
	EC	0.001710483	0.005685715	0.003280546	0.001703089	0.008635677	0.003717024
	ERP	0.0080154	0.023281588	0.005036477	0.016478987	0.015765135	0.015151712
	SCM	0.00379063	0.009632052	0.005494339	0.006835661	0.019299663	0.006698389
	CRM	0.000815262	0.007766957	0.003187386	0.006134056	0.043105547	0.005775855
	KM	0.001923499	0.006421367	0.003777359	0.00361888	0.008204546	0.003426528
	BI	0.001690919	0.007469753	0.003111646	0.004109455	0.004252533	0.003269721

Figure 8: *Global weights of ISs regarding six sub-criteria of Sustainability criteria.*

6.3. Determining the effectiveness of information systems

After calculating the global weights of ISs regarding all 31 sub-criteria, it is possible to calculate the total weights of each IS regarding supplier selection showing its effectiveness. To this end, all 31 global weights of each IS (resulting from its 31 global weights regarding 31 sub-criteria) must be aggregated for every single IS. In other words, in this step, all 31 global weights of each IS illustrating its effectiveness in 31 sub-criteria of the SS model should be summed to determine the total weights (effectiveness) of the specific IS. Accordingly, this process should be repeated for all other nine ISs. In the following, Figure 6 shows the total weights of ISs regarding only sustainability criteria. In fact, this figure possesses only one more column than Figure 8, aiming to show the steps more precisely.

		Sustainability						
		Productivity	Reusability, recycling and reverse logistics program	management	Order status	quality	material	Aggregated weights
ISs	TPS	0.002116242	0.004396612	0.003220044	0.005089325	0.010760326	0.002927368	0.028509916
	OAS	0.001834827	0.00225316	0.001656127	0.00399945	0.010136831	0.00154447	0.021424865
	MIS	0.003306204	0.005031174	0.012320169	0.004366832	0.011369402	0.003204544	0.039598325
	DSS	0.002346581	0.005285457	0.005004399	0.003895182	0.009207478	0.003091563	0.028830661
	EC	0.001710483	0.005685715	0.003280546	0.001703089	0.008635677	0.003717024	0.024732534
	ERP	0.0080154	0.023281588	0.005036477	0.016478987	0.015765135	0.015151712	0.083729299
	SCM	0.00379063	0.009632052	0.005494339	0.006835661	0.019299663	0.006698389	0.051750733
	CRM	0.000815262	0.007766957	0.003187386	0.006134056	0.043105547	0.005775855	0.066785063
	KM	0.001923499	0.006421367	0.003777359	0.00361888	0.008204546	0.003426528	0.027372179
	BI	0.001690919	0.007469753	0.003111646	0.004109455	0.004252533	0.003269721	0.023904027

Figure 9: *Total weights of ISs regarding six sub-criteria of Sustainability criteria.*

Similarly, this step should be repeated for the sub-criteria of the other five criteria. Figure

10 below illustrates the aggregated weights of all ISs regarding all 31 sub-criteria. That is to say, this figure shows the last column of Figure 9, but for all six criteria.

		Criteria						
		Sustainability	Reliability	Resiliency	Greenness	Cost	Risk	Final scores
ISs	TPS	0.028509916	0.005289351	0.002337732	0.006737271	0.010459697	0.006779245	0.060113212
	OAS	0.021424865	0.003297017	0.002424187	0.005230125	0.010016199	0.004692222	0.047084614
	MIS	0.039598325	0.00716201	0.00422044	0.01387594	0.018819556	0.011538932	0.095215202
	DSS	0.028830661	0.004706711	0.00308054	0.008983455	0.015348606	0.007785471	0.068735445
	EC	0.024732534	0.010353809	0.00509769	0.017015923	0.019763517	0.011544644	0.088508116
	ERP	0.083729299	0.014635201	0.007317286	0.020711953	0.028782139	0.01858452	0.173760399
	SCM	0.051750733	0.024239072	0.011046371	0.026006724	0.071273335	0.032118577	0.216434812
	CRM	0.066785063	0.012139412	0.004418379	0.011749668	0.020350719	0.009660968	0.125104209
	KM	0.027372179	0.005395652	0.002554158	0.007807178	0.014218913	0.007270925	0.064619005
	BI	0.023904027	0.006654324	0.002673321	0.007862158	0.013319805	0.006011307	0.060424941

Figure 10: *Total weights of ISs regarding six sub-criteria of Sustainability criteria.*

As a result, the last column of Figure 10 shows the total weights of all 10 ISs in the SS problem. Accordingly, among the all different ISs, SCM plays the most effective role with 0.216434812; it has the largest weights in five out of six criteria (except in sustainability). Conversely, OAS is the least effective IS (0.047084614), and the least effective IS in five out of six criteria (Except in resiliency). ERP and CRM have the second and the third largest weights at 0.173760399 and 0.125104209, respectively. By contrast, TPS and BI are the second and the third least effective ISs (with the weights of 0.060113212 and 0.060424941, respectively). Nevertheless, the values for KM and DSS were slightly more than those of TPS and BI, whereas the values for MIS and EC are more than those values at 0.095215202 and 0.088508116, respectively.

6.4. Managerial decision in Emdadkhodro

As mentioned, there are seven different information systems in Emdadkhodro company: TPS, CRM, MIS, OAS, KM, SCM, and ERP. According to this company's managers, these ISs in decreasing order of significance are CRM, ERP, MIS, SCM, KM, OAS, TPS. That is to say, they spend the largest and the smallest amount of money, energy, and time on CRM and TPS, respectively. Furthermore, the first four ISs in this company account for around 85% of the resources. What is more, they mainly place the premium on sustainability, risk, and cost. On the other hand, based on Figure 10, although the four most important ISs are the same (SCM, ERP, CRM, MIS), their order are completely different. In other words, SCM is the most effective IS and other items in decreasing order are ERP, CRM, SCM. Plus, considering the figure (Figure 10), these four ISs make up 60% of the importance, and there should be at least 10 ISs. Therefore, there are some essential lessons that Emdadkhodro should consider. To begin with, by considering that they are working on sustainability, risk and cost, giving ERP and SCM priority in sustainability and risk and cost, respectively. It means that there is no one-size-fits-all, and they should focus on different ISs for different purposes. However, in general, SCM still should be the most important IS. And there are three other ISs: DSS, EC, and BI that, according to Figure 10, are almost as important as TPS and KM and are more important than OAS. This shows that undoubtedly they should start working on these ISs in their companies. In addition, it seems that they underestimate the significance of TPS, while Figure 10 illustrates that it would be considered as much as DSS, KM, and BI. Thus, this comparison shows that if wanting to maximize the effectiveness of its ISs in the SS problem, the Edadkhodro company ought to revise its ISs in different parts and reorganize its focus on them.

7. Managerial implication

As mentioned in the introduction section, nowadays, the supplier selection problem has been turned into an inescapable part of business and organization because of several contributing social and economic factors. On the other hand, several studies have shown the indispensable role of different information systems in not only the SS problem, but also organizations as independent meas. However, there has not been any study in the literature showing the effectiveness of a wide range of information systems on the supplier selection process by considering some of the most important criteria and sub-criteria. Nevertheless, this is not the only contribution that this study has been represented. One of the most advantageous contributions of this study is the practical horizon. This means that this study has considered some of the most important and practical criteria and sub-criteria in the SS model. Undoubtedly criteria including sustainability, reliability, resiliency, greenness, risk, and cost are not only current issues of the literature, but also are some of the most essential factors that almost all organizations consider in the contemporary market. In addition, regarding the sub-criteria, this study has considered the same approach.

What is more, through using BWM in two consecutive stages, the effectiveness of all different components of this study, including criteria, sub-criteria, ISs on criteria, and ISs on sub-criteria, have been clarified. That is to say, beside Figure 6 showing the weights of criteria and sub-criteria that could be so important for decision-makers because of the significance and practicality of those factors, Figure 8 helps managers in order to know the effectiveness of each single IS on every single sub-criterion. For instance, managers could understand that ERP is the most effective IS on productivity, Reusability, recycling, and reverse logistics program, order status, and material, while MIS and CRM are the most effective ISs on management and quality, respectively. Similarly, there is the same information about the least effective ISs. This, actually, enables managers and decision-makers to take the most optimized factors in their decisions to minimize the risk, cost, and error. The information in Figure 9, on the other hand, benefits the managers in a more general way so that they are able to know about the effectiveness of ISs on criteria. For example, if focusing on sustainability, the company could know that ERP is the most effective IS, whereas OAS has the least importance. And according to Figure 10, managers could optimize their concentration and investment of their whole ISs regarding the SS problems because they can know different levels of effectiveness of ISs. Accordingly, they could strengthen their weaknesses and better understand the importance of different ISs in the SS problem by considering some of the most practical criteria and sub-criteria that normally all organizations take into account. Finally, although almost all of the criteria and their sub-criteria have been used in different studies and there have been so many studies taking sustainability, resiliency, greenness, reliability, cost, and risk independently into consideration, this study provides decision-makers with a comprehensive model including all of those significant contributing factors in order to show the effectiveness of almost all using ISs on those factors by considering sustainability, reliability, resiliency, greenness, risk, and cost which are some of the most practical and important criteria in SS problem.

8. Conclusions

Although there are so many studies in the literature about supplier selection, it is rarely found that research has proposed a model including a wide range of major criteria and sub-criteria. On the other hand, there are so many studies in the literature about the importance of information systems in the business, and several studies have shown the significance of ISs in SS problems, but mainly as a sub-criterion of the SS models. However, there has not been any research illustrating the effectiveness of some ISs on SS by considering some of the most important and current criteria consisting of sustainability, reliability, resiliency, greenness, risk, and cost.

Accordingly, this study has proposed a SS model including sustainability, reliability, resiliency, greenness, risk, and cost as criteria and 31 sub-criteria. In this way, almost all of the current important and practical contributing factors in the SS problem are considered. Furthermore, a two-stage BWM is used to determine the effectiveness of ISs on the SS problem. To this end, firstly, the global weights of sub-criteria are calculated. Secondly, this method is used again to determine the global weights of ISs regarding sub-criteria. Finally, the aggregated weights (effectiveness) of ISs on the SS problem are calculated. In addition to the advantages of BWM as a methodology mentioned, its simplicity and practicality enable managers and decision-makers to adopt it. However, the results of this study show that Sustainability and resiliency are the most and the least important criteria in the SS problem. Similarly, the most and the least effective sub-criteria on every criterion are represented. In addition, according to the result, SCM and ERP are the most effective ISs regarding the SS problem with 0.216434812 and 0.173760399, respectively. Conversely, OAS and TPS have the least and the second least amount of effectiveness on the SS problem, respectively. Other ISs in decreasing order of effectiveness are CRM, MIS, EC, DSS, KM, and BI.

Indeed, the most important contributions of this study are; initially proposing a thorough and comprehensive SS model including the main new and practical criteria and sub-criteria, evaluation of ISs performance in this SS model, and using an accurate, easy to use and practical Method to address the problem. This is because managers enable to consider and be informed about the all-different components of this problem, including criteria, sub-criteria, and ISs that provide decision-makers with accurate and detailed information minimizing errors, risk, and cost in realistic situations.

Undoubtedly two of the most important limitations of this study were; finding a company in which there are a sizeable number of ISs set and organized systematically and finding a company seriously taking sustainability, resiliency, reliability, greenness, risk, and cost into account in their processes. However, the concept of this study could create several ideas for future studies by emphasizing the effectiveness of ISs on different important problems, evaluating the effectiveness of other important and practical factors on the SS problem, and even using some other method to cope with this problem.

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