Title: Quantitative framework for managing value, risks, and opportunity of a supply chain

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Abstract
This study develops a framework for monitoring supply chain Value, Risks, and Opportunity in terms of the key attributes affecting the stakeholders. Doing so provides organizations with a method to filter, organize, and analyze essential information to facilitate better supply chain planning and control.

Keywords: Supply chain risk management, Value management, Opportunity management

Introduction

A supply chain involves moving either a product or service from supplier to customers through a network of organizations, people, activities, information, and resources (Stadtler, 2015). Components, natural resources and raw materials are transformed by supply chain activities in order to ensure that the end customer will be able to receive the finished product or service. In some occasions, used products with certain recyclable residual value may be reintroduced back into the supply chain at any point which gives rise to more complex supply chain systems.

Nagurney (2006) proposed that supply chains link value chains because a supply chain is also otherwise known as an industry value-chain: a physical representation of the various processes involved in creating product or service, beginning with components, natural resources and raw materials, and ending with the delivered product or service. Similarly, Porter (2008) noted that a value chain is a chain of activities that a company with its operations in a specific industry executes in order to deliver a valuable product or service for the market which is analogous to the definition of a supply chain. His idea of the value chain is based on the process view of organizations which implies the idea of seeing manufacturing or service organization as a system, made up of subsystems each with inputs, transformation processes and outputs.

Therefore, a supply chain should create value but uncertainties will definitely hinder the routes to this destination. In light of this information, this study proposes the use of value management techniques for supply chain management. However, traditional methods such as earned value management focus on time and cost (Fleming and Koppelman 2006) which is not suitable for applications to supply chains because they failed to account for uncertainty, risk, and opportunity. Thus, it will be of value to have an integrated approach that can also account for these. This paper presents the concepts of a framework for quantifying and monitoring supply chain risk and value in terms of the key attributes affecting the stakeholders. Doing so provides organizations with a method to filter, organize, and analyze essential information to facilitate better supply chain planning and control.

Supply Chain Value, Risks and Opportunity Framework

This section presents the components of the framework and integrates them. Supply chain goals and capabilities are the two major components which are introduced separately and then combined to yield supply chain risk and opportunity metrics and value gaps. The supply chain goals, capabilities, risks, and opportunities are evaluated with respect to each key performance attribute.

I. Supply Chain Value

It is crucial to make a distinction between the four aspects of supply chain value: desired, actual, goal, and likely values. First, stakeholders would expect a certain amount of value from the supply chain, which can be defined as the supply chain's desired value. Second, at a certain predetermined time point (For example: End of financial year), the supply chain realizes and provides a certain amount of actual value which may or may not match the stakeholder's desired value. Third, goals are chosen (deadline, budget, and requirements) sometime before the end of the financial year (For example: Beginning of financial year), if met, would yield an amount of value called the supply chain goal value. Fourth, at any time before the end of financial year, whether the supply chain will meet its goals is uncertain, so the actual value exits only with certain likelihood. However, uncertainties in its capabilities and outcomes would reduce as time goes on, and its likely value evolves towards its actual value, and hopefully approaches the goal value. It is also not uncommon for supply chains to have changes in the goals, making the supply chain's goal value a moving target. Thus, the stakeholder's desired value might not be achieved by targeting for the wrong set of goals.

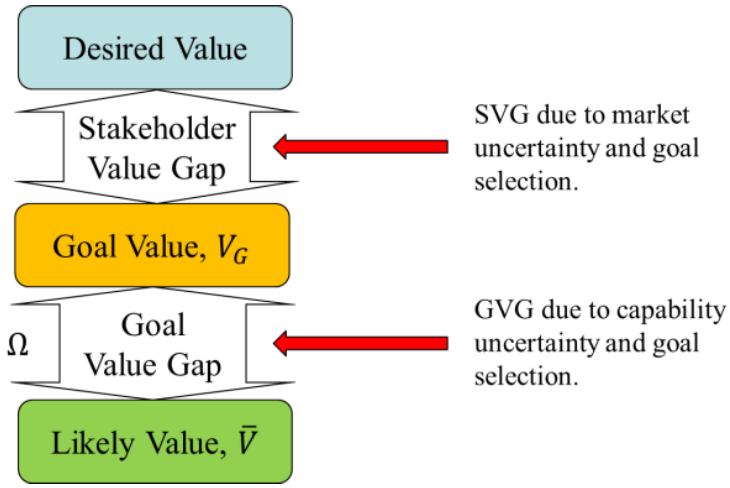

Figure 1 –Setting the goal value "bar" adapted from Browning (2014).

Figure 1 illustrates the relationship between desired, goal, and likely values (Browning 2014) at the beginning of financial year for the supply chain. The goal value gap (GVG) exists when there is a variation between the supply chain's goal and likely values. This can also be interpreted as the supply chain's risks of not performing up to its goals, given its capabilities. At the end of the financial year, the supply chain will be considered as successful if it achieves its goals and its actual value equals its goal value. But achieving the goal value when the wrong goals are chosen might not necessarily satisfy the stakeholders (i.e. the goal value "bar" might have been set too low). Similarly, a stakeholder value gap (SVG) exists when inadequate goals are selected. The SVG represents any difference between a supply chain's chosen goals and the goals its stakeholders really desire and is sometimes referred to as market risks (Shenhar 2004) which cannot be perfectly known a priori. Thus, SVG is not considered in details, in order to merit discussion in this paper.

Depending on the value "bar" settings, GVG and SVG changes accordingly: easy (hard) goals decrease (increase) the GVG while increasing (decreasing) the SVG. Consider the analogy by Browning (2014) of a high jump competition where each jumper's capability to achieve a specific height is represented as a probability distribution across a range of potential outcomes with their own distribution of outcomes and expected capability. However, depending on the jumper's consistency, there is a possibility that the results might be better or worse on the actual match day. The risk of not being able to clear the bar is dependent on two components: jumper's capability (likely value) and the height of the bar (the goal value). Choosing to set the bar low (small GVG) implies a low probability of failure (and a high probability of success) vice versa. The risk of failure (and GVG) increases when the bar get rose higher increases the jumper's probability of achieving results beyond the goal value, leaving an avenue for opportunity value and perhaps not providing the *desired* value of winning the competition (a large SVG).

II. Identifying Performance Attributes

Initially, it may be challenging to determine an appropriate set of prominent, discriminating attributes that account for the bulk of stakeholders' value. However, there are various supply chain models in literatures, which address both the upstream and downstream sides such as: Supply-Chain Operations Reference Model by the Supply Chain Council (Council 2012), and the Process Classification Framework by the American Productivity and Quality Centre (Cragg et al. 2007).

The model of particular interest in this study would be the Supply-Chain Operations Reference Model (SCOR) endorsed by the Supply Chain Council (SCC). SCOR has become the cross-industry de facto standard diagnostic tool for supply chain management. SCOR measures total supply chain performance because it is a process reference model for supply-chain management, spanning from the supplier's supplier to the customer's customer. It includes delivery and order fulfilment performance, production flexibility, warranty and returns processing costs, inventory and asset turns, and other factors in evaluating the overall effective performance of a supply chain.

Performance attributes are usually linked to a corporate strategy. Each of them consists of one or more measurements, also known as Level 1 metrics. Level 1 metrics may be branched out into the lower level or level 2 metrics for more control of particular processes. The example of the metrics decomposition will be shown as follows in Table 1:

Table 1 – SCOR Metrics adapted from (Council 2012)

Scor Metrics

Performance Attribute	Level 1 Metric	Level 2 Metric
Supply Chain Delivery Reliability	Delivery Performance	No metric decomposition
	Perfect Order Fulfillment	No metric decomposition
Supply Chain Responsiveness	Order Fulfillment Lead Times	Customer authorization to order entry complete Order entry complete to start manufacturing Start manufacturing to manufacturing ship Manufacturing ship to order received at W/H Order received at W/H to order shipped to customer
Supply Chain Agility	Supply Chain Response Time	Re-Plan Response Time Source Response Time Make Response Time Deliver Response Time
Supply Chain Costs	Total Supply Chain Management Costs	Cost of Goods Sold Order Management Cost Material Acquisition Cost Planning Cost Inventory Carrying Cost IT Cost for Supply Chain
	Warranty / Returns Processing Costs	Return Authorization Processing Cost Returned Product Warehouse Cost Returned Product Transportation Cost Warranty Cost
Supply Chain Asset Management Efficiency	Cash-to-Cash Cycle Time	Inventory Days of Supply Days Sales Outstanding Days Payable Outstanding
	Asset Turns	No metric decomposition

The value of the supply chain outcome can be modelled as a vector, ϑ, of n performance attributes, φ. Over time, firms can refine the set into the basis for a more personalized model with the integration of techniques such as Value Stream Mapping (VSM) and Design Structure Matrix (DSM). This area definitely constitutes one of the important components for future research.

III. Quantifying Supply Chain Value

Every performance attribute selected must contribute value to the supply chain in one way or another. Von Neumann and Morgenstern (2007) utility theory may be utilised to model how a single-attribute utility function describes the variation in stakeholder value as a function of the attribute's performance level under the assumption that the performance of all the other attributes are reasonable. There will be three main types of value functions for a holistic consideration: Best to Increase (BI), an increasing function such as delivery reliability; Best to Decrease (BD), a decreasing function, such as unit cost; and Best at Nominal (BN), a concave function, where an ideal amount of an attribute provides maximum utility.

One possible approach for constructing the model is to employ the Delphi method (Rowe and Wright 1999) in an interview with the primary stakeholder, while accounting for the preferences of others, leads to the following utility function for the total profit with respect to a certain performance attributes, φ. For example:

$$Profit_{\varphi}\begin{cases} 0, & x < A \\ Cx - D, & A \leq x \leq B \\ E, & x > B \end{cases} \tag{1}$$

As shown in equation (1), the stakeholder preference for attribute φ can be represented with a single-attribute value function, $V_{\varphi}\,(x)$. For all attributes, a vector of *n value functions* is obtained:$V_{\vartheta} = \left[\, V_1\, V_2\, \ldots\, V_n \,\right]$. Each V_{φ} may be expressed in terms of utility, sales, profit, or other appropriate measure, although the units must be consistent.

IV. Quantifying the Goal Value of a Supply Chain *(V_G)*

Supply chain managers are given or must determine a goal (requirement, objective, target), G_{φ}, for each attribute. A set of goals for a supply chain's n value attributes is given by $G_{\vartheta} = \left[\, G_1\, G_2\, \ldots\, G_n \,\right]$. Collectively, these goals define "the job to be done" by the supply chain. Doing that job will provide some value and V_G is the total value provided by achieving the exact goal that has been predetermined for each of its *n* attributes:

$$V_G = \sum_{\varphi=1}^{n} w_{\varphi} V_{\varphi}\left(G_{\varphi}\right) \tag{2}$$

Where the attribute weights, w_φ, are determined through interactions with stakeholders and normalized such that:

$$\sum_{\varphi=1}^{n} w_\varphi = 1 \tag{3}$$

V. Quantifying the Likely Value of a Supply Chain

The likely value of a supply chain is the value of its potential outcomes, weighted by their probabilities which are similar to the concept of statistical expectation. Knowledge of the supply chain's capabilities can be represented as a probability distribution for each attribute, $\tilde{P}_\varphi$. $\tilde{P}_\varphi(x)$ represents the probability that attribute φ will have outcome x. For n attributes $\tilde{P}_\vartheta = [\tilde{P}_1 \tilde{P}_2 \ldots \tilde{P}_n]$ and $\bar{P}_\varphi$ is the expected value of $\tilde{P}_\varphi$ and σ_φ is its standard deviation.

Lévárdy and Browning (2009) approached the challenge of the lack of information to define $\tilde{P}_\varphi$ by seeking estimates of the pessimistic, most likely, and optimistic outcomes — *a*, *b*, and *c*, respectively as illustrated in Figure 2 and utilises these to build a triangle distribution, where:

$$\tilde{P}_\varphi(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)}, & a \leq x \leq b \\ \frac{2(c-x)}{(c-a)(c-b)}, & b < x \leq c \\ 0, & otherwise \end{cases} \tag{4}$$

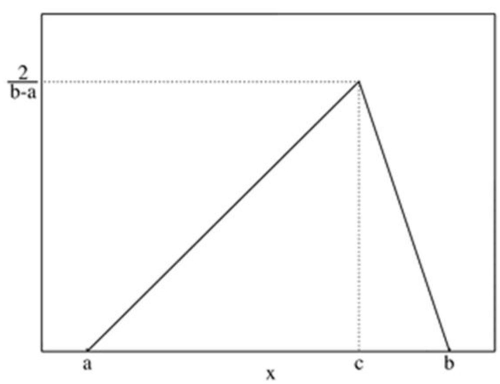

Figure 2 – Triangle distribution's probability density function

Benaroch and Goldstein (2009) noted that when a triangle distribution is used for $\tilde{P}_\varphi$, its mean $\bar{P}_\varphi$ and standard deviation σ_φ are given by:

$$\bar{P}_\varphi = \frac{a+b+c}{3} \tag{5}$$

$$\sigma_\varphi = \sqrt{\frac{a^2+b^2+c^2-ab-bc-ac}{18}} \tag{6}$$

These distributions could be replaced with outputs from models or simulations, as well as historical data, distribution libraries, and other forecasting techniques.

The likely value of the supply chain's capability to provide an outcome for attribute φ is given by:

$$\bar{V}_\varphi = \int_{-\infty}^{\infty} \tilde{P}_\varphi(x)\, V_\varphi(x)\, dx \tag{7}$$

And it might be highly improbable that $\bar{V}_\varphi = V_\varphi\left(\bar{P}_\varphi\right)$ because of the varying slope of the value function.

The likely value of an overall *supply chain*, represented by a set of attributes, is given by:

$$\bar{V} = \sum_{\varphi=1}^{n} w_\varphi \bar{V}_\varphi \tag{8}$$

Where:

$$\sum_{\varphi=1}^{n} w_\varphi = 1 \tag{9}$$

VI. The Supply Chain's GVG *(Ω)*

The GVG of the supply chain is the difference between the instantaneous likely value of all of its capabilities and its goal value:

$$\Omega = \bar{V} - V_G \tag{10}$$

The GVG captures the difference between the supply chain's expected outcomes, given its capabilities, and its goals. Positive Ω implies the likelihood that the supply chain's actual value will exceed its goal value.

VII. Quantifying Supply Chain Risks

Since very early, and in the SCRM literature (Tang 2006), the risk associated with an outcome has been defined as its consequence weighted by its likelihood, thus modelling the risk as the expected loss from a set of possible outcomes:

$$Risk = Probability \times Impact \tag{11}$$

The impact, $I_\varphi(x)$, of attribute φ's actual outcome, x, differing from its goal, G_φ, is a value gap:

$$I_\varphi(x) = V_\varphi\left(x_\varphi\right) - V_\varphi\left(G_\varphi\right) \tag{12}$$

$I_\varphi(x)$ is defined such that a negative impact results from failing to achieve the goal while a positive impact provides greater value than meeting the goal.

The risk value for a BI attribute is the probabilistically weighted sum of the impacts caused by all adverse outcomes:

$$\mathfrak{R}_\varphi = -\int_{-\infty}^{G_\varphi} \tilde{P}_\varphi\left(x_\varphi\right) I_\varphi\left(x_\varphi\right) dx \tag{13}$$

The negative sign at the front annuls the negative values of $I_\varphi(x)$, making $\mathfrak{R}$ a positive and since any lost in value cannot exceed the goal value, $0 \leq \mathfrak{R}_\varphi \leq V_\varphi\left(G_\varphi\right)$.

The risk value for a BD attribute will have the integration limits are reversed

$$\mathfrak{R}_\varphi = -\int_{G_\varphi}^{\infty} \tilde{P}_\varphi\left(x_\varphi\right) I_\varphi\left(x_\varphi\right) dx \tag{14}$$

For a BN attribute, two integrands, a BI and a BD, must be integrated together to capture the risk in both tails of $\tilde{P}_\varphi$ (negative values of $I_\varphi(x)$)

The risk value for an overall supply chain is given by

$$\mathfrak{R} = \sum_{\varphi=1}^{n} w_\varphi \mathfrak{R}_\varphi \tag{15}$$

Where

$$\sum_{\varphi=1}^{n} w_\varphi = 1 \tag{16}$$

VIII. Quantifying Supply Chain Opportunity

The opportunity value for a BI attribute is given by the probabilistically weighted sum of the rewards of all favourable outcomes:

$$\mathfrak{O}_\varphi = \int_{G_\varphi}^{\infty} \tilde{P}_\varphi\left(x_\varphi\right) I_\varphi\left(x_\varphi\right) dx \tag{17}$$

$\mathfrak{O}_\varphi$ is bounded by $0 \leq \mathfrak{O}_\varphi \leq V_\varphi\left(Max(x)\right) - V_\varphi\left(G_\varphi\right)$. This implies that the maximum reward possible should not exceed the difference between the supply chain's goal value and its maximum capabilities.

For a BD attribute will have the integration limits are reversed

$$\mathfrak{D}_{\varphi} = \int_{-\infty}^{G_{\varphi}} \tilde{P}_{\varphi}(x_{\varphi}) I_{\varphi}(x_{\varphi})\, dx \quad (18)$$

For a BN attribute, the integration occurs over all outcomes for positive values of $I_{\varphi}(x)$.

The opportunity value for an overall supply chain is given by

$$\mathfrak{D} = \sum_{\varphi=1}^{n} w_{\varphi} \mathfrak{D}_{\varphi} \quad (19)$$

Where

$$\sum_{\varphi=1}^{n} w_{\varphi} = 1 \quad (20)$$

Summary

Table 2 summarizes the framework's input and output variables. Although not shown explicitly, each output is available for each individual attribute, φ, as well as for the overall supply chain. On its own, each of these components can be useful to a supply chain manager. However, when integrated and analysed together, they can provide many useful insights for supply chain planning and management, including supply chain risk management.

Table 2 – Summary of the framework's input and output variables

Inputs		Outputs	
ϑ	vector of n supply chain value attributes, φ	V_G	the supply chain's overall goal value; the anticipated value of a supply chain that meets all of its goals
V_{ϑ}	vector of n value functions, V_{φ}	$\bar{V}$	the supply chain's overall likely value
w_{ϑ}	vector of weightings of n attributes' relative importance, w_{φ}	Ω	the supply chain's overall GVG relative to its goals; difference between goal and likely value
G_{ϑ}	vector of n supply chain goals, G_{φ}	$\mathfrak{R}$	the portion of the supply chain's overall value at risk; the expected loss in supply chain value due to uncertain outcomes that fail to meet the goals
$\tilde{P}_{\vartheta}$	vector of n supply chain capability distributions, $\tilde{P}_{\varphi}$, representing the prevailing uncertainty in the supply chain's initial capability to provide a particular outcome for each value attribute	$\mathfrak{D}$	the portion of the supply chain's overall value at opportunity; the expected gain in supply chain value due to uncertain outcomes that exceed the goals

This framework will be able to help supply chain managers facilitate improvement because the value of the various supply chain activities can now be examined in terms of their collective effects, cost, performance, value, risk, and opportunity. Potential improvements to a supply chain in terms of its people, processes, or tools can also be examined in terms of the supply chain capabilities they might add versus the time and cost that they might require. These will impact attributes such as supply chain costs and delivery performance. Novel formulations of supply chain risk, opportunity and value are introduced to track supply chain performance and provides a new platform/direction for future research, especially the applications of this framework to the planning and monitoring of supply chain value will be of upmost interest.

Bibliography

Stadtler, H. 2015. *Supply chain management: An overview*. Springer, Berlin.

Nagurney, A. 2006. *Supply chain network economics: Dynamics of prices, flows and profits*. Edward Elgar Publishing, Great Britain.

Porter, M. E. 2008.*Competitive advantage: Creating and sustaining superior performance*. Simon and Schuster, New York.

Fleming, Q., Koppelman, J. 2006. *Earned value project management* (3rd Edition), Project Management Institute, United States of America.

Browning, T. R. 2014. A Quantitative Framework for Managing Project Value, Risk, and Opportunity. *IEEE Transactions on Engineering Management.***61(**4): 583-598.

Shenhar, A. J. 2004. Strategic Project Leadership® Toward a strategic approach to project management. *R&D Management*, **34**(5), 569-578.

Cragg, P., Tagliavini, M., Mills, A. 2007. Evaluating the alignment of IT with business processes in SMEs. *ACIS 2007 Proceedings*: 10.

Council, S. C. 2012. Supply chain operations reference model. *SCOR*, *Version*, *11*. Available at http://www.apics.org/sites/apics-supply-chain-council/frameworks/scor (accessed Feb 1, 2015).

Ziemba, W. T., Vickson, R. G. 1975. *Stochastic optimization models in finance.* Academic Press. NewYork.

Neumann. J. V., Morgenstern. O. 2007. *Theory of Games and Economic Behaviour*, 4th ed. Princeton Univ. Press, Princeton, NJ, USA.

Rowe, G., Wright, G. 1999. The Delphi technique as a forecasting tool: issues and analysis. *International journal of forecasting*. **15**(4): 353-375.

Lévárdy, V., Browning, T. R. 2009. An adaptive process model to support product development project management*. IEEE Transactions on Engineering Management*. **56**(4): 600-620.

Benaroch, M., Goldstein, J. 2009. An integrative economic optimization approach to systems development risk management. *IEEE Transactions on Software Engineering*, **35**(5): 638-653.

Tang, C. S. 2006. Perspectives in supply chain risk management. *International Journal of Production Economics*. **103**(2): 451-488.