A comprehensive analysis of diverse risk management strategies in healthcare supply chain

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Abstract— The purpose of this paper is to propose a comprehensive framework for healthcare supply chain risk management, in order to explore, evaluate and prioritize risk factors, as well as to validate the proposed model empirically. The proposed method combines a review of published articles, questionnaire surveys, and Fuzzy Analytic Hierarchy Process (AHP) to identify risk factors, as well as Interpretive Structural Modelling (ISM) to investigate the inter-relationships among the risks. The identified 34 risk factors that affect the management of hospital supply chains can be divided into three main categories. To mitigate these identified risks, various strategies have been studied through empirical research. The outcomes provide a guideline for hospital managers to anticipate and prepare for potential risks.

Keywords—Healthcare, supply chain management, risk management

I. INTRODUCTION

As a matter of fact, a growing number of disruptive cases with negative consequences on the performance of organizations in recent years. There have been many cases of when disruption has paralyzed the supply chain. For example, a fire which lasted for only ten minutes in a Phillips semiconductor plant disrupted Ericsson's delivery of microchips for more than one month, which eventually led to a $400 million loss [1].The bankruptcy of a UK-based supplier, UPF-Thompson, forced Land Rover to make 1,400 workers redundant. Similarly, nearly 420 KFC stores around UK were forced to close due to the delivery problems incurred by its delivery partner, a UK based food delivery specialist Bidvest Logistics in 2018. It is still possible to recall how the earthquake, tsunami and the subsequent nuclear crisis occurred in Japan in 2011 caused Toyota's production to drop by 55,000 vehicles, costing $72 million in profits per year [2]. For the last decade, few areas of management interest have risen to prominence as rapidly as supply chain risk management (SCRM) [3].

The remainder of the paper is structured as follows: after the introduction section, Section 2 analyses the associated theoretical background on supply chain risk management and current statue of SCRM in healthcare sector. The proposed methodological framework for healthcare SCRM is presented in Section 3. Afterwards, the empirical studies describing different phases of prioritization of risk factors, identification and evaluation of relevant mitigation strategies are presented in Section 4. Section 5 outlines the managerial implications of the research. Finally, the paper ends with Section 6 which provides the summaries, limitations and scope for future work.

II. LITERATURE REVIEW AND THE FRAMEWORK

A. *Literature review*

According to a study conducted by the Computer Sciences Corporation in 2004, 60% of the surveyed companies recognised that their supply chains are vulnerable to disruptions. Ghadge *et al.*, [4] observed that there are considerable number of researchers that started researching SCRM in early 2000, according to their preliminary search. The 9/11 terrorist attack (2001) affected the major global supply chain, and this triggered interest in the SCRM field [5][6], causing the increase in the number of articles on SCRM during 2003 and 2004 [4]. The early research tended to be a reactive approach to risk management, which explored the improvement of the capability to respond to uncertain events. Moreover, the focus was on the supply chain design to address a single company. After that, the business environment is becoming more unpredictable and increasingly unstable due to globalisation, shorter product life time, and the series of crises and economic recessions. The risk management process has become more proactive and the focus goes beyond the boundaries of the single company until the year of 2003, as the collaborative sharing of information and best practices among supply chain partners received increased attention. Accordingly, Jüttner *et al.*, [7] built a foundation of effective SCRM as 'the specification and management of risks for the supply chain, through a co-ordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole'. Researchers [8] extended this definition by combining with others to define SCRM as 'the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity'. There is a slight difference in the managerial objectives for both definitions. In comparison with the former studies, Thun [6] aimed not just to reduce risks but also to achieve business continuity. More importantly, without a mutual understanding and clear definitions, researchers could be confused when communicating with practitioners.

Alternatively, a consistent definition would help researchers estimate and evaluate the probability and consequences of the full set of supply chain risks and measure the effectiveness of SCRM methods [9]. One comprehensive definition of SCRM was recently suggested by Ho *et al.*, [9] who defined SCRM as an inter-organisational collaborative endeavour using quantitative and qualitative risk management methodologies to identify, evaluate, mitigate, and monitor unexpected macro and micro level events or conditions that might adversely affect any part of a supply chain. Their definition is built on the existing researches [10][7][6][11].

As a pioneer of studying risk management in the UK NHS pharmaceutical supply chain (PSC), Breen [12] investigated the thirty-five prevalent risks existing in the whole process. Those identified risk factors have been divided into three distinct sections: supply chain structure, controllability, and strategy. The fragmentation of the supply chain has the highest rating due to a lack of uniformity in decision making within the PSC. This was followed by the lack of visibility of stock, unexpected increases in demand, demand versus capacity, and lack of information, which also have high ratings. Maryland [8] highlighted the collaboration among all stakeholders involved in the healthcare supply chain is needed to ensure a reliable supply chain operations. A system dynamics model for assessing supply risk impact on medicine supply chain in Colombia[13]. The finding point out some of the main problems in the Colombian health systems are related to the availability of essential medicines. Kanyoma et al. [14][15] investigated the role of single sourcing strategy in either exacerbating or mitigating persistent supply failure in Malawi's public healthcare delivery supply chain. Elleuch et al. [16] proposed a SCRM framework to support the decision making process by comprising of different techniques and specialized procedures by using Failure mode effects and criticality (FMECA), Design of experiment (DOE), Discrete event simulation (DES), AHP and Desirability optimization. Zepeda et al. [17] investigated the potential mitigating effects of affiliation with multi-hospital supply chain systems for managing hospital inventory levels. For the cold chain in healthcare sector, Riley et al. [18] highlight the interaction and exchange of information between intra-organisational entities would positively affect organisations' warning and recovery capabilities. An official report produced by Lord Carter (2016), investigated the issues involved in the SC operations and provided the associated recommendations for the UK NHS sector. Five strategies for managing the unwarranted variations in the NHS supply chain were suggested as follows: collaboration, supply chain integration, outsourcing the non-core supply chain activities to a third party, NHS e-procurement strategy, and implementing information system technology. Moreover, some other researchers also indicated that building vertical inter-organisational relationships between an organisation and its suppliers is a key element to manage supply chain risk [19][20]. Limitations exist in the above articles. AHP has a subjective modelling process nature, which is a constraint to the results [21]. The historical data was used to determine the severity index, and the probability of the identified risk factors would not be reliable [16]. A common limitation of the above articles is the applied qualitative methods for risk factors identification [12][8][21][15], and they did not quantify the negative effects and severity of the risk factors. Therefore, there is still an immense need for exploring and ranking the most prominent risk factors in healthcare SC and suggesting concrete and feasible mitigation strategies to manage these risks in a stepwise manner.

The generic decision making process on the rank ordering based on the priority setting among a set of attributes. However, in reality it covers a wide variety of questions at multiple dimensions [22]. The decision making problem becomes complicated due to the broad variety and the complexity of the interrelationships among the attributes. There is a growing studies on adopting multi-criteria decision-making (MCDM) methods combined with fuzzy set theory in SCRM in general because of the multiple factor nature of supply chain risks. It is a powerful tool widely used for evaluating and ranking problems containing multiple criteria. Moeinzadeh and Hajfathaliha [23] developed a SC risk assessment approach based on the analytic network process (ANP) and the VIKOR methods to evaluate the risks through ranking the relative importance of the risk categories. Wang et al., [24] applied fuzzy Analytic Hierarchy Process (FAHP) to assess risk of implementing various green initiatives in the fashion industry. Since a single method is not sufficient to solve the problem involving complex decision variables, thus it is strongly required to apply an integrated MCDM method under fuzzy environment. Samvedi et al., (2013) applied fuzzy AHP and fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) to quantify the risks in a supply chain, and aggregated the values into a comprehensive risk index. Similarly, Nazam et al., [25] proposed a hybrid model to rank and assess the risks associated with implementation of green supply chain management (GSCM) practices under the fuzzy environment using fuzzy AHP and fuzzy TOPSIS approaches. Based on the existing researches, the MCDM method can be considered as the best approach for solving the problem under study of managing the risks and suggesting the most efficient mitigation strategies in healthcare supply chain. Contrary to applying single method, the integrated model would facilitate the decision making in a comprehensive way across the whole SCRM process, AHP is able to decompose an unstructured risks into a reliable hierarchic structure and enables the decision makers to determine their weights by conducting pair-wise comparisons between each risk factor in an intuitive way. Afterwards, an admissible consistency ratio (CR) is applied to validate the consistency of the decision-making process. TOPSIS is characterized by its simplicity and has capability to maintain the same amount of steps regardless of problem size. The risk mitigation strategies are compared with those ideal and negative solutions to find out the distances. A sensitive analysis is also provided for a deeper comprehension results reliability. Moreover, ISM is used to facilitate AHP method to get the overall understanding of complex interconnections of each risk factor in risk assessment stage. Therefore, this paper aims to provide the practical decision support tool to address the industrial needs and also introduce a new SCRM framework as a guidance for the future research in healthcare industry.

Interpretive Structural Modelling (hereinafter, "ISM") is a qualitative and interpretive method that supports the decision-making process to identify the structure of complex relations of elements by analysing two elements pair-wisely

[26]. The structural mapping of the ISM model provides decision makers with the solutions to complex issues by highlighting the interconnections of elements in a graphical manner. It is seen as an interactive learning process by considering different direct and indirect relations among each risk factor so that complex interconnections of risks can be portrayed within a model. In fact, knowledge of individual risks alone may not be enough for an organization planning to understand the relationship between the various risks. In this respect, ISM can provide insightful understanding of those relations to describe the situation more accurately than the individual risks taken in isolation [5]. In SCRM studies, ISM has been applied by several researchers focusing on various problems [27][5][28].

Additionally, the model is appropriate for use in capturing experts' practical experience and knowledge for modelling and to portray a structure in a carefully designed pattern. In this paper, the ISM model is applied to determine the interdependencies among the selected risk factors from the last phase and obtain a hierarchy to synthesize the knowledge about these risks. It will facilitate the decision makers in easily understanding the dependence and driving power of those significant risks in their SC network while formulating the appropriate risk mitigation strategies. Decision-Mking Trial and Evaluation Laboratory (DEMATEL) can be another approach used to develop relationships between the various elements but requires selection of a threshold value to generate impact diagraph map. DEMATEL and ISM are similar as both use diagraphs. DEMATEL can divide the factors into cause group and effect group. In this paper, the author are not particularly focused on dividing the risk factors into cause and effect groups, but pay more attention on how interaction between each risk factor, thus ISM is considered to be the most appropriate methodology for this research.

There are several steps that are involved in ISM modelling, which include the following:

Step 1 Construction of structural self-interaction matrix (SSIM) by pairwise comparison. It is through such a matrix that the pair-wise relationship accorded for the system's elements is established. In this stage, the experts are required to make the decision upon which one element leads to another one. Keeping in mind the contextual relationship for each element, the existence of a relation between any two sub-elements ($i\, and\, j$) and the associated direction of the relation is questioned. Four symbols are used to denote the direction of the relationship between the elements $i\, and\, j$:

V – for the relation from $i\; to\; j$ but not in both directions;
A – for the relation from $j\; to\; i$ but not in both directions;
X – for both direction relations from $i\; to\; j$ and $j\; to\; i$; and
O – if the relation between the elements does not appear to be valid.

Step 2: Developing a reachability matrix from the SSIM and checking for transitivity. The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting 1 or 0 for the original symbols, *V, A, X* and *O*. The rules for the substitution are the following:

(1) If the $(i\,,j)$ entry in the SSIM is *V*, then the $(i\,,j)$ entry in the reachability matrix becomes 1 and the $(j\,,\,i)$ entry becomes O.
(2) If the $(i\,,j)$ entry in the SSIM is *A*, then the $(i\,,j)$ entry in the reachability matrix becomes O and the $(j\,,\,i)$ entry becomes 1.
(3) If the $(i\,,j)$ entry in the SSIM is *X*, then both the $(i\,,j)$ and $(j\,,\,i)$ entries of the reachability matrix become 1.
(4) If the $(i\,,j)$ entry in the SSIM is *O*, then both the $(i\,,j)$ and $(j\,,\,i)$ entries of the reachability matrix become O.

Following these rules, the initial reachability matrix for the elements is built. Then the final reachability matrix is developed by incorporating the transitivity which is a basic assumption in ISM. It stated that if element A is related to B and B is related to C, it may be inferred that A is related to C. If element $(i\,,j)$ of the initial reachability matrix is zero, which means there is neither any direct nor indirect relationship from element i to element j. The initial reachability matrix may not have this characteristic because when there is no direct but an indirect relationship from element i to j, entry $(i\,,j)$ is also zero. Indirect relationships can be found by raising the initial reachability matrix (with diagonal entries set to 1) to successive powers until no new entries are obtained [29].

Step 3: Ensuring that the reachability matrix is appropriately partitioned into several levels. In this stage, two different sets (reachability and antecedent sets) can be obtained from the final reachability matrix by level partitioning. The purpose of this step is to facilitate the construction of the diagraph from the reachability matrix [26]. The reachability set R (S_i) consists of the element itself and other elements which are reachable from S_i, whereas the antecedent set A (S_i) consists of the element itself and other elements that may impact it. Thereafter, an intersection of the reachability set and antecedent set (R(S_i) ∩ A(S_i)). The element for which the reachability and the intersection sets are the same occupies the top-level position in the ISM hierarchy. The top-level element in the hierarchy has no relation to any other elements above its own level. Once top-level elements are identified, they are discarded from the other elements. The same process is then repeated until the levels of all elements are achieved.

Step 4: Drawing of diagraph with removed transitivity links. An initial diagraph including transitivity links is found from the conical form of the reachability matrix. Then, by partitioning the reachability matrix by rearranging the elements according to their level, the appropriate conical matrix is achieved. That means all the elements having the same level are pooled. For the sake of simplicity, sketching the final digraph in relation to the affiliations identified in the reachability matrix and ensuring that transitive links are removed. If there is a relationship between risk i and j, this is shown by an arrow which points from i to j.

Step 5: Conversion of diagraph with removed transitivity links. Translating the resultant digraph into an ISM-based model. This can be done by putting statements in places of element nodes. Finally, the ISM model is reviewed to check conceptual inconsistency.

Step 6: MICMAC analysis. MICMAC stands for Matriced'Impacts Croisés-Multiplication Appliquée a'un Classement, which means "cross-impact matrix multiplication applied to classification". The object of the

MICMAC analysis is to assess the driving power and dependence of each element. All elements have been classified into four categories based on their dependence and driving power:

(1) Autonomous elements, which have weak driver power and weak dependence.
(2) Dependent elements, which have weak driver power and strong dependence.
(3) Linkage elements, which have both strong driving and dependence power.
(4) Independent elements, which have strong driving power but poor dependence power.

B. *Proposed framework and Application of MCDM in SCRM*

The aim of this section is to validate the feasibility and reliability of the presented integrated framework (Figure 1) in a real context of healthcare industries, and obtain the valuable viewpoint from industrial and academic experts who are extensively involved in the related fields on healthcare and supply chain management in both UK and China.

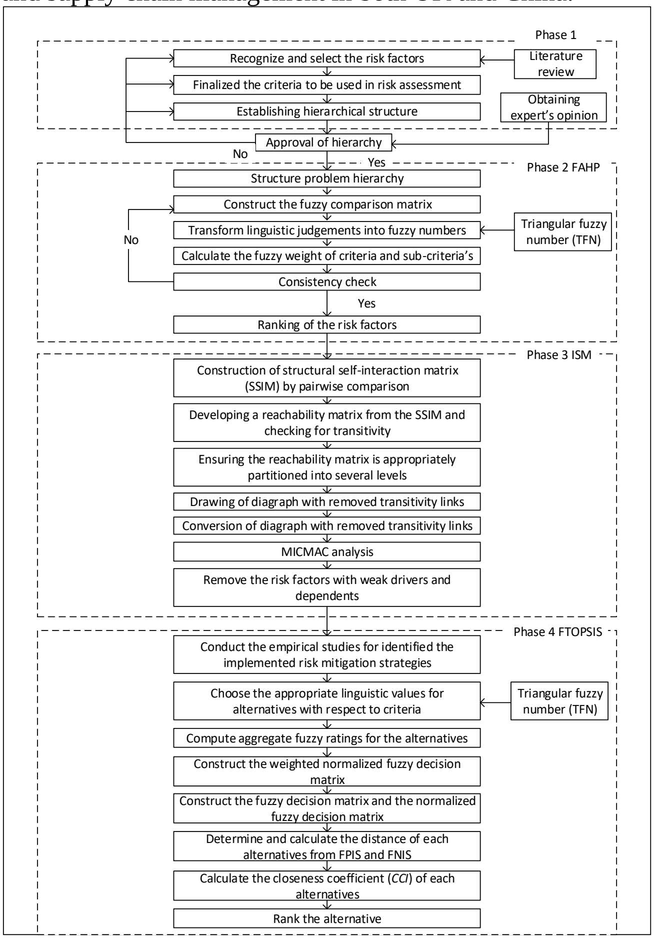

FIGURE1PROPOSED FRAMEWORK OF HEALTHCARE SC

The oversharing goal of this paper is to point out the top priority risks, analyses the interdependence of each risk factor, and select the best mitigation strategies for managing those identified risks in healthcare supply chain. In order to fulfil this aim, the proposed framework for this paper is composed of fuzzy AHP, ISM and fuzzy TOPSIS methods as shown in Figure 1. The framework consists of four basic phases:

- *Phase 1: design of the study and risk factors identification.* In the first stage, both literature review and qualitative questionnaire survey are the risk factors identification methods which serves as a base and guide to build upon throughout the risk factors identification research process. The expert panel are established, consists of the experts from both academic and industrial fields. In this paper, it starts with the literature review and then an initial healthcare supply chain risk taxonomic diagram is developed. More specifically, the focus of the risk review needs to be defined in advance and an organized HCSC risk classification schema is mapped for creating a more complete picture of each stakeholder, responsibilities and three different kind of flows (i.e. material, information and cash flow) in the network. It provides an overview by enumerating all possible threats that could produce the adverse consequences for the SC performance. However, it is clear that not all risks are easy to find out. Feedback loops and dependent events chains often pose additional challenges for risk factors identification. Therefore, by conducting the qualitative survey, the obtained risks are analysed to verify the comprehensiveness and validation as well as to confirm the appropriateness of risk classification method. Besides this, an initial assessment is conducted to quantify the important level of identified risks as this paper only focuses on those risks requiring most attention by experts.
- *Phase 2: fuzzy AHP model for the determination of the weights of risk factors in healthcare setting.* In this stage, the fuzzy AHP method is applied to calculate the weight of each risk factor. The initial pairwise comparison matrices are constructed to obtain the criteria and sub-criteria weights based on the scale. Afterwards, every preferences made by the individual respondent were aggregated into a group preference for each risk factor in order to construct the final pairwise comparison matrix. The aggregation of the triangular fuzzy numbers (TFNs) were performed by applying the mathematical method, namely Geometric Average method. Finally, the weights of the criteria and sub-criteria are calculated based on this final comparison matrix as described in the previous section.
- *Phase 3: ISM model for the understanding of the interdependencies of risk factors in healthcare setting.* It needs to be mentioned that using quantitative or qualitative risk assessment methods solely is inadequate for prioritising risks [25], as the main drawback of employing fuzzy AHP is that it cannot examine the contextual relations between each variable. By contrast, in the ISM model, no weights are associated with the variables to take into account their relative importance. The model should combine both numerical and graphical results. In this stage, ISM model is used to investigate the inter-relationships among each risk factor.
- *Phase 4: identification and evaluation of the related mitigation strategies in healthcare setting (fuzzy*

TOPSIS). This paper focuses on the current implemented risk mitigation strategies existing in both UK and China healthcare organizations. It provides the latest information that can reflect the current situation in both countries' healthcare industry. Especially, instead of identifying the risk mitigation strategies through a literature review, this paper explored the currently implemented strategies which turned out to be more reasonable in actual situations. Empirical studies were conducted in both UK and China healthcare industries to extract the appropriate number of mitigation strategies for further evaluation. The studies were conducted in three phases: (1) review of official documentation and other published materials, (2) direction observation, and (3) conducting semi-structured interviews. Afterwards, the fuzzy TOPSIS method is utilized to acquire the priority ratings of identified mitigation strategies for managing the associated supply chain risks. The linguistic values and related TFNs are used for the evaluation of strategies toward the risk factors. The ranking of strategies can be accomplished based on CC values obtained by fuzzy TOPSIS in descending order.

III. MANAGERIAL IMPLICATIONS

The proposed methodological risk management framework provides a comprehensive and systematic way to define priorities and interdependency among risks in healthcare SC alongside mitigation strategies to manage these risks. The risk assessment results show that, "Shortage of drug, unavailability of drugs on the market (S4)" with global weight of 0.160 has the highest risk compared with other risk items, followed by "counterfeiting (S1)"; "poor IT system, lack of data standardization (S8)"; "capability versus demand; inability of capacity to meet demand (S5)". As these factors have the significant impact on supply chain operational performance, the uncertainty associated with these factors will make the supply chain more complex to manage. Therefore, proper care to the above concerns could help managers in designing a more robust and responsive supply chain. It is not surprising to see "shortage of drug, unavailability of drugs on the market (S4)" at the top of the risk ranking because unlike other consumer products where the customer can either defer their purchase or acquire an alternative, shortage of drugs can adversely affect patient outcomes and increase health care costs. "Counterfeiting (S1)" is the second most risky factor, which can be defined as drugs sold under a product name without proper authorization, where the identify or the source of the drug is knowingly and intentionally mislabelled to suggest that it is an authentic Food Drug Administration (FDA) approved product. The results also support some existing findings, *e.g.*, findings from [26][27] and [28][29], that determined that counterfeiting also has serious risk consequences among other risk factors, especially when hospitals depend on third Furthermore, the difficulty faced by UK National Health Service (NHS) trusts is that the available data in a large volume whereas quality information is in short supply. In fact, in the NHS database, there are 130 different information descriptions for a single product. Therefore, to promote operational improvement and healthcare supply chain integration, standardisation is of concern. Implementation of supply chain standard data contributes to information synchronisation so that all stakeholders in the industry can speak the same electronic language. The developed risk-based model can be simply established at various hierarchical levels according to the needs of users and existing data. Additional, it can aggregate various groups of risk factors along with a consistent order to generate useful risk-based information for decision makers. It can be simply applied on the other risk factors not mentioned in this study (such as patient pathway related risks, *etc*).

By applying ISM model, the result provides an understanding of identified risk factors in different levels of ISM hierarchy model and the cluster in MICMAC diagram. In order to facilitate prioritization of the risks for the decision-making process, the developed hierarchical ISM model contains all types of risks starting from the highest to the lowest in different levels. Accordingly, this mapping of inter-relationships is a useful method for supply chain risk managers to evaluate supply chain risks and learn about the impact chains of these risks [30]. Thus, understanding the impact of risks at each level is indeed important as it will help managers to construct and implement successful risk management strategies towards achieving the efficacy of the healthcare supply chain management [31]. The developed hierarchical ISM model comprises 11 risk factors. Among the 11 risk factors, "poor quality in the purchased drugs from suppliers" and "dispensing/picking errors" were placed on the top level. These are the risks that can produce a major impact on healthcare SC systems. The findings agree with that of Liu *et al.'s* [15] findings that the lack of skilled staff and handling material could lead to the human error in handing or storing of drugs. One re-occurring issue was the larger number of patient transports made by nursing staff, despite it being the transportation departments' responsibility [32]. The transportation department was perceived as lacking the capacity to handle all transports and often late with deliveries, thus the nurses were forced to carry out transportation which is time wastage and the products are likely to be spoilt hence increasing chances of errors. Meanwhile, automatic transport systems are introduced as a founding principle for current hospital logistics, such as automated guided vehicles (AGVs) that handle the major part of all deliveries of food, linen, waste, and goods, while pneumatic dispatch systems are used for samples, blood, and medicine shipments. Furthermore, lower level risks like "clinician's preference" and "high produce and supplier/brand variety" have strong influence to the middle-level risks like "counterfeiting", "shortage of drugs", "capability versus demand", "high purchase price", "weak logistics service infrastructure", "poor IT system", and "lack of visibility concerning placement and availability of stock". Also, the aforementioned middle-level risks again seen to influence the top-level in the ISM model. In terms of lack of visibility concerning placement and availability of stock, one purchase and supply manager in hospital during the telephone interview stated:

"*There are various challenges that are faced by our organization, such as lack of space for storage, the procedures needed the involvement of clinicians, wastage of* *products and lack of traceability as well as product visibility. We are highly concerned with inventory management because the fluctuated level of stock, product identification was difficult, and storage was spread across the hospital. Thus, these problems prompted us to adopt an innovative inventory management system…'* Top-level factors are more risky than the others and can cause serious consequences for supply chain systems. Nevertheless, lower level factors are mainly responsible for increasing the degree of risk exposure as they have strong influence to the top-level factors. In this regard, it is worth noting that interdependency among various risk factors plays an important role in the assessment of risk impact on the healthcare supply chain performance.

MICMAC analysis was carried out by classifying the 11 risk factors into four clusters comprising autonomous, dependent, linkage, and independent, based on their driving power and dependence power. The risk factors are namely, "poor quality in the purchased drugs from suppliers" and "dispensing/picking errors" are dependent factors. The impact of these risks depends on the remaining risks of the healthcare supply chain and seriously affects the supply chain system. Similarly, the risk factor "clinician's preference" has been found independent with strong driving power: it plays a key role in influencing others and finally intensifies to the strength of its impact on the healthcare supply chain system. The remaining risk factors are clustered as linkage risks with both strong driving and dependence power. Those should be assigned as high priority and the manager should understand the dependence of these risks on lower level risks, in achieving the risk management objectives. Autonomous risks are weak driving power and dependence power and lack influence on the supply chain system. In this paper, no risk factor in this cluster. Thus, all the risk factors should be included when determining the relevant risk mitigation strategies in next phase. As a result, this cluster analysis provides valuable insight into the extant body knowledge to the researchers to understand and assess the intensity of risk factors as well as to manage these risks by implementing an effective risk management strategy.

Choosing the appropriate risk mitigation strategies is deemed to be an important step in mitigating supply chain related risks. Although the hospital managers did not realized that they had similar approaches to ensure the supply chain operates more efficiency. Instead of identifying the relevant mitigation strategies based on the literature review, in this paper, the current implemented management strategies were identified as the risk management solutions through empirical studies. Thereafter, the Fuzzy TOPSIS method was employed to rank the importance levels of those mitigation strategies in relation to 11 risk factors. The mechanism of the Fuzzy TOPSIS model was to analyse twenty experts' subjective judgements. It is an appropriate tool to help MCDM under a fuzzy environment where the available data is subjective and vague. Moreover, these strategies also consider all potential risks and the effectiveness of individual strategies in mitigating these risks. It provides a practical decision support tool for taking explicit account of multiple types of risk in aiding decision-making, and compares and ranks alternative strategies in indicator basis individually. To change any management practices or implement any new strategies would require significant additional resources and time before they can commit to investing in the new practices. Theoretically speaking, the costs for implementing these strategies can be viewed as "insurance premiums" that will safeguard the supply chains from major disruptions. However, it is difficult to quantify the return on these insurance premiums, especially in the absence of reliable data (probability that a disruption would occur, potential loss due to a disruption, etc.). More importantly, the healthcare industry is currently under increasing pressure to reduce costs while maintaining the quality of care. The decision of adopting appropriate mitigation strategies requires a trade-off between cost saving and the benefits of implementing such strategies. Therefore, the alternatives with the highest ranking should be given the priority in formulating the strategic plan, *i.e.* strategy A2, "developing advanced information technology and system" and strategy A5, "implementing eProcurement strategy."

Furthermore, through our interview with the hospital managers, the major challenge of implementing those strategies is to have supply chain risk management become a part of the job responsibility across different departments with all functions involved collaborating and communicating effectively. The use of the tool as a cross-functional risk mitigating and monitoring process should be considered as a long-term objective. And as such, the involvement of top managers from different areas is essential in establishing a thorough consideration of critical issues and interdepencies in determining a complete supply chain risk management process. In addition to this, Van Vuuren [30] stated that the success of a strategy is related to the congruency between organizations' strategies and culture. Risk management culture is embedding formally risk management within the decision-making processes at every level of the company operating within the culture of the organization. It is emphasized that risk management culture can impact on manager's ability to process risk and disruption information, rationalize and exercise discretion in their vulnerability mitigation decision-making processes. The risk management culture within an organization is important to transform vulnerability awareness into mitigation actions. Therefore, hospital managers should give importance to risk management culture, which can become a tool to provide the legal path for risk decisions in a supply chain operation.

More especially, the strategy A2, "developing advanced information technology and systems" provides enabler for managing the healthcare supply chain to increase visibility, traceability and security. As mentioned earlier, advances in interoperability standards and other technology tools, the advanced information technology and system helps in facilitating the aggregation as well as ensuring a timely exchange of useful data among the stakeholders in the supply chain. This, in turn, could provide a rich pool of data to support regulation and oversight of the medicine delivery system from the initial to the end. Instead, paper-based systems are still be common at most hospitals, which are all but "drowning" in paperwork. Therefore, it requires an effort to develop an infrastructure capable of connecting, integrating and supporting various information systems as well as applications at health facilities nationwide. In spite of the demonstrated benefits, financial constraints in many hospitals means creating different systems for different settings is not feasible. The challenge will be generating a flexible system, duplicable for various circumstances without investing extra resources. Further, the benefits of developing new information technology and systems are not immediately visible, but the costs are. For instance, the cost of an RFID tag can range from £950 to £1,150 per reader. As the fully functioning RFID system requires tags, readers, infrastructure, middleware, and printers and can cost a hospital millions of pounds. However, a significant resistance to adoptation of technology and changes in work processes and reluctance in the division of labour among health care specialists is actually existing. There is a significant impact in implementing technologies and tools that can only be realized if management can persuade the supporting staff to change their work practices and organization.

Furthermore, strategy A5, "implementing eProcurement strategy" is one of the most effective ways to facilitate the order and demand information among each member in the chain. As such, it is critical for hospital managers to ensure that they share the integrated system with supplier under the same standard (*i.e.* global GS1 coding and PEPPOL messaging), which as a consequence, will be more collaborative than conducting the traditional approach for the procurement procedure. Employing e-procurement process means that the healthcare provider must simplify the existing procurement procedure and shorten the administration lead time. Beyond the benefit that comes from the efficient operation process and enhanced collaboration among trading partners, the strategy also drives patient safety benefits. Automatic Identification and Data Capture like barcodes based on the GS1 standards, can now be accessed and read at any point in the supply chain process. This enables them to quickly locate the safety alert regarding the product. Besides the benefits, there is a significant up-front cost and the continuing costs of implementing this practice are particularly burdensome for small-size hospitals or individual healthcare providers. The relevant costs include the cost of hardware, software and technical support and also the costs of intensive staff training. Hence, this is a considerable limitation to currently implementing the strategy at the national level.

The least important is strategy A6, "outsourcing the non-core supply chain activities to the 3rd party logistics service provider." The healthcare organizations benefit more through outsourcing expanding activities beyond core and clinical activities and build an environment which is more cooperative with their suppliers. However, some healthcare organizations do not achieve the expected benefits from the outsourcing strategy because outsourcing activities are incredibly complicated and lack a formal outsourcing decision making process, such as medium and long-term cost-benefit analyses, reluctance to embrace any changes. Moreover, it also requires a decision on which activities should remain within the hospital or be outsourced, whether all or part of the supply chain activities should be outsourced, and also how to manage relationships with suppliers rather than internal functions and processes[33]. Another major issue that concerned by hospitals managers is losing good long-term employees if they outsource some functions. Hence, mistakes in identifying core and noncore activities can lead hospitals to outsource their competitive advantages, which are difficult to rebuild. Therefore, this may explain why this strategy became the least important one among the nine identified strategies

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