A Physics-Based Approach for Managing Supply Chain Risks and Opportunities Within Its Performance Framework

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Abstract. Managing a Collaborative Network (such as a supply chain) requires setting and pursuing objectives. These can be represented and evaluated by formal Key Performance Indicators (KPIs). Managing a supply chain aims to stretch its KPIs towards target values. Therefore, any Collaborative Network's goal is to monitor its trajectory within the framework of its KPIs. Currently potentiality (risk or opportunity) management is based on the capacity of managers to analyze increasingly complex situations. The new approach presented in this paper opens the door to a new methodology for supply chain potentiality management. It offers an innovative data-driven approach that takes data as input and applies physical principles for supporting decision-making processes to monitor supply chain's performance. With that approach, potentialities are seen as forces that push or pull the network within its multi-dimensional KPI space.

Keywords: risk management, opportunity management, supply chain management, and physics.

1 Introduction

A Collaborative Network, as defined by [1], is a network of diverse entities (organizations or people) that are autonomous, geographically dispersed and heterogeneous in terms of their operating environment, culture and goals, but willing to collaborate together by exchanging information, resources and responsibilities in order to more easily achieve common goals. Moreover, [2] defines a supply chain as a network of organizations interlinking suppliers, manufacturers and distributors in different activities and processes in order to produce products and services delivered to the final customer. Considering these two definitions, a supply chain can easily be seen and described as a Collaborative Network.

Today's managers are faced with increasingly complex situations in an uncertain environment, especially in the management of risks and opportunities. Although there are already many tools at their disposal, most of them only allow them to visualize and format data related to potential risks and opportunities. The processing of the results provided by these tools is essentially based on the knowledge, experience and understanding of the tool by managers. Is this enough to manage a supply chain in an increasingly competitive market?

This paper claims that (i) the identification of objectives and metrics, and (ii) an intuitive tool to support decision-making are essential for managing efficiently a supply chain. These decisions make it possible to seize opportunities or keep out of risks in order to reach the targeted values of its objectives. This paper answers the following question: "*how to improve the management of a supply chain by piloting its trajectory in its performance framework where risks and opportunities are modelled by physical forces deviating it from its target trajectory?*". This paper is organized according to the following structure: Section 2 provides an overview of existing research works and scientific contributions relating to performance management and the management of elements disrupting the achievement of performance targets. Section 3 describes our physics based approach. Finally, section 4 mentions some perspectives.

2 Background

2.1 Performance Management

In today's world, supply chain management is essential for increasing organizational efficiency and achieving organizational goals such as improving competitiveness, profitability and customer service [4]. Performance measurement is a process that quantifies the effectiveness and efficiency of an action [5]. This process maintains various metrics (like KPIs) that are used to support decision making and management. Indeed, it is not possible to manage an organization without any measures [6]. Measurement is one of the most important activities in management. Most of the studies argue that performance metrics should be composed with financial and non-financial KPIs [6]. Some performance frameworks have been proposed such as: the balanced scorecard of Kaplan and Norton [6], activity-based costing of Anderson and Young [7], Neely's performance prism [8] and the Supply Chain Operations Reference (SCOR) developed by the Supply Chain Council [9].

Therefore, the management of a supply chain involves shaping and pursuit goals and objectives evaluated by formal KPIs. Evaluating supply chain performance is complex due to its multidisciplinary field and the number of actors with different perspectives that create many barriers such as: decentralized data, little cohesion in the chosen indicators, poor communication and no common decision [10]. [4] identified and suggested three levels of performance measurement according to decision making process: operational, tactical and strategic. In a synthetic study that reviewed the literature, [11] identified 27 key performance indicators for the supply chain. 50 percent of these performance metrics are linked to the internal business of the supply chain. The other 50 percent are related to the final customer.

2.2 Supply Chain Risk and Opportunity Management

Supply chain is impacted by predictable or unexpected events that threaten the achievement of its performance targets [12]. According to [13], there are a lot of source of risks (which originate from the operational part of a company or from the uncertainty of its external business environment). Moreover, due to the increasing complexity of manufacturing systems and the evolution of legal context which enforces companies to improve their maturity in this domain (for example the ISO 9001), risks management becomes a huge challenge [14]. Therefore, supply chain management needs to deal with them.

In this section the concept of risk and opportunity will be studied from the literature to deliver guidelines for their characterization. First of all, as described in [15], risk management process is divided in four steps:

- Risk identification: detection of risks by studying an organization and its environment with techniques and methodologies such as SWOT analysis or force field analysis [16].
- Risk Assessment: evaluation of the impact of the risk on the organization, it is divided in two parts: qualitative and quantitative analysis.
- Risk Response Strategies: avoidance, sharing, mitigation and acceptance.
- Risk Monitoring and Control: monitor the status of identified risks.

According to [16], the existing results and methods on the domain of risk management can be extended to the question of opportunity management. Thus opportunity management process can be divided in four steps:

- Opportunity identification: does not require any changes to the risk identification step, the same methodologies can be used. In the SWOT analysis, opportunities are taken into account. The force field analysis is a technique widely used in strategic decision-making to identify positive (opportunity) and negative (risk) influences in the achievement of goals [16].
- Opportunity Assessment:
  - A common quantitative analysis can be used to take both the positive and negative effects of uncertainty into account.
  - In [17], risk is defined as a combination of its impact on the organization and its probability of occurrence. So, this very used two-dimension framework can be used for the common qualitative analysis.

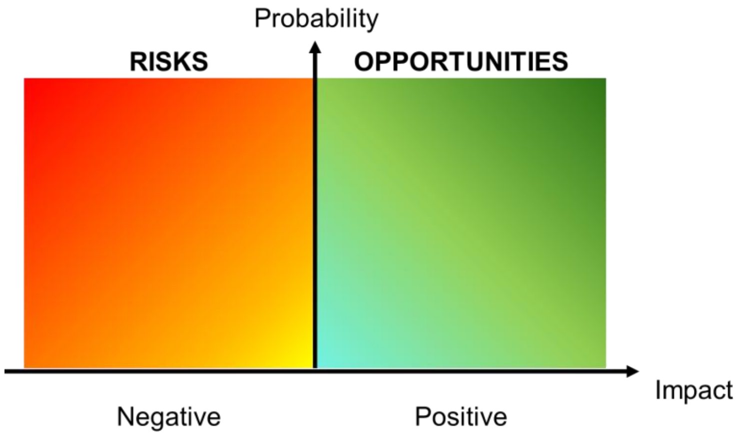

Fig. 1 Two-dimension framework for Risks and Opportunities analysis adapted from [18].

- Opportunity Response Strategies:
  - exploitation: this strategy is symmetrical to "avoidance" strategy, whereas "avoidance" seeks to decrease the probability of occurrence of a risk to 0%, "exploitation" seeks to increase this probability to 100% for an opportunity,
  - sharing: transfers a risk or an opportunity to another member of the network which is abler to deal with it,
  - enhancing: increases the probability and/or the impact in order to maximize the benefit of an opportunity (inversely, "mitigation" seeks to reduce the degree of exposure to a risk),
  - acceptance: no active measure to deal with a risk or an opportunity.
- Opportunity Monitoring and Control: do not require any changes to the risk monitoring and control step, the same methodologies can be used. It aims is to monitor the status of identified risks and opportunities, to identity new risks and opportunities, to ensure the proper implementation of the corrective actions put in place and to review their effectiveness [16].

As discussed in [19] risks and opportunities are very close. The existing research results on the field of risk management can be symmetrically extended to opportunity management. From our vision, both together are considered as potentiality management.

[20] advises managers to focus on two major activities of this four steps process: potentiality assessment and monitoring. Potentiality assessment is a critical and complex step because of the complexity of the models required and the subjective nature of the data available to conduct the analysis [21]. In the literature, many methods have been developed in order to assess and prioritize potentialities. According to [22], the top six of risk assessment tools in automotive supply chains are: cost/benefit analysis, business impact analysis, scenario analysis, environmental risk assessment, FMEA and cause and consequence analysis.

The necessity to rank many quantitative and qualitative conflicting criteria of a finite number of potentialities imposes to regard this problem as a multi attributes decision making (MADM) problem. According to ([21], [23], [24], [20], [25] and [26]), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) or Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) are MADMs largely used in the literature (see Table 1 for a short description of these methods). The ISO 31000 standard identifies more than thirty tools and methodologies for risk assessment [22].

Table 1. Short description of these MADMs:

MADM	*Description*
AHP	technique which can combine qualitative and quantitative factors for prioritizing, evaluating and ranking alternatives.
ANP	a broader form of AHP, structures a decision problem as a network.
TOPSIS	a compensatory aggregation method that compares a set of alternatives by calculating the geometric distance between each alternative and the ideal alternative.
ELECTRE	used to reject some alternatives to a multi-criteria problem.
PROMETHEE	allows to establish a ranking between alternatives based on a comparison pair per pair of possible decisions along each criterion [25].
MACBETH	the approach, based on the additive value model, requires only qualitative judgments about differences of value [26].

3 Proposal: A Supply Chain Management Physics-based Approach

The new approach presented in this paper offers a new and original method for supply chain management. This approach takes data as input and applies physical principles for supporting decision-making processes to control a supply chain's trajectory within multi-dimensional KPI space. This performance space (Figure 2) allows to locate the considered supply chain in terms of its KPIs and is composed of:

- the performance of the considered supply chain: its current performance according to selected KPIs (orange sphere),
- the target zone: a part of the performance space reflecting the current target of the considered supply chain in terms of KPIs (green sphere),
- the forces: these are the forces to model in the performance space in order to control supply chain performance (color vectors).

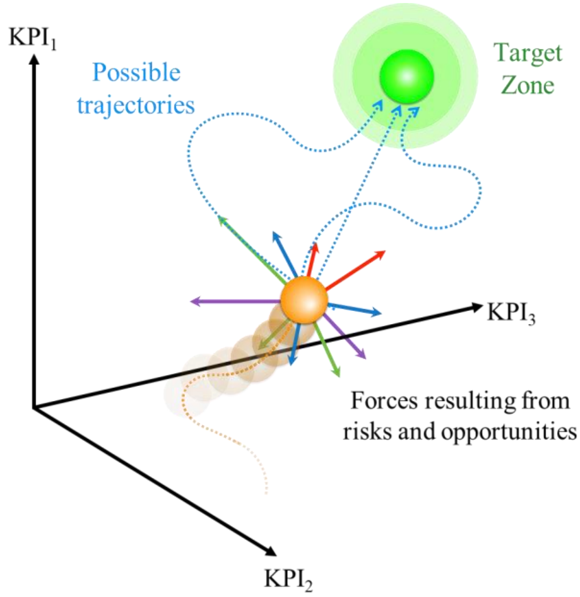

Fig. 2. Definition of target zone within the performance framework

The evolution of KPIs and therefore the evolution of the supply chain's position in its performance space are due to the occurrences of risks or opportunities, when they become actualities. Basically, a risk (a hurricane for example) will move the supply chain away from its objectives, while an opportunity (a new cheaper supplier for example) will bring the supply chain closer to them. Indeed, in the Figure 3 example, the fictitious considered supply chain is represented in the following performance framework: profit, lead time and product quality (respectively KPI_1, KPI_2 and KPI_3). Some of its suppliers are located in the Gulf of Mexico. They are therefore subject to a high hurricane risk. If its suppliers are hit by a hurricane, it is easy to imagine that the performance of this supply chain will be strongly impacted and degraded: profits will decrease and lead times will strongly increase due to impassable roads, damaged infrastructures and warehouses (violet sphere in Figure 3 represents its new position in its performance framework). Conversely, if this supply chain seizes the opportunity to source from a new cheaper Asian supplier but with a lower quality, the supply chain will thus move in its performance framework (green sphere in Figure 3). Its performance in terms of profit will be improved, while the quality of its products decreases.

Thus with that new approach, potentialities can be seen as forces that push and pull the system within its KPIs framework. Indeed, each force reflects the probable consequences of each identified potentiality. The obtained forces, in addition to their direction and intensity (given by the framework of the KPIs dimensions), are different types (please see [18], if you want more information about the four types of forces: internal, external, collaboration and gravity).

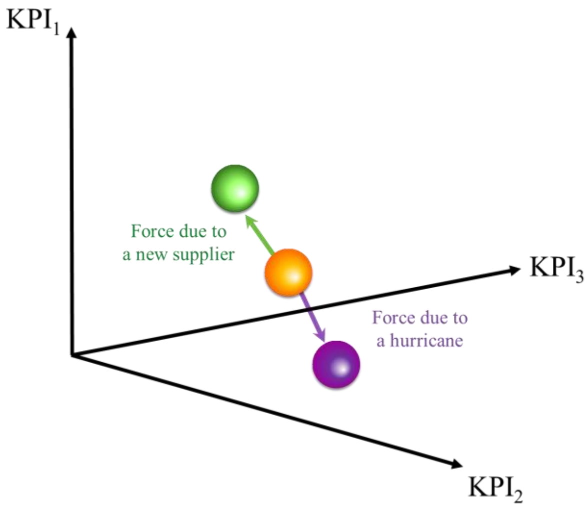

Fig. 3. Fictitious considered supply chain within its KPIs framework

In order to realize links between KPIs and forces and to be able to observe the impact of forces on the KPI values, forces and KPIs will be modeled by functions of attributes. These attributes characterize and describe the supply chain. They are divided into three categories:

- Internal: attributes that characterize the company we are focusing on (capacity, number of employees, ...),
- External: business environment-related and location-related attributes (new laws, environmental hazard, …),
- Interface: attributes that characterize the different partnerships of the considered organization (customer demand, lead time of suppliers, ...).

Moreover, this framework can be seen as a decision framework and used to define target zone. An in-depth analysis of the attributes impacted by the identified forces will make it possible to define the lever attributes for decision-making. And thus, find the best possible strategies to reach the target zone. This target zone corresponds to the area of the KPI target value space. The requirements and objectives of the various stakeholders will take into account in this zone. By the intensity of the identified forces, one can study how to define the best compromise between the best combination of potentialities and the required effort to join the target zone (possible trajectories in Figure 2). Indeed, the intensity of the forces will modify over time the values of the attributes, thus modifying the value of the considered KPIs.

4 Perspectives & Conclusion

The presented approach opens the door to an innovative vision for supply chain management and decision making. The following list is the roadmap to turn that approach into a workable practice:

- In the short term, the bulk of the work is to design and to develop the fictitious supply chain simulation model of a famous commercial aircraft manufacturer using Anylogic software. The goal is to perform multiple simulations of the various potentialities (risks and opportunities) that the aircraft manufacturer's logistics network may face. Indeed, for example, rising and falling demand or stopping the manufacture of a model, which offer the possibility to study their impacts on its supply chain and its performance. In addition, as defined in the article [18], there are four types of forces. Therefore, in a first step, the impacts of the potentialities modelled by each type of force will be studied separately. After multiple simulations of the model, regressions will be performed on the obtained KPIs values. These regressions aim at identifying the impacts on the KPIs of these macro events (potentialities) represented by specific micro-consequences (for example: "*between 20% and 30% of the delivery trucks will face a 2 to 3 hours' delay*" [18]). And thus, subsequently be able to study the movement and trajectory of the considered supply chain in its performance framework. The last step will consist in repeating this process, but simultaneously simulating all the considered potentialities. This last series of simulations will enable us to answer the two following points.
- The study of independence or not of the forces in order to determine accessible KPI space areas and efforts to join these areas (analogies with the work of a force and kinetic energy could be exploited).
- How to characterize a force and a decision in terms of time (i.e. over what period of time this strength applies, how much time a manager has to take a decision in order to avoid a risk or to seize an opportunity, what is the time frame to implement a decision, ...), costs, reversibility, confidence and type (impulse, progressive, continue, ...).
- Taking into account the notions of robustness and resilience of the supply chain in decision making. As defined in [27], supply chain robustness "refers to the ability of a supply chain to withstand disruption and continue operating" and supply chain resilience "references the ability of a supply chain to bounce back from disruption".
- The objective is to develop with this new approach an intuitive and dynamic decision support system where managers are able to pilot the trajectory of the supply chain in its performance framework. So, to be able to observe and visualize the supply chain within its multidimensional KPI space is already a hard challenge. Indeed, its performance framework will surely consist of more than three dimensions. Therefore, we need to find a visualization system: allowing us to abstract ourselves from this problem of representing an n-dimensional space and that is dynamic and intuitive. Thus, Virtual Reality is considered a potent medium for supporting such visualization.

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