Sustainable Supplier Selection with Risk Considerations Towards System Reliability

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***Abstract*—As the contemporary business model put high premium on outsourcing, the world's supply chain becomes even more ramified, and entities entangled face inevitable risk as a consequence. Owing to such backdrops, researchers imply outsourcing decisions with which corporations often deal is of paramount importance in this day and age thus entailing the incorporation of reliable supply chain to dwindle risk reverberations. This notion gives rise to the development of tremendous numbers of researches carried out in this domain, inclusive of stand-alone systematic literature review. In point of fact, the systematic review on supplier selection and order allocation (SSOA) has been prevalently addressed in the literature, yet very little research is being exerted into SSOA taking risk management into account. This study thus aims to solicit a collection of supplier selection and order allocation articles when risk enter the equation in pursuit of highlighting the most utilized approach in SSOA and presenting the most suitable technique in risk measurement. Based on our survey methodology, we reviewed as many as 124 papers collected from our campus' electronic academic database, namely Universitas Gadjah Mada-subscribed database. To our knowledge, this is the first survey in the literature employing UGM-subscribed database to deeply investigate SSOA with risk. Our findings indicated that Analytical Hierarchy Process, Goal Programming, and Genetic Algorithm to be the most utilized multi-criteria decision-making, mathematical optimization, and artificial intelligence approach, respectively, in the reviewed literatures.**

Keywords—supplier selection, order allocation, risk, literature review, reliability

I. INTRODUCTION

In today's competitive market, enterprises are inclined to outsource some of their business processes to external entities, making full use of advantages stemming from improved product quality, low-cost labor, and service innovation. An overarching instance of such outsourcing practice is purchasing components and services through global suppliers [1]. Reference [2] indicated that outsourcing is 21st-century business trends and its increase in number cause supply management decisions to become ever more intricate. This ramification, moreover, also propelled by delocalization, globalization, high transportation charges, inadequate infrastructure, terrorist attack, and weather-related calamities [3].

The increased complexity of supply chain has sparked various kinds of risks to arise [4]. Broadly speaking, the risks linked with supply chain can be divided into two main categories: operational and disruption [5]. Operational risks encompass the typical occurrences in everyday process within a supply chain, including customer demand fluctuation, key personnel absence, power outage, and uncertainty in supply and transportation cost [6]. Disruption risks, on the other hand, involve significant disruptive events such as human-made threats, labor strikes, and natural disasters. These events, particularly natural disasters, are disruptions that are less likely to occur but have a potential impact, arguably resulting in short or long-term negative effects on supply chain operations.

Many researchers have pointed out its far-reaching repercussions, oftentimes terrible, arising from disruption events. Ensuing 2011 Japanese earthquake and tsunami, Toyota halted a considerable portion of its production at manufacturing facilities throughout Japan, leading to scarcity of parts globally [7]. Numerous automotive enterprises both in the UK and the US faced significant challenges in the aftermath of Japanese earthquake owing to their reliance on a factory in the earthquake-affected area, which supplied 12% of their engines [8]. Meanwhile, Apple suffered from a shortage of sensors for its iPhone since the facility which sensors were exclusively manufactured was damaged by the Japanese tsunami [7].

Such colossal disruptions in the supply chain can result in high losses and supplementary recovery cost [100]. For example, in March 2000, lightning precipitated fires at Philips' semiconductor production plant which led to supply dearth for Ericsson and Nokia over the course of six weeks. It incurred Ericsson a financial loss of $400 million in the North American mobile market [101]. Recognizing, managing, and controlling such risks are imperative to effectively handling supply chain [89]. Proactive and reactive mitigation strategies are known to be two fundamental approaches to hedge against such risks, particularly the disruptive ones [101]. Literature on supply chain risk management (SCRM) articulates a set of vital capabilities for mitigating risks, reliability is one among it and presumed to be the most effective proactive strategic capabilities for managing risks. Reliability is one of the pivotal factors having the ability to dampen the repercussion of unprecedented disruptions. It raises a need for supply chain model considering reliability for designing its network. The reliability of supply chain leans on the reliability of each of its entity, inclusive of supplier reliability [89].

The supplier selection problem (SSP) has emerged as a key issue due to the growth of global supply chains and strategic outsourcing. It aims at choosing the best portfolio of suppliers among a set of alternatives and to optimally allocate demand among the selected suppliers to fulfill distinct procurement criteria [1]. Selecting suppliers is a multifaceted decision-making problem encompassing both tangible and intangible attributes [9]. This phase constitutes a significant portion of the overall product expenses within the supply chain. Typically, a company allocates nearly 60% of its total revenue towards procuring items like raw materials, parts, sub-assemblies, and components. In sectors like automotive, these expenditures may exceed 50% of the total revenues, while in high-tech industries, they could escalate to as much as 80% of the total product costs [10]. These figures show that supplier selection is an important component in the supply chain [3]. Furthermore, selecting suppliers help the firms significantly to supply the right amount and price of the products. Therefore, the supplier selection and ordering process are introduced as an essential part of the supply chain in the modern production space [11].

Supplier evaluation and selection problem has been studied extensively. Various decision-making approaches have been proposed to tackle the problem. However, diverse past studies have centered merely on supplier selection and order allocation, with noticeably scant research being carried out into supplier selection and order allocation with risk. Thus, the objective of this work is to draw up a collection of papers that incorporate risk into supplier selection and order allocation decisions, then to review literature in the field to attempt to answer the following questions:

- Which approach has been prevalently utilized in the field of supplier selection and order allocation with risk (SSOAR) considerations?
- What are the most suitable techniques to measure risk within supplier selection and order allocation?

II. METHODOLOGY

The literatures considered in this work were discovered through our campus' electronic academic database, namely Universitas Gadjah Mada (UGM) Summon Serials Solutions, which is UGM-subscribed database. We utilized this database since it is made up of sundry databases such as Emerald, IEEE, JSTOR, SAGE, Springer, and Taylor & Francis. To our knowledge, this is the first systematic review of literature taking advantage of UGM-subscribed database to deeply explore supplier selection and order allocation while taking risk into account. The prominent purpose of this study is to solely select the papers dealing with selecting suppliers and allocating orders with risk, excluding the ones taking only supplier selection and order allocation. Hence, we are seeking works with keywords "supplier selection and order allocation with risk," as our research descriptor. To attain the highest level of reliability, only English-written papers from year 2008 to 2024 from international journal articles and conference articles have been taken into consideration, we intend to eliminate stand-alone literature review papers. Magazine articles, master's and doctoral dissertations, project papers, and unpublished articles were also omitted in this review. Built on these conditions, a total of 124 papers were identified as suitable for our review.

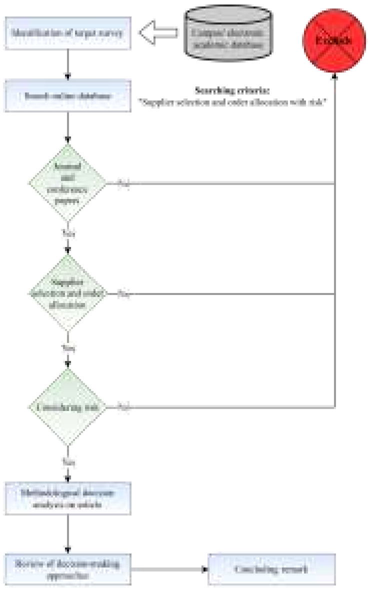

Fig. 1. Research methodology of this survey

III. RESULT AND DISCUSSION

In response to the two research questions, we dissociate our paper into two distinct sections of discourse. First, we group identified SSOAR literatures by approaches utilized. We refer to [22, 23] for classification benchmarking. There are three approaches commonly considered in the literatures by which researchers usually employ when dealing with SSOAR, namely Multi-Criteria Decision-Making approach (MCDM), Mathematical Programming approach (MP), and Artificial Intelligence approach (AI). Having arranged the literature by its approach, we then bring risk techniques used to measure the degree of risk to the forefront. As our introductory discussion, it is recognized that there is evolving trend of SSOAR researches in the literature as depicted in Figure 2. It is worth underscoring that despite the number of publications in this domain seems to heighten, the literatures in the field are disproportionately smaller if it be juxtaposed with the ones not taking risk into consideration. From our exploration through the database, it found that there are 214 vis-à-vis 709 number of papers conferring supplier selection and order allocation with risk and the ones without, respectively. Not to mention, there has been very little research incorporated risk measurement techniques such as Value at Risk (VaR), mean variance analysis, and exponential utility function, we will also deal with this matter later in the paper.

Fig. 2. Distribution of papers by year

Multi-Criteria Decision-Making Approach. Extensive MCDM approaches have been proposed for supplier selection, analytic hierarchy process (AHP), analytic network process (ANP), and technique for order performance by similarity to ideal solution (TOPSIS), to name a few. These techniques have been applied in many studies. Reference [12] proposed an integrated methodology to classify, manage, and gauge inbound supply risk. They enhanced AHP as a technique to ensure consistent ranking of risk factors for suppliers. Reference [13] presented a comprehensive model that integrates supplier selection, order allocation, and customer order scheduling under uncertainty. ANP was integrated with Fuzzy Preference Programming (FPP) became FANP to account for interdependencies between criteria and handle inconsistencies in supplier evaluation. Reference [14] introduced a multi-phase hybrid model to segment, select, and prioritize suppliers while considering their technological capabilities and resilience to disruption risks. TOPSIS was used to further evaluate and rank a set of efficient suppliers. Reference [58] addressed the need for selecting reliable suppliers and managing order allocation in a centralized supply chain under disruption and environmental risks. Failure Mode and Effects Analysis (FMEA) was applied to assess the reliability of suppliers by assigning a Risk Priority Number (RPN) to each. Suppliers with lower RPN values are considered more reliable and are given preference in the supplier selection process. Reference [48] introduced the notion of what so-called gresilient within supply chain management which is essentially a term combining green and resilient practices. This integrated concept addresses the growing urgency for supply chain to be both environmentally sustainable and resilient. VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Decision Making Trial and Evaluation Laboratory (DEMATEL) were used to assess and rank suppliers based on their gresilience performance. This approach provides a means to evaluate suppliers by balancing traditional business goals, green supply chain goals, and resilience requirements. Reference [47] presented a comprehensive approach for classifying suppliers in emerging economies by integrating sustainable and resilience criteria using ELECTRE TRI-nC technique. The uses of ELECTRE TRI-nC allows Multiple Criteria Decision Analysis (MCDA) by considering qualitative and quantitative data which is essential for comprehensive supplier evaluation. Reference [35] presented an extensive study on supplier selection and order allocation problem under disruption risk. Fuzzy Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) along with fuzzy-AHP were used to evaluate and rank suppliers based on multiple criteria. This amalgamation of two techniques provides a robust mechanism for supplier evaluation and ranking considering inherent uncertainties and subjectivities in decision making.

Mathematical Programming. In this category of approach, we can cite linear programming (LP), mixed-integer linear programming (MILP), mixed-integer non-linear programming (MINLP), goal programming (GP), and data envelopment analysis (DEA). Reference [15] presented a model for multi-level supplier selection and lot sizing in supply chain management, LP was used to optimize orders and allocate capacity among efficient suppliers. Reference [16] discussed a bi-objective sustainable supplier selection and order allocation model with economic, environmental, and social criteria as the total weighted score objective along with total cost objective. MILP was then proposed to minimize the total costs and maximize the total score of all suppliers in regard to three sustainability aspects considering quantity discounts and disruption risks. Reference [72] presented a MINLP model that addresses the complexities of supplier selection and order allocation in centralized supply chains, considering disruption risks. The model incorporates protective policies such as protected suppliers and emergency inventory allocation to mitigate the effects of disruptions. Reference [66] presented a decision support system (DSS) aimed at managing procurement risks in the context of spot markets. The proposed system leverages Monte Carlo simulation and GP to address the complexities of supplier selection and order allocation in dynamic market conditions. They introduced the Expected Profit–Supply at Risk (A-EPSaR) model to quantify risks and optimize procurement decisions. Reference [62] proposed a comprehensive multi-objective model to optimize closed-loop supply chains (CLSC) and enhance supplier selection under competitive conditions. They addressed the integration of quantity discount policies in a competitive environment, aiming to maximize profit and efficiency while minimizing defects and delivery delays. DEA and Nash bargaining game theory were used to evaluate supplier efficiency and competitiveness while addressing the complexity of real-world supplier selection and order allocation problems.

Artificial Intelligence. A myriad of studies has been carried out in this domain utilizing Artificial Intelligence (AI) as its approach to seeking solutions. Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Best-Worst Method (BWM) and more are among AI technique we found in the literatures. Reference [17] explored models and strategies for managing risks in the supply chain, centered on supplier selection, order allocation, and decision-making under various uncertainties. They used GA as a solution approach to solve the optimization problem. Reference [18] explored sourcing decisions and optimal order allocation in the presence of supplier disruption risk. PSO was applied to solve multi-objective model capturing the qualitative aspect of suppliers by maximizing the total purchase value along with minimizing the expected total cost. Reference [19] focused on developing a two-layer optimization model to enhance supply chain resilience by addressing supply disruptions through product design changes and alternative supplier selection. The model aims to minimize the repercussions of product changes while maximizing the manufacturer's total profit. ACO algorithm is proposed to efficiently solve the optimization model and reduce losses caused by disruptions. Reference [93] introduced a comprehensive model for supplier selection that integrates sustainability and resilience criteria using fuzzy MCDM methods. The study employed Fuzzy-BWM to determine criteria weights and combines grey relational analysis (GRA) with TOPSIS to evaluate suppliers under uncertainty.

For illustrative purposes, we present Table 1 detailing each of approaches, the techniques, the abbreviation, the amount of publication employing respective techniques, the percentage of each and every of the techniques, and the representative literatures.

Table 1. Distribution of papers by approaches

The used DM techniques	Abbreviations	Number of papers	Percentage (%)	Selected literatures
Multi-Criteria Decision-Making Approach (MCDM)				
1. Analytical hierarchy process	AHP	19	15.70%	[14],[24]—[41]
2. Analytical network process	ANP	6	4.95%	[13],[42]—[46]
3. Elimination and choice expressing reality	ELECTRE	1	0.82%	[47]
4. Preference ranking organization method for enrichment evaluation	PROMETHEE	1	0.82%	[35]
5. Technique for order performance by similarity to ideal solution	TOPSIS	18	14.87%	[14],[24],[26],[29],[33],[36],[40],[41],[46],[49]—[55]
6. VIseKriterijumska Optimizacija I Kompromisno Resenje	VIKOR	3	2.47%	[27],[34],[48]
7. Decision making trial and evaluation laboratory	DEMATEL	2	1.65%	[48],[54]
8. Multi-attribute utility theory	MAUT	1	0.82%	[56]
9. Failure modes and effects analysis	FMEA	4	3.30%	[54],[57]—[59]
10. Game theory	GT	1	0.82%	[60]
Mathematical Programming (MP)				
1. Data envelopment analysis	DEA	6	4.95%	[14],[15],[61]—[64]
2. Chance-constrained programming	CCP	1	0.82%	[65]
3. Dynamic programming	DP	1	0.82%	[32]
4. Goal programming	GP	6	4.95%	[29],[42],[66]—[69]
5. Integer non-linear programming	INLP	1	0.82%	[70]
6. Mixed possibilistic-stochastic programming	MPSP	1	0.82%	[71]
7. Mixed-integer non-linear programming	MINLP	1	0.82%	[72]
8. Mixed-integer linear programming	MILP	1	0.82%	[73]

9. Robust programming	RP	1	0.82%	[74]
10. Stochastic programming	SP	2	1.65%	[75]—[76]
11. Weighted sum approach	WSA	1	0.82%	[77]
Artificial Intelligence				
1. Genetic algorithm	GA	16	13.22%	[4],[17],[18],[78]—[90]
2. Ant colony optimization	ACO	1	0.82%	[19]
3. Particle swarm optimization	PSO	6	4.95%	[4],[18],[35],[52],[78],[82]
4. Artificial neural network	ANN	2	1.65%	[40],[63]
5. Bayesian network	BN	1	0.82%	[91]
6. Decision tree	DT	1	0.82%	[92]
7. Best-worst method	BWM	9	7.43%	[16],[52],[53],[55],[93]—[97]
8. ε-constraint method		5	4.13%	[37],[43],[77],[98],[99]
9. Grey relational analysis	GRA	2	1.65%	[39],[93]

Although there has been a vast majority of literatures exploring supplier selection and order allocation taking risk into consideration, these papers seldom incorporate risk measurement technique into the discussion. We found that merely 18 out of 124 papers surveyed incorporate these techniques. Reference [4] addressed the supplier selection and order allocation problem in supply chain management, focusing on risk management and decision-making under disruption risks. They introduced a risk-averse model utilizing Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) measures to optimize total supply chain costs. Reference [20] used mean-variance analysis to simplify the stochastically distributed utility function by assuming a normal distribution and constant absolute risk aversion. This would help in transforming complex stochastic-fuzzy multi-objective problems (SFMOP) into more manageable quadratic multi-objective problems (QPMOP). Reference [21] explored a single-product single-period inventory model where a risk-averse retailer must decide on optimal order quantities from a cheaper but unreliable primary supplier and a more expensive but reliable secondary supplier. By using an exponential utility function to quantify risk, the study demonstrates how risk aversion impacts decision-making, leading to lower order quantities from the primary supplier compared to risk-neutral scenarios. The application of risk measurement techniques is varied and there is no one-size-fits-all technique. To put it in slightly different words, we did not find any risk measure which is the most suited nor superior over the rest.

IV. CONCLUSION AND FUTURE DIRECTION

This study undertakes a systematic review of literature on supplier selection and order allocation with risk considerations, which is a part of supply chain risk management. The survey examines 124 selected papers published in journals and conference proceedings utilizing our campus' electronic academic database, that is Universitas Gadjah Mada (UGM) Summon Serials Solutions, which is UGM-subscribed database. The purpose of this survey is two-fold, we attempt to search for the most prevalent techniques being used in the domain of supplier selection and order allocation with risk as well as to highlight the suitable risk measurement techniques already existed in the literature. Our findings show that Analytical Hierarchy Process (AHP), Goal Programming (GP) together with Data Envelopment Analysis (DEA), and Genetic Algorithm (GA) are on the top list of techniques employed in this domain according to their own class of approaches. We found that AHP, GP/DEA, and GA proportionately contribute 15.7%, 4.95%, and 13.22% on global percentage of total reviewed papers, respectively. As to risk measurement techniques, we discovered techniques such as Value-at-Risk (VaR), Conditional Value-at-Risk (CVaR), mean-variance analysis, and exponential utility function with VaR and CVaR are quite omnipresent compared to others. Despite there have been researches utilized such measure, it remains underexplored thus there is a need for future research incorporate risk measurement techniques into equation considering the benefit by which the techniques can offer.

Aside from the aforementioned concluding remarks, this study fails to distinguish techniques' nature advancement or extension, such as fuzziness. This survey considers the ones prior to extension and the ones after as the same technique. Thus, our calculations put no difference between those two. It is then suggested for future researches to differentiate it since such extension offers its own robustness and uniqueness compared to the prior version.

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