Evaluation of Supply Chain Tools with Fuzzy AHP-COPRAS Methodology for Intelligent Supply Chain Management

Esin Mukul, Merve Güler, Gülçin Büyüközkan
Industrial Engineering Department
Galatasaray University
Ortaköy-Istanbul, 34349, Turkey
{emukul, mguler, gbuyukozkan}@gsu.edu.tr

Abstract*. Intelligent supply chain management, which emerged with the integration of digitalized processes into supply chain management, encourages companies to redesign their supply chains to meet customer needs and expectations for improved purchasing and service quality. Most companies try to strike a balance between working capital, operating costs, and optimal service levels. For this reason, it is very important to use the right supply chain tool that provides the most efficiency in supply chain management. In this study, the evaluation of supply chain tools for intelligent supply chain management is considered as a Multi-Criteria Decision Making (MCDM) problem. However, it becomes difficult for experts to evaluate and make decisions about the system when the information is insufficient and uncertain. Therefore, in this study, the fuzzy approach is used to evaluate the MCDM problem more realistically and flexibly. The aim of the study is to propose an evaluation model and integrated analytic methods for the evaluation of supply chain tools for the intelligent supply chain management. The fuzzy Analytic Hierarchy Process (AHP) method is used to calculate the weights of the criteria and fuzzy COmplex PRoportional ASsessment (COPRAS) is used to rank the supply chain tools. Finally, an application is offered to demonstrate the proposed methodology's possible use. This paper guides researchers and practitioners with an evaluation methodology based on fuzziness for intelligent supply chain management.*

Keywords. AHP, COPRAS, fuzzy approach, supply chain tools, intelligent supply chain management

1 Introduction

Many sectors are changing and developing with Industry 4.0, which has emerged with the developments in technology. One of the issues most affected by this change and development is supply chain management. Intelligent supply chain management, which emerged with the integration of digitalized processes into supply chain management, encourages companies to redesign their supply chains to meet customer needs and expectations for improved purchasing and service quality (Khan et al., 2010; Fore et al., 2016).

Companies want to create a more efficient, fast, and high-quality communication network with their rapidly changing business processes and business partners in the digital age. In addition, they try not to break away from the competition by being more efficient, more effective, and faster integrating into the market in subjects such as inventory optimization, supply chain optimization, forecasting and demand models planning, and supply chain strategies (Büyüközkan & Göçer, 2018; Liao et al., 2019). In this context, companies need several digital tools (i.e. software and programs) in order not to fall behind in this digitalization, manage their stock correctly, determine supply chain strategies and minimize operational costs by communicating with customers actively and dynamically in this context.

In addition, most companies try to strike a balance between working capital, operating costs, and optimal service levels. However, they need to focus their time and effort on the areas that yield the greatest return. For this reason, it is very important to use the right tool that provides the most efficiency in supply chain management (Hosseini et al., 2019).

There are many tools on the market that integrate with the ERP system, thereby facilitating and optimizing the management of the supply chain. In this study, the evaluation of supply chain tools for intelligent supply chain management is considered as a Multi-Criteria Decision Making (MCDM) problem (Hwang and Yoon, 1981). However, it becomes difficult for experts to evaluate and make decisions about the system when the information is insufficient and uncertain. Therefore, in this study, the fuzzy approach (Zadeh, 1965) is used to evaluate the MCDM problem more realistically and flexibly. This approach facilitates the decision-making processes of decision-makers (DMs) in complex and uncertain situations.

The aim of the study is to propose an evaluation model and integrated analytic methods for the evaluation of supply chain tools for the intelligent supply chain management. The fuzzy Analytic Hierarchy Process (AHP) method is used to calculate the weights of the criteria and fuzzy COmplex PRoportional ASsessment (COPRAS) is used to rank the supply chain tools. Finally, an application is offered to demonstrate the proposed methodology's possible use.

In addition, this study will help companies streamline the supply chain management process, determine which system provides the best inventory optimization while minimizing all supply chain management costs and help businesses achieve high returns.

The organization of this paper is as the following: In the next section, intelligent supply chain management is presented. Then, the third section shows the proposed methodology, and the application is provided in the fourth section. Finally, the last section concludes the paper.

2 Intelligent Supply Chain Management

The managerial tasks in which the material and information flow is effectively provided between suppliers, manufacturers, distributors, retailers, and customers in this logistics system where raw materials are transformed into products or services and delivered to the end-user are defined as supply chain management. All supply chain functions should be integrated in supply chain management (Stadtler, 2008).

The benefits of supply chain management are to increase customer satisfaction, continuity in production, performance improvement in deliveries, helping to reduce stocks, efficiency, capacity increase, saving by helping to reduce costs, shortening the supply cycle time, and facilitating adaptation to sudden changes in the market (Lambert & Cooper, 2000).

It is possible to see that many sectors have changed and developed with Industry 4.0, which has emerged with the developments in technology. One of the subjects most affected by this change and development is supply chain management. In this study, the concept of "Intelligent Supply Chain Management", which emerged with the integration of digitalized processes into supply chain management, will be presented (Agrawal et al., 2019; Özek & Yıldız, 2020).

Intelligent supply chain management aims to optimize the supply chain, actively apply modern technologies and strengthen the existing system. In this context, companies can provide the opportunity to save costs, generate more income, increase the speed of reaching customers and move to the forefront of the competition thanks to the intelligent supply chain (Scuotto et al., 2017; Büyüközkan & Göçer, 2018). It differs from traditional supply chains because the latter mainly aims to minimize production, transportation, and logistics costs. It is a customer-centric platform model that leverages and maximizes real-time data from many sources and assists businesses in collaborating by integrating the complete supply chain.

Along with Industry 4.0, evolutions in production, retail, distribution, logistics, inventory planning, customer parameters, along with the developing technology, have taken place rapidly on the path of digitalization. Companies are trying to achieve the success they could not achieve in the increasing digitalization with external resources.

In this study, supply chain tools that will support intelligent supply chain management are evaluated and this evaluation is handled by analytical methods.

3 Proposed Methodology

The proposed methodology consists of three basic steps:

- *Step 1 (Problem definition):* Identification of the criteria and alternatives.
- *Step 2 (Fuzzy AHP method):* Computation of criteria's weights with fuzzy AHP method.
- *Step 3 (Fuzzy COPRAS method):* Ranking supply chain tools with the fuzzy COPRAS.

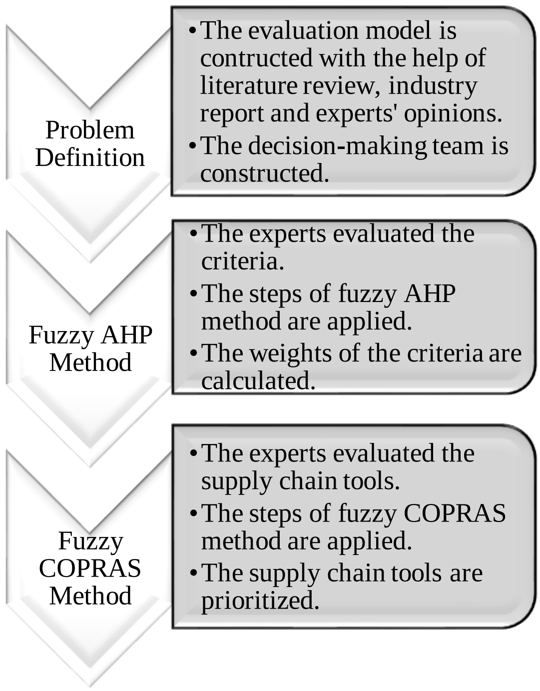

Figure 1. The steps of the proposed methodology

3.1 Proposed Evaluation Model and Supply Chain Tools

This study proposes the evaluation model by conducting a literature review, investigating industrial reports, and taking the experts' opinions. The proposed evaluation model for intelligent supply chain management is as in Table 1.

The supply chain tools to be evaluated in this study are as follows:

- *Slimstock Slim4:* Slim4 provides an end-to-end solution for demand planning, forecasting, and inventory control. It is a software add-on that can be easily, transparently, and quickly integrated with all ERP systems on the market. Portfolio companies in all industries can benefit from Slim4. The software relies on clear and reliable analysis. With Slim4, inventory is delivered at the right time, to the right place, and in the right quantity (URL1; SoftwareConnect, 2016).
- *SAP Integrated Business Planning:* Powered by SAP HANA memory technology, SAP IBP is a cloud solution that offers real-time supply chain management by providing a balance of supply and demand in the medium and short term, while providing strategic planning understanding in line with long-term goals. With SAP IBP, many modules such as demand planning, order fulfillment, inventory optimization, stock management, sales, and operational planning, control tower, production and supply planning, response and supply management are managed on a single platform (Minnock, 2020).
- *Oracle SCM Cloud:* Oracle offers a platform, infrastructure, and data services as well as software as a service. With Oracle SCM Cloud, it enables organizations to quickly respond to changing demand, supply, and market conditions. It aims to create a resilient network and process designed to lead change. It helps companies modernize their supply chain management processes by providing services to customers such as supply chain planning, product lifecycle management, and order management (URL2, Minnock, 2020).
- *JDA SCM:* JDA Software Inc. has implemented its end-to-end supply chain portfolio as a development platform to further its goal of providing an autonomous supply chain. The AI-powered supply chain management platform enables JDA to build cutting-edge applications in addition to its solutions for the first time. The supply chain management platform allows customers to connect their core business and SaaS applications and combine end-to-end planning, execution, and delivery capabilities (URL3).

Table 1. Evaluation model

Main Criteria	Sub-criteria	References
Customer based (C1)	Service quality (C11)	Büyüközkan & Göçer (2018); Liao et al. (2019); Özek & Yıldız (2020)
	Flexibility and visibility (C12)	Büyüközkan & Göçer (2018); Liao et al. (2019); Hosseini et al. (2019)
	Supplier compatibility (C13)	Scuotto et al. (2017); Büyüközkan & Göçer (2018)
	Ease of use for users (C14)	Özek & Yıldız (2020)
Technology based (C2)	Digital competence (C21)	Büyüközkan & Göçer (2018); Liao et al. (2019)
	Technology capability and integration (C22)	Büyüközkan & Göçer (2017); Scuotto et al. (2017); Büyüközkan & Göçer (2018); Özek & Yıldız (2020)
	Digital performance management (C23)	Özek & Yıldız (2020)
	Real-time monitoring technology (C24)	Agrawal et al. (2019); Özek & Yıldız (2020)
Organization based (C3)	Continuous collaboration (C31)	Scuotto et al. (2017); Büyüközkan & Göçer (2017); Büyüközkan & Göçer (2018); Hosseini et al. (2019); Liao et al. (2019)
	Respect for the privacy (C32)	Büyüközkan & Göçer (2018); Özek & Yıldız (2020)
	Adopting advanced analytics (C33)	Büyüközkan & Göçer (2017); Scuotto et al. (2017); Büyüközkan & Göçer (2018)
	Technology specialized human resources (C34)	Scuotto et al. (2017); Agrawal et al. (2019)
Financial based (C4)	Implementation cost (C41)	Scuotto et al. (2017); Agrawal et al. (2019)
	Service costs (C42)	Agrawal et al. (2019)
	Coordination costs (C43)	Scuotto et al. (2017); Sembiring et al. (2020)
	Financing efficiency (C44)	Büyüközkan & Göçer (2018); Liao et al. (2019)

3.2 Fuzzy AHP-COPRAS Methods

Saaty (1980) invented AHP, which is perhaps the most well-known and commonly utilized decision-making model. It is a strong decision-making approach for determining the priority among several criteria.

Fuzzy AHP is a decision-making strategy that allows decision-makers to make decisions in an MCDM process and facilitates decision-making in uncertain conditions (Aya, 2005). When the literature is investigated, it is discovered that various writers provide a wide range of fuzzy AHP methods.

The following stages are included in the Fuzzy AHP utilized in this paper (Büyüközkan and Çifçi, 2012):

Step 1: Create the fuzzy comparison matrices in Table 2 by utilizing triangular fuzzy numbers.

Table 2. Fuzzy scale

Linguistic expression	Fuzzy Scale
Extremely more importance (EMI)	(8, 9, 10)
Very strong importance (VSI)	(6, 7, 8)
Strong importance (SI)	(4, 5, 6)
Moderate importance (MI)	(2, 3, 4)
Equal importance (EI)	(1, 1, 2)

Step 2: α-cut matrices are built. The α-cut is thought to reflect DMs' confidence in his or her choices. The optimism index μ indicates the level of satisfaction for the judgment matrix. A higher index μ score suggests a higher level of optimism. The optimism index is a linear convex combination defined as

$$\tilde{a}_{ij}^{\alpha} = \mu\tilde{a}_{ijl}^{\alpha} + (1-\mu)\tilde{a}_{ijl}^{\alpha} \forall\alpha \in [0,1] \quad (1)$$

Step 3: Using eq. 2, matrices are normalized, and the consistency ratio (CR) for each matrix is determined.

$$\tilde{r}_{ij} = \frac{\tilde{a}_{ij}^{\alpha}}{\sum_i^k \tilde{a}_{ij}^{\alpha}} \quad (2)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

where CI refers to consistency index, λ_{max} is the largest eigenvector of the matrix, n is the number of criteria, and RI is the random index.

Step 4: The weights of the main criteria ($\tilde{w}_i^{CR}$) are obtained using the arithmetic mean. And, these steps are applied for each sub-criteria, and global weights ($\tilde{w}_{ij}^{G}$) are calculated by multiplying the weight of the main criteria.

$$\tilde{w}_{ij}^{G} = \tilde{w}_i^{CR} \times \tilde{w}_j^{CR} \quad (5)$$

Zavadskas et al. (1994) proposed the COPRAS method and proved its validity. It evaluates alternatives by making step-by-step sequencing of alternatives in terms of importance and utility ratings. It is also an approach based on distance. Zavadskas and Antucheviciene (2007) offer the COPRAS method with fuzzy logic for the evaluation of rural building regeneration alternatives in the literature.

The fuzzy COPRAS method steps are as follows:

Step 1. DMs evaluate the alternatives by using the fuzzy scale given in Table 2. These fuzzy numbers are defuzzified with the center of area method. The crisp value x_{ij} can be found using eq. 6.

$$x_{ij} = \frac{[(U_{x_{ij}} - L_{x_{ij}}) + (M_{x_{ij}} - L_{x_{ij}})]}{3} + L_{x_{ij}} \quad (6)$$

Step 2. The normalized decision matrix is calculated with eq. 7.

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (7)$$

Step 3. The weighted normalized decision matrix is calculated by using eq. 8.

$$d_{ij} = x_{ij}^{*}.w_j \quad (8)$$

Step 4. The S_i^- and S_i^+ values are calculated using eq. 9 and eq. 10 for both beneficial and non-beneficial criteria.

$$S_{i^+} = \sum_{j=1}^{k} d_{ij} \quad (9)$$

$$S_{i^-} = \sum_{j=k+1}^{n} d_{ij} \quad (10)$$

Step 5. The relative importance values (Q_i) for each alternative are calculated by using the eq. 11.

$$Q_i = S_{i^+} + \frac{\sum_{i=1}^{m} S_{i^-}}{S_{i^-} * \sum_{i=1}^{m} \frac{1}{S_{i^-}}} \quad (11)$$

Step 6. The biggest relative priority (Q_{max}) value is found.

Step 7. The performance index (P_i) of each alternative is computed with eq. 12.

$$P_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \quad (12)$$

4 Application of the Proposed Methodology

A company operating in the retail sector has some problems in stock management in its warehouses, especially after the COVID-19 pandemic. Especially in warehouses and stores connected to the warehouse, they try to keep stock in hand according to the outlets, and they do not want to be out of stock. For this reason, it wants to invest in a supply chain tool supported by digital technologies.

In this context, an evaluation model consisting of 4 main criteria and 16 sub-criteria was created in this study. This model will be evaluated for 4 different supply chain tool alternatives determined after the literature review and expert opinions. The names of the tools were kept confidential during the evaluation process and they were named A1, A2, A3, and A4.

The weights of the criteria of the evaluation model will be computed with the fuzzy AHP method. The fuzzy COPRAS method will be used to rank the supply chain tools. Evaluations in this study are made by three DMs. All three DMs are sufficiently knowledgeable and experienced in the field of supply chain management. The weights of the DMs are considered equal. DM1 has 15 years of private sector experience in supply chain management. DM2 has been conducting academic studies, lectures, industrial research, and consultancy on supply chain management for 20 years. DM3 has consulting and project management experience in digital supply chain management.

4.1 Calculation of Criteria Weights with Fuzzy AHP Method

As a starting point, the evaluation model is constructed as in Table 1 with a literature review and expert opinions. Then, the fuzzy comparison matrix between these criteria is structured by using triangular fuzzy numbers in Table 2. The comparison matrix for the main criteria is shown in Table 3.

Table 3. The comparison matrix for the main criteria

	C1			C2		
C1	1,000	1,000	1,000	4,000	5,000	6,000
C2	0,167	0,200	0,250	1,000	1,000	1,000
C3	0,125	0,143	0,167	0,125	0,143	0,167
C4	0,167	0,200	0,250	0,250	0,333	0,500
	C3			**C4**		
C1	6,000	7,000	8,000	4,000	5,000	6,000
C2	6,000	7,000	8,000	2,000	3,000	4,000
C3	1,000	1,000	1,000	0,125	0,143	0,167
C4	6,000	7,000	8,000	1,000	1,000	1,000

α-cut matrices (α=0.5; μ=0.5) are constructed by using eq. 1 and these matrices are normalized as in Table 4. CR is checked by using eq. 3 and eq. 4.

Table 4. The normalized matrix for the main criteria

	C1	C2	C3	C4
C1	0,160	0,217	0,190	0,064
C2	0,480	0,578	0,635	0,596
C3	0,120	0,120	0,127	0,255
C4	0,240	0,084	0,048	0,085

These steps are applied for all sub-criteria, and final global weights for all criteria are calculated. The final criteria weights are shown in Table 5.

Table 5. The final criteria weights

Main Criteria	Weights	Sub-Criteria	Weights	Global Weights
C1	0,158	**C11**	0,542	0,0855
		C12	0,076	0,0119
		C13	0,081	0,0128
		C14	0,302	0,0476
C2	0,572	**C21**	0,332	0,1902
		C22	0,468	0,2680
		C23	0,050	0,0285
		C24	0,150	0,0856
C3	0,156	**C31**	0,090	0,0141
		C32	0,569	0,0885
		C33	0,296	0,0461
		C34	0,045	0,0070
C4	0,114	**C41**	0,355	0,0406
		C42	0,491	0,0561
		C43	0,112	0,0128
		C44	0,042	0,0048

According to the final weights, the most appropriate criteria are “Technology capability and integration (C22)”, “Digital competence (C21)” and “Respect for the privacy (C32)”.

4.2 Evaluation of Supply Chain Tools with Fuzzy COPRAS Method

Firstly, the matrix between evaluation criteria and supply chain tool alternatives is constructed with the help of the fuzzy scale in Table 2. Table 6 shows the DMs’ evaluations for sub-criteria of customer-based (C1).

The evaluation matrices of the other criteria are also formed in this way.

Table 6. The evaluation matrix for sub-criteria of C1

	C11	C12	C13	C14
A1	SI	EI	EI	EI
A2	SI	MI	SI	MI
A3	VSI	EMI	EMI	EMI
A4	EMI	EMI	EMI	EMI

These fuzzy numbers are defuzzified with eq. 6. The weighted normalized decision matrix of the alternatives is calculated. The values of *Qi*, *Si+*, *Si-*, *Pi* are computed using eq. 9-12. Finally, Table 7 shows the results.

Table 7. The final values

	Si-	Si+	Qi	Pi	Ranking
A1	0,719	3,291	4,050	89,967	2
A2	0,981	3,945	4,502	100,000	1
A3	0,675	2,787	3,596	79,882	4
A4	0,625	2,977	3,851	85,550	3

At the conclusion of the fuzzy COPRAS method, the most appropriate supply chain tool is “Slimstock Slim4”. The second, third, and fourth alternatives are ranked as A1, A4, and A3 respectively. The names of other companies are not disclosed due to company policies and privacy.

5 Conclusion

Digitalization, which is an absolute business necessity of our age, is also reflected in supply chain management applications, in this case, it increases smart supply chain management applications.

This paper aimed to propose an evaluation model for intelligent supply chain management and rank supply chain tools using an integrated fuzzy MCDM approach. The weights of the criteria were obtained with the fuzzy AHP method, and the fuzzy COPRAS method was used to rank supply chain tools.

An application was shown to demonstrate the methodology's efficacy, and the outcomes of this examination were presented. The most appropriate criteria were found as “Technology capability and integration (C22)”, “Digital competence (C21)” and “Respect for the privacy (C32)”, and the first ranked supply chain tool was determined as “Slimstock Slim4”.

Slim4 offers a complete solution to its customers in stock optimization and inventory management. It works to maximize profits by optimizing the stocks and inventories managed by its customers. In addition to the current business rules it contains, it is supported by updates and new business rules in order to follow a successful path in market movements that differ from sector to sector, in line with the wishes and needs of the customers (URL1).

The number of supply chain tools can be considered as the limitation of the article. A more comprehensive evaluation can be made by increasing this number.

For future investigation, aggregation operators can be used to aggregate DMs' evaluations in group decision-making. On the other hand, other extensions (e.g. elicit information, pythagorean fuzzy sets, spherical fuzzy sets) of fuzzy sets may be implemented into the framework.

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