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ON SUPPLY CHAIN NETWORK RISK MANAGEMENT, USING TAGUCHI METHOD

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Abstract

Robustness of Supply chain network is a growing subject in recent decades. It is essentially multi-dimensional topic which needs some comprehensive approach to deal with. In this paper, a new method is introduced in order to quantitatively manage supply chain network risk (SCNR) and achieving higher level of robustness. The method is based on Taguchi method (Tm) as a statistical design of experiments (SDOE) methods. A set of risk factors divided to internal and external factors are built. Most important ones are extracted and the Tm is designed based on these selected factors. The factors are presented to some experts to have some conceptual judgments about the risk level of each state and the results are added up and analyzed. Finally, the method is practically tested in Iran Tractor manufacturing supply chain network and the results are illustrated in the following paragraphs.

Key words: *Supply chain management, Network risk management, Robustness, Taguchi method, Uncertainty*

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1. Introduction

Now a days globalization, unpredictable demand, cost pressures, increasing use of outsourcing, are some of drivers to make higher levels of uncertainty for enterprises in supply chain networks (Shin et al., 2012). In addition, poor execution and lack of contingency plans may result in many failures in business (Wu, Blackhurst and Chidambaram, 2006). Pfohl, Kohler and Thomas (2010) and Shin et al. (2012) suggest that the lean supply networks, applied to cope with the uncertainty, significantly result in higher levels of vulnerability in the field of disturbances but these may have negative effects on robustness of supply chain networks. Therefore, Pfohl, Kohler and Thomas (2010) introduce SCNR management (SCNRM) as an effective success factor for supply chain network management (SCNM) which is increasingly amplified in recent years.

Uncertainty may exist due to many elements as scholars mentioned (Chopra and Sodhi 2004). Stewart (2005) illustrate that uncertainty leads to risk (Klibi, Martel and Guitouni, 2010). Kiser and Cantrell (2006) summarize SCNR factors in internal and external classes similar to Wu, Blackhurst and Chidambaram (2006) who identify them in inbound and outbound factors. In the field of research methods to manage SCNR, there are two classes of methodologies: qualitative and quantitative studies (Pfohl, Kohler and Thomas, 2010) and qualitative methods are more usual than quantitative ones (Tang and Nurmaya, 2011). A challenge in using

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quantitative methods is to find the suitable information to quantify the risk measures (Knemeyer, Zinna and Eroglu, 2009). (Klibi, Martel and Guitouni, 2010) reveal that the concept of robustness has raised a lot of discussion in the literature on decision-making under uncertainty.

Although there is the widespread literature on robust or strategic supply chain network design (SSCND), they are not holly consider the network exhaustively. These weaknesses may be more critical, in view of these facts that mitigating one risk can aggravate the exposure to another risk (Miller, 1992; Chopra and Sodhi, 2004) and mitigation plan of the one firm in the supply chain network may create a new risk for other its members Chopra and Sodhi (2004). So, it is not expected that a set of independent approaches or action plans can lead the supply chain network to be robust. Therefore, it is necessary to establish the good SCNR strategic plan to deal with uncertainties and their variety and provides robustness and resilience for the entire supply chain network (Gaonkar, and Viswanadham, 2007; Pfohl, Kohler and Thomas, 2010; Shin et al., 2012). But according to Gaonkar, and Viswanadham, (2007), the previous methods are introduced to increase efficiency of a SCN and not for achieving its robustness and resilience under uncertainty.

The aim of this paper is to introduce a new quantitative model to obtain a robust plan not for one side or one component of the SCN, but for the entire network. But, there are so many risk drivers when we talk about the entire SCN with some suppliers, focal company and customers which may belong to controllable, incontrollable, internal or external/environmental ones. Thus, the Tm is used to make economical design of experiments in order to have robust SCN with any types of risk drivers. The reminder of this paper is structured as follows: in section 2 the conceptual framework for Taguchi method is derived. Section 3 presents the corresponding model for SCNRM model. General application and robustness achieving of the model are highlighted in section 4 and the conclusion is provided in section 5.

2. Theoretical Background and the Concept of the Taguchi method

Genichi Taguchi is a Japanese engineer who has proposed both philosophy and methodology of Taguchi method (Tm) as the statistical design of experiments (SDOE) in early 1980s (Maghsoodloo et al., 2004; Antony and Antony, 2001). Taguchi (1986) defines quality as "The loss a product causes to society after being shipped, other than any losses caused by its intrinsic functions". Many scholars till date have focused on the Tm applications in service and manufacturing industries. few researchers had applied Taguchi‘s Design-of-Experiment in managing software projects. Rawlands, Antony and Knowles (2000) and Antony and Antony (2001) summarize some of Tm's applications; Tsai, Moskowitz, and Lee (2003) integrate orthogonal array (OA) with critical resource diagram (CRD) to allocate the appropriate human resources (developers) for the proper task. Salem, Rekabb and Whittaker (2004) have applied Taguchi‘s OA to develop a logistic regression model and Maghsoodloo et al. (2004) introduce the essential and literature of the method in a good manner. Zeng, Yao and He (2009) introduce an optimal scheduling model for centralized SCNM including both discrete events and continuous-time dynamics using a hybrid systems method. Tseng and Liu (2011) present a hybrid Taguchi-genetic algorithm for selecting and scheduling a balanced project portfolio and Shi, Wang and Qi (2012) introduce a hybrid genetic algorithm for scheduling and selecting a project portfolio. Sadeghi (2012) presents a project scheduling non-linear bi-objective model to minimize cost and time of projects and Zoraghi, Najafi and Niaki (2012) propose an integrated model of project scheduling and material ordering to minimize the total material holding and ordering costs. In the both methods, Tm is used for tuning parameters of the algorithm to increase its performance.

The process of performing a Tm is as follows: (1) Full understanding and formulating the nature of the problem, (2) Identifying the most relevant output performance features, (3) Full identifying of control factors – that can be controlled under normal conditions –, noise factors – which are too difficult to control in normal conditions – and signal factors – which affect the performance of the process, (4) Defining factor levels, their interactions and degrees of freedom, (5) Selecting/designing an appropriate (OA) – that provide an alternative to standard factorial designs, (6) Preparing the experiment, (7) Collecting data and running the experiment, (8) Analyzing the results (Antony and Antony, 2001; Maghsoodloo et al. 2004). Selecting an appropriate lose function is a basic subject to prepare the statistical analysis based on the Tm. There are three types of lose functions which are used in the Tm: (1) nominal the best, (2) smaller the best and (3) larger the best. *S/N* ratio as a class of statistics which can be applied in order to measure the effect of the noise factors on the process performance is used instead of the lose function, regarding to its type. Taguchi introduced that by maximizing the *S/N* ratio, the loss function is minimized. After the *S/N* ratios calculation, the effect rang of each factor can be calculated to have a comparison among the effect of the factors.

This ratio regarding to the smallest the better lose function is as follows which must be maximized:

$$S/N_s = -10\log\frac{1}{n}\sum_{i=1}^{n} y_i^2\,,\qquad \bar{y}_i = \frac{1}{r}\sum_{j=1}^{r} y_{ij} \tag{1}$$

Index s refers to the type of the lose function; $\bar{y}_i$ is the integrated output of the i^{th} experiment; y_{ij} is the output of the j^{th} times of the i^{th} experiment, and n is the number of experiments defined by OA. Noise factors are factors which influence the output of a process, but cannot be controlled, economically (Roy, 1990).

3. Proposed SCNRM model, Empirical Study and Results

For the purpose of this study, the Taguchi method is applied in order to introduce a comprehensive quantitative robust SCRM method. The method is designed to cope with all the SCR factors which are categorized into two controllable and uncontrollable classes. Table 1 contains of 62 risk factors which are regulated based on the Pareto method (for simplification, we suppose that the correlation between the factors is equal to zero). For this purpose, the factors are presented to some experts to be evaluated conceptually in five levels of importance (The qualitative evaluation is quantified using five-point-Likert method). Suitable factors level is defined and the output factor is featured based on the level of overall risk in each statement which is designed by appropriate Taguchi's OA. The levels are prepared according to experts integrated ideas which are quantified either by five-point-Likert. Recall that the study is about the risk, so it is obvious that the appropriate function is the smaller the better lose function, so, the *S/N* ratio is calculated by Eq. (1). Analysis of variance (ANOVA) is performed to identify the most crucial risk factors and the effect of the risk factors. Finally, response curve analysis is done to determine influential parameters.

Table 1

SCR factors classification (Wu, Blackhurst and Chidambaram, 2006; Williams, Lueg and LeMay 2008; McFadden and Arnold, 2010)

F. classification		**Type**	**Factors**	**Sub-factors**
Controllable risk factors	**Full controllable factors**	**Internal**	Quality	Customer reputation
			Cost	Cost model
			On-time delivery	Logistic (1), Non-delivery loses (2)
			Engineering/ Production capability	Design, Manufacturability, Production capabilities and limitations, Capacity utilization, Production capability, Buffering capacity
			Product flexibility	Product and process changes, Nature of product, Change in production volume and mix (4), Substitution policies, Entry barrier, Inability to change
			Technical/ knowledge resources	Incompatible knowledge system, Knowledge management, Training, Changes in technology, Supplier risk awareness (3)
			Financial & insurance	Financial health, Multi-factor business, Non completed risk coverage
			Management related	Management vision, Make-buy opportunity, Break-even stability
		Ext.	2nd tier supplier	Same 2nd tier supplier
	Partially controllable factors	**Internal**	Accidents	Fire accidents, Employee accidents, Accidents in transportations
			Market strength	Supplier Market strength, Possibility of the suppliers becoming a competitor for the focal company
			Internal legal issues	Labor union, Labor strikes
			Continuity of supply	Supply availability, Unpredictable cycle time, Supplier backing up
		External	External legal issues	Legal claims by customers (5), Legal status of product/services
			Demand	Demand loss, Expected demand growth
			Security	Maritime pirate attack, High-way theft
Full Uncontrollable risk factors		**External**	Natural/man-made disaster	Earthquake, Volcano, Flood, Communal riots, Terrorism, Sabotage, Counterfeiting
			Politics/ economics stability	Economy down-turn (6), New government, Rules/regulation changes, Actions and sanctions of governments
			Market characteristics	Raw material cost trend, Loss of contract, Low profit margin, Market growth, Market size
			Competitive	Uncertainty about competitors' actions

As an empirical study, the Iran tractor manufacturing supply chain (ITMSC) is proposed to demonstrate usefulness and validity of the proposed method. The data for this study were collected in winter 2013 in Iran. A group of four top manager of the ITMSC is asked to choose the most important risk factors which are classified into two external and internal classes as shown in Table 1. Subsequently there are four internal factors and two external ones which are become distinguished numerically in Table 1, are selected.

The mixed orthogonal array shown in Table 2 is selected for the experimental investigation. "smaller-the-better" is being taken as a quality characteristic, since objective function is to minimize the risk of the Supply chain. Those top managers are asked together to fulfill the table subjectively. Their judgments are shown in Table 2.

The average risk levels and S/N ratios are calculated for each experiment and the ANOVA is performed to recognize the most important risk factors as shown in Table 1.

Table 2

Taguchi layout and results

#	Internal variables				Ex. Var.	Overall risk level				$\bar{y}_i$	*S/N*
	(1)	(2)	(3)	(4)	(5)	2	1	1	2		
					(6)	1	2	1	2		
1	1	1	1	1		1,1,2,1	1,1,2,1	1,1,1,1	4,5,4,4	1.9375	-5.7448
2	2	2	1	1		2,3,4,4	3,2,3,2	4,1,2,1	6,6,5,5	3.3125	-10.4031
3	2	1	2	1		3,2,4,4	3,7,3,3	5,4,4,5	8,8,6,8	4.8125	-13.6474
4	1	2	2	1		5,4,4,5	4,6,3,4	4,5,5,6	10,9,7,9	5.625	-15.0025
5	2	1	1	2		5,4,5,6	1,4,3,2	5,5,4,5	6,4,5,6	4.375	-12.8196
6	1	2	1	2		5,4,7,6	4,4,4,4	3,4,5,3	7,5,6,8	4.9375	-13.8701
7	1	1	2	2		5,6,6,5	6,5,6,6	1,1,3,3	5,5,7,5	4.6875	-13.4188
8	2	2	2	2		6,7,6,7	4,5,6,6	1,3,4,2	9,7,10,10	5.8125	-15.2873

Table 3

The ANOVA results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	52.141	3	17.380	6.714	.001
Within Groups	72.484	28	2.589		
Total	124.625	31			

The results are laying stress on the significant effect of the risk factors. The average of S/N ratios is calculated at each factor level in order to have the response curves as shown in Table 4.

Table 4

The parametric effects of factors

Factors	Level 1	Level 2	(Level 2 - Level 1)
(1)	-48.0362525466408	-52.1573530543553	-4.12110050771447
(2)	-45.6306358357802	-54.5629697652158	-8.93233392943559
(3)	-42.8376552823212	-57.3559503186749	-14.5182950363536
(4)	-44.7978173484634	-55.3957882525327	-10.5979709040693

The greater difference between the levels, the parametric effect will be much. This effect is shown not only in Table 4, but in Fig. 1. In this figure the slope of each line, introduces the effect of that factor. So the 3rd risk factor – supplier risk awareness – has a higher parametric effect and “change in production volume and mix”, “non-delivery loses” and “logistic” are in the latter levels of effect.

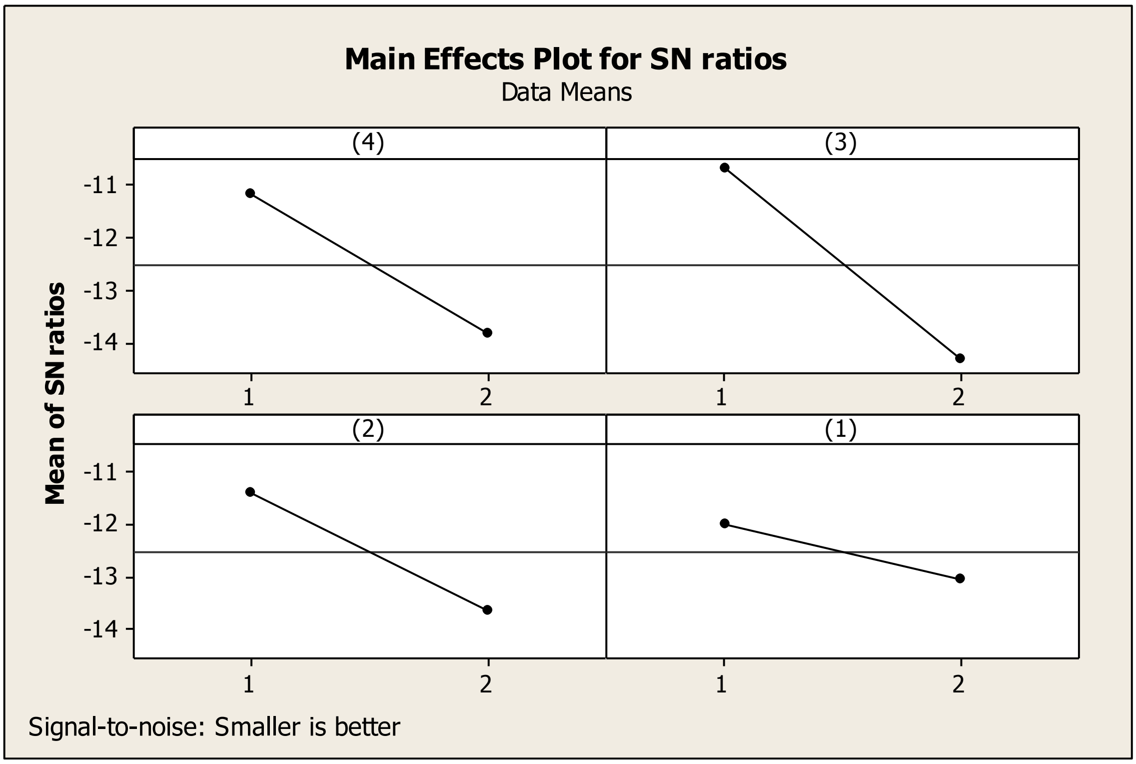

Fig. 1. **The response curves**

As you see in Table 2, the better state for the ITMSC is the state that internal and environmental risk factors are in their lower level. This table not only shows the better state of the ITMSC, but the better state for any condition of the supply chain in any level of its internal risks, according to dependency of the external risk factors. For instance, one can see that if all of the external risk factors are in their higher levels, and the 2nd risk factor – non-delivery loses – is either in its higher level, the better condition is occurred in raw 2 which says that in this statement, the ITMSC most try to being in lower level of the 3rd and 4rd risk factors and the 1st risk factor can be in its higher level and it is because of their interactions and interdependencies.

4. Conclusion

In this paper, we consider the supply chain under the effect of internal and external risk factors. To handle the uncertainties of the various risk factors and to achieve the high level of robustness, we adopt the Taguchi method. The basic major superiority of the method is its ability to explain a strategic plan for the supply chain as a combined interrelated network to achieve robustness. The method is successfully installed in ITMSC and the results illustrate the applicability and validity of it.

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