Key Performance Indices Evaluation in Multi-Layer Supply Chain Using Mathematical Model

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Abstract: This study aims to design and optimization of multi-layer supply chain with identifying the appropriate processes in economic, operational and strategic perspectives that result to optimal decisions. In the current issue, the Key Performance Indicators in a 3-layer supply chain is analyzed and finally it leads to design a mathematical model for the decision making. Decisions of the discussed mathematical model are in the class of the operational decisions in supply chain and a good guideline for managers and users of supply chain. Considering Key Performance Indicators creates favorable Executive Perspective during transferring the flow of materials and information for chain including suppliers, manufacturers and customers. In order to optimize the mathematical model, risk and profits are also considered. Finally, after the model is implemented in the Lingo software, effective key indicators are to be identified in order to improve the supply chain performance and increase profits.
Keywords: Supply Chain; Key Performance Indicator; Mathematical Model

1 INTRODUCTION

Using measurements to support manufacturing operations dates back to the late 19th and early 20th centuries with Fredrick W. Taylor applying scientific methods to running business. His ideas for time and motion studies of operations were successfully used to scientifically manage production lines and warehouse operations. Today, performance measurement has become a part of all business processes, which are thriving to be more efficient and cost effective. Over the last decade, companies have spent a lot of time and money to improve their supply chains. Their efforts have been made easier by the Enterprise Resource Planning/Supply Chain Management (ERP/SCM) software vendors, which have developed sophisticated software solutions, both for supply chain operations and supply chain planning. Whereas, all these software solutions enable companies to drastically improve their supply chain performance, yet they do not provide adequately the tools needed to measure the improvements (or performance levels). Thus companies need to develop its own set of performance metrics or KPI's, so as to know how close or how far it is from meeting set objectives. In the context of a dynamic supply chain, continuously improving performance has become a critical issue for most suppliers, manufacturers, and the related retailers to gain and sustain competitiveness. In practice, supply chain based companies (e.g., Dell, Wal-Mart, Samsung, Toyota, Lenovo, Gome, etc.) have used different

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performance management tools to support their supply chain strategies. Monitoring and improvement of performance of a supply chain has become an increasingly complex task. A complex performance management system includes many management processes, such as identifying measures, defining targets, planning, communication, monitoring, reporting and feedback. These processes have been embedded in most information system solutions, such as i2, SAP, Oracle EPM, etc. These system solutions measure and monitor key performance indicators (KPIs) which are crucial for optimizing supply chain performance.

Performance measurement is critical for companies to improve supply chains' effectiveness and efficiency (B.M. Beamon, 1999, C. Shepherd, H. Günter, 2006). Decision-makers in supply chains usually focus on developing measurement metrics for evaluating performance (B.M. Beamon, 1999, A. Gunasekaran et al, 2004). In practice, once the supply chain performance measures are developed adequately, managers have to identify the critical KPIs that need to be improved. However, it is difficult to figure out the intricate relationships among different KPIs and the order of priorities for accomplishment of individual KPIs. As a matter of fact, determination of priorities within a given set of KPIs has become a bottleneck for many companies in their endeavors for improving their supply chain management (SCM). As these problems have received relatively less attention in previous research (C. Shepherd, H. Günter, 2006), significant gaps remain between practical needs and their effective solutions. To address these issues, our research proposes a systematic approach that helps analyze and select the right KPI groups and strategies for their accomplishment, for improved supply chain performance.

1.1 The challenges of supply chain performance management

Improving supply chain performance is a continuous process that requires both an analytical performance measurement system, and a mechanism to initiate steps for realizing KPI goals; herein we call the mechanism to achieve KPI goals as “KPI accomplishment”, which connects planning, and execution, and builds steps for realization of performance goals into routine daily work. To measure supply chain performance, there are a set of variables that capture the impact of actual working of supply chains on revenues and costs of the whole system (K. Ramdas, R.E. Spekman, 2000). These variables as drivers of supply chain performance are always derived from supply chain management practices (K. Ramdas, R.E. Spekman, 2000). After identifying KPIs, managers have to achieve improvement in them, through continuous planning, monitoring and execution. According to the results of selected KPIs' accomplishment, managers may create current reports on KPIs, to compare multiple plans of supply chain management. In this performance management cycle, there are many challenges, both in performance measurement, and its improvement.

1.2 Performance improvement work dependencies and conflicts

Once critical KPIs have been identified and selected effectively, another challenge is that it is difficult to coordinate the parallel steps required for accomplishment of improvement in identified KPIs. Generally speaking, there are two methodological streams to cope with this problem in previous literature. One stream involves finding out the bottlenecks in the supply chain by implementing the KPIs. For instance, the Theory of Constraints (TOC) (S. Rahman, 2002) is a set of concepts and tools that can be used to implement the widely used continuous improvement management philosophy. TOC improves performance in a system by focusing attention of management on the system's constraints. Thus, by preventing distractions from its primary purpose and concentrating limited resources on efficacious management of the constraint, decision makers are able to gain significant leverage, sufficient to attain the desired performance levels (S. Rahman, 2002). In the TOC theory, the method is to find a suitable approach to identify and solve bottlenecks in production, delivery, and service processes. However, the TOC method does not deal with selection of crucial bottlenecks and it doesn't provide the optimal solution of performance improvement for each KPI. Sometimes, the KPIs are coupled or correlated, and it is hard to find the precise bottleneck; improving one KPI might undermine performance of another.

The second stream focuses on performance optimization; the optimization philosophy assumes that there is an optimal performance point, when maximizing or minimizing the identified indicators. Although the performance optimization approach, in theory, is widely accepted by researchers, it is difficult to ensure that an optimized KPI accomplishment strategy is implemented by different members of the supply chain. First, it is difficult to apply in practice, in terms of both data acquisition and computing. It is also difficult for decision-makers to understand in real SCM situations.

Second, it does not take into account the relationships among indicators. Though classified into different categories, different measures in a measurement system are often correlated. The correlations among different measures arise from the inherent internal relations of different SCM processes, and the interdependent influences of different KPIs' accomplishment tasks. Therefore, a feasible methodology of identifying and analyzing the relationships among KPIs related to different SCM processes is important and necessary for improving SCM performance. For supply chain performance optimization, identifying important measures at multiple levels is more important than just maximizing or minimizing the identified indicators. One approach towards evaluating important indicators is the fuzzy logic technique, which is a problem-solving tool for handling vague and imprecise information, to get a definite decision (F.T. Dweiri, M.M. Kablan, 2006). Although specific applications of the fuzzy logic tool for decision-making have been presented in the hierarchical measurement system (F.T.S. Chan, H.J. Qi, 2003), there have been few studies of using this tool in performance management, in practice, in comparison to other practical areas (e.g., project management (F.T. Dweiri, M.M. Kablan, 2006).

In practice, organizations are prone to making rushed decisions, when faced with continuously changing goals and tight deadlines. Managers are short of time to compare all the options when situations demand immediate solutions. Therefore, it is important to describe the mutually dependent relationships among KPIs, and to optimize their accomplishment, based on their complex interdependence. However, most of the previous researches do not provide specific operational procedures for analyzing KPI accomplishment. Considering pros and cons of different methods, this paper provides a framework of supply chain performance measurement and improvement, based on a systematic approach to analyzing KPI accomplishment.

2 PROBLEM DESCRIPTIONS

In this research after determining key performance indices, we are seeking to find the effective indices on the performance of supply chain. To configure the problem, consider a three layer supply chain and analyze the impacts of performance indices using a mathematical model. The objective of the mathematical model is to maximize the profit of whole supply chain. The effective performance indices lead to customer satisfaction and therefore investigating which set of indices are effective in an appropriate layer of the SCM. Here, a three layer supply chain is designed having supplier, producer and customer. Raw materials are provided by suppliers and then transferred to the producer to perform the processing required for a final product. Then, the produced products are sent to customers to complete the chain. To maximize customers' satisfaction, effective performance indicators in each layer are obtained and the profit of the whole chain is optimized.

In the proposed three layer supply chain the following performance indices are considered:

Supplier: cooperation of suppliers, Delivery of defect-free products by suppliers, Assistance supplier solving technical issues, Ability of supplier quality, Cycle time of Purchase Order, Time the order is received, Good record of cooperation, Investment supplier, Delivery Cost.

Producer: Time cycle, total time of Cash flow, Diversity of products and services, Deviations from budget, Cost-saving innovations, The accuracy of prediction methods, New product development cycle time, Ordering Methods, Main produced Schedule, Rate of return on investment, Levels of inventory turnover, Lead Time, Minimizing the time between order and delivery, Return rate returned, Guarantee, good performance of the product, Transportation costs.

Customer: Customer perception of product value, Degree of flexibility satisfying customer needs, Supply rate, Customer Satisfaction, Minimizing response time to customer, Flexibility Orders.

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2.1 Introduction of indices, parameters and variables

2.1.1. Indices

Key performance indicators	i=1,2,…,I
Supply chain layers	j=1,2,…,J

2.1.2 Parameters

Initiation cost for each index i in layer j	cij
The significance of each of the indicators	wij
The funds available to each layer	Bj
Risk Launch	Rij
Economic profit percent is allowed	θ
Random variable corresponding to each index	yj

2.1.3 Decision variables

If select key performance indicator i in layer j	Xij=1
Otherwise	Xij=0
The amount of any proceeds	Eij

2.2 Mathematical model's objectives

$MaxZ_1 = W_{ij} X_{ij}$

Weights for indicators,

$MinZ_2 = R_{ij} X_{ij}$

Risk of performance indicator in each layer,

$MaxZ_3 = E_{ij} X_{ij} - C_{ij} X_{ij}$

Profit of the supply chain.

2.3 Constraints

$\sum_i C_{ij} X_{ij} \le B_j \qquad \forall j$

These constraints reflect the investment for indicators in each layer, limited to the available budget in each layer.

$\sum_j \sum_i W_{ij} = 1$

This constraint shows that the total weights are sum up to 1.

$\lambda(y) = \left| t - y_j \right|^2$

This constraint reflects the loss function is any indicator.

$\Lambda = \int_{\infty} \lambda(y) f(y) dy \quad \Leftrightarrow R_{ij}$

This constraint implies that the risk function using the probability density function associated with each indicator, the risks of this relationship will be achieved.

$E_{ij} X_{ij} - C_{ij} X_{ij} \le (\theta + 1) B_j$

The above equation shows that the profit is confined with a coefficient $(1+\theta)$ of the available budget.

$E_{ij} \ge 0$

The above relation certifies that the earning for each indicator in each layer is more than or equal to zero.

$X_{ij} \in \{0,1\}$

Above relation represent the sign of the binary decision variable.

3 AN EXAMPLE

The supply chain of this research is 3layer supply chain that includes a supplier, Producer and customer. The Suppliers offer Basic Material for Produce Production during the transition to the company. The company put products during another transition for consumers to our customers. In the following data collection process has been expressed. After identifying key performance indicators of the supply chain by the review of the literature, variables, was examined and the 32 factors was chosen as supply chain factors affecting the supply chain layers that in the table 1 have been distributed:

Table 1. Key performance indicators identified by the review of the literature

Supplier		Producer		Customer	
1	Cooperation Of Suppliers	1	Time Cycle	1	Customer Perception Of Product Value
2	Delivery Of Defect-Free Products By Suppliers	2	Total Time Of Cash Flow	2	Degree Of Flexibility Satisfying Customer Needs
3	Assistance Supplier Solving Technical Issues	3	Diversity Of Products And Services	3	Supply Rate
4	Ability Of Supplier Quality	4	Deviations From Budget	4	Customer Satisfaction
5	Cycle Time Purchase Order	5	Cost-Saving Innovations	5	Minimizing Response Time To Customer
6	Time The Order Is Received	6	The Accuracy Of Prediction Methods	6	Flexibility Orders
7	Good Record Of Cooperation	7	New Product Development Cycle Time		
8	Investment Supplier	8	Ordering Methods		
9	Delivery Cost	9	Main Produced Schedule		
		10	Rate Of Return On Investment		
		11	Levels Of Inventory Turnover		
		12	Lead Time		
		13	Minimizing The Time Between Order And Delivery		
		14	Return Rate Returned		
		15	Guarantee		
		16	Good Performance Of The Product		
		17	Transportation Costs		

Table 2. The cost of setting up key performancindicators

	Supplier	Producer	Customer
1	9	12	16
2	20	6	7
3	16	9	7
4	7	4	15
5	13	13	13
6	19	11	10
7	10	8	
8	12	11	
9	12	14	
10		5	
11		10	
12		9	
13		19	
14		18	
15		15	
16		7	
17		11	

The costs of each indicator in each layer are given in table 2.

Due to importance of each performance indicator a corresponding weight is allocated. To do that a general ranking method of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used. The pairwise comparison matrices are filled with respect to four criteria of quality, price, product differences, and safety. The obtained weights are shown in table 3.

An example for a typical uniform distribution follows here:

1) $f(y)=\frac{1}{b-a}$

$$\Rightarrow f(y_1)=\frac{1}{80-30} \qquad \rightarrow f(y_1)=0.02 \quad C_{ij}$$

Table 3. Weight of key performance indicators

W_{ij}	Supplier	Producer	Customer
1	0.019	0.073	0.030
2	0.023	0.034	0.047
3	0.004	0.027	0.008
4	0.010	0.009	0.057
5	0.069	0.040	0.021
6	0.018	0.005	0.047
7	0.015	0.073	
8	0.012	0.027	
9	0.032	0.053	
10		0.069	
11		0.031	
12		0.023	
13		0.020	
14		0.010	
15		0.063	
16		0.007	
17		0.024	

Risk of implementing each performance indicator is followed by uniform probability distribution

Then the loss function is formed as,

2) $\lambda(y)=\left|t-y_j\right|^2$ (t = 0.2 2)

$$\Rightarrow \lambda(y_1)=\left|0.2-y_1\right|^2$$

And finally the risk is computed by,

3) $\Lambda_1=\int_0^{0.2} 0.02(0.04-0.4y_1+y_1^2)dy$

$$\Rightarrow R_{11}=0.02(0.04y_1-0.2y_1^2+\frac{y_1^3}{3})\Big]_0^{0.2}=0.000053333$$

And the rest of performance indictors risk computations is given in table 4.

Table 4. Initiation Risk of KPI Rij

Supplier	*a*	*b*	$f(y)=\frac{1}{b-a}$	$\Lambda=\int_0^{0.2} f(y)*(0.04-0.4y_1+y_1^2)dy$
1	30	80	0.02	5.3333E-05
2	15	63	0.02083	5.5556E-05
3	30	90	0.01667	4.4444E-05
4	12	82	0.01429	3.8095E-05
5	6	64	0.01724	4.5977E-05
6	10	75	0.01538	4.1026E-05
7	33	51	0.05556	1.4815E-04
8	5	73	0.01471	3.9216E-05
9	48	91	0.02326	6.2016E-05

Producer	a	b	$f(y)=\frac{1}{b-a}$	$\Lambda=\int_0^{0.2} f(y)*(0.04-0.4y_1+y_1^2)dy$
1	12	71	0.01695	4.5198E-05
2	20	98	0.01282	3.4188E-05
3	18	49	0.03226	8.6022E-05
4	21	77	0.01786	4.7619E-05
5	35	85	0.02	5.3333E-05
6	10	60	0.02	5.3333E-05
7	45	96	0.01961	5.2288E-05
8	33	78	0.02222	5.9259E-05
9	30	80	0.02	5.3333E-05
10	17	82	0.01538	4.1026E-05
11	15	68	0.01887	5.0314E-05
12	17	91	0.01351	3.6036E-05
13	34	88	0.01852	4.9383E-05
14	41	93	0.01923	5.1282E-05
15	23	79	0.01786	4.7619E-05
16	9	77	0.01471	3.9216E-05
17	11	89	0.01282	3.4188E-05

Customer	*a*	*b*	$f(y)=\frac{1}{b-a}$	$\Lambda=\int_0^{0.2} f(y)*(0.04-0.4y_1+y_1^2)dy$
1	16	86	0.01429	3.8095E-05
2	25	91	0.01515	4.0404E-05
3	14	73	0.01695	4.5198E-05
4	33	89	0.01786	4.7619E-05
5	12	90	0.01282	3.4188E-05
6	10	90	0.0125	3.3333E-05

The budget available for each layer using inquiry and cooperation of Factory accounting and finance sector is as follows (Table 5):

Table 5. The budget allocated to each layer in the supply chain

B1	100
B2	300
B3	100

Finally, the percentage of profit allowed $\theta = 0.25$ to be considered. As a result after implementing the problem in Lingo optimization software, the effective KPI are obtained and the corresponding earning is also in hand. The results are shown in tables 6 and 7.

Table 6. The obtained effective KPI

X_{ij}	j=1	j=2	j=3
i=1	0	0	0
i=2	0	1	1
i=3	0	0	0
i=4	1	0	0
i=5	1	0	0
i=6	0	0	1
i=7	0	1	
i=8	0	0	
i=9	0	0	
i=10		1	
i=11		0	
i=12		0	
i=13		0	
i=14		0	
i=15		0	
i=16		1	
i=17		0	

Table 7. The obtained earnings

E_{ij}	j=1	j=2	j=3
i=1	0	0	0
i=2	0	383	132
i=3	0	0	0
i=4	132	0	0
i=5	138	0	0
i=6	0	0	135
i=7	0	382	
i=8	0	0	
i=9	0	0	
i=10		380	
i=11		0	
i=12		0	
i=13		0	
i=14		0	
i=15		0	
i=16		382	
i=17		0	

4 CONCLUSIONS

In this paper, a collection of key performance indices are extracted from the relater literature. Then, a mathematical model was developed for a three layer supply chain including supplier, producer and customer. The objectives were to maximize the profit, maximize the effective KPI importance weights and minimize the risk of investment. The target was to improve the whole supply chain. The decision variables were the allocation of KPI in each layer and the economic earning reasonable for each indication. The numerical results show that the model can be employed as a helpful decision aid for managerial decision making in real world industries.

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