USE OF TAGUCHI METHOD FOR SUPPLY CHAIN DESIGN PROCESS

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Abstract: To survive on today's global market; enterprises can no longer optimise their businesses isolated from their business partners, because a sum of sub optimal solutions does not have to present global optimal solution. An optimal supply chain is one that can respond with the shortest order-lead time and the minimal overall cost. In this paper the potential of Taguchi method is used in a supply chain design process.

Keywords: Taguchi method, supply chain, discrete event simulation

I. INTRODUCTION

Today's enterprises are faced with the situation that can be characterized by competition and uncertainty. It is no longer acceptable to assume that good products will sell for ″them selves″ or that present market success ensures future success. To ensure the success of an enterprise on the market, it is common practise for enterprises to set some form of business alliances. In the last decade of the past century many new organizational concepts emerged. Those concepts focused on the closer relationship between the involved parties. One of those concepts is supply chain management (SCM). The purpose of SCM is an integration of all involved parties and their respective processes and strategies, from sourcing to delivering. Implementation of such organization, which will efficiently accomplish the integration, is rather complex task.

An optimal supply chain is one that can respond with the shortest order-lead time and the minimal overall cost. Identification of non-controllable factors that affect a supply chain is of essential importance. Building those effects, in the optimal supply chain configuration, it is possible to design a system that is insensitive, or at least less sensitive, on those effects. In this paper the design and optimisation of a supply chain, which built-in insensitivity on variations has caused by the non-controllable factors, is presented.

I. TAGUCHI METHOD

To design a product, and also the process that generates a product, which will efficiently respond in multiple customer environments is decisive factor for success or the failure of an enterprise. Important role in such a process has the design of experiments (DoE). Prof. Genichi Taguchi tried to eliminate the major drawbacks of classical DoE (large number of experiments and elimination approach of so-called nuisance factors [1].

The essence of Taguchi method is quality and how the customer perceives it. The product/process quality improvement is achieved by reducing the effects of variation but without its elimination. Every product/process can be described by using P-diagram, Fig. 1 [2]

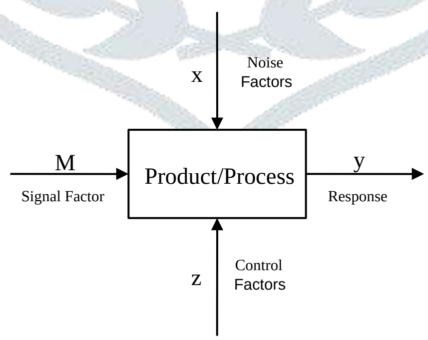

Figure 1: P-diagram [2]

Figure 1: Represents factors that influence a product/process. These factors are:

- **Signal Factor *(M)*** is the factor whose value is directly set by the user or the operator of the product to express the intended value for the response of the product (precisely signal factor is what the user of a product expects of it, e.g. selection of tolerances for a component).
- **Noise Factors *(x)*** are factors whose values are either difficult to control, impossible to control or too expensive to control in the field of use. The noise factors cause the response ***(y)*** to deviate from the target specified by the signal factor ***(M)*** and lead to quality loss.
- **Control Factors *(z)*** are the factors whose values can be specified freely by the designer. In fact, it is the designer's responsibility to determine the best values of these factors.
- **Response *(y)*** represents the actual value of the product's/process' quality or, in other words, response of the product's/process' function. Each of these factors can take different values, so-called levels.

As it is previously said, the goal of Taguchi method is to reduce the effects of product/process variation without their elimination. The metric of product/process insensitivity to variation is signal-to-noise (S/N) ratio. The S/N represents the ratio between the signal of a product/process and noises in its environment (Fig. 1). By increasing the S/N ratio a product/process becomes more insensitive to variations in its environment. In simple words, it is a measure of functionality of a process' to improve product performance (quality). The expression used to calculate the S/N ratio depends on chosen QC (Quality Characteristic) and it is expressed in dB (decibels), Table 1:

Table 1: S/N ratios [2]

Quality Characteristic QC	S/N ratio (dB)
Smaller-the-better	$-10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$
Nominal-the-best	$10 \cdot \log_{10}\left(\frac{\mu^2}{\sigma^2}\right)$
Larger-the-better	$-10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right)$

The terms used in Table I, can be described:

n - Number of observations,
y_i - The QC value of the observation "I",
μ - The average value of a sample.
σ - Standard deviation of the sample.

II. OPTIMIZATION OF A SUPPLY CHAIN WITH TAGUCHI METHOD

In this section the application of Taguchi method is illustrated on a supply chain model. The supply chain was modelled and simulated using eM-Plant^{TM} software package for the discrete event simulation [3].

The supply chain is consisted of four producers (P1-P4), four distributors (D1-D4) and two wholesalers (W1 and W2), Figure 2.

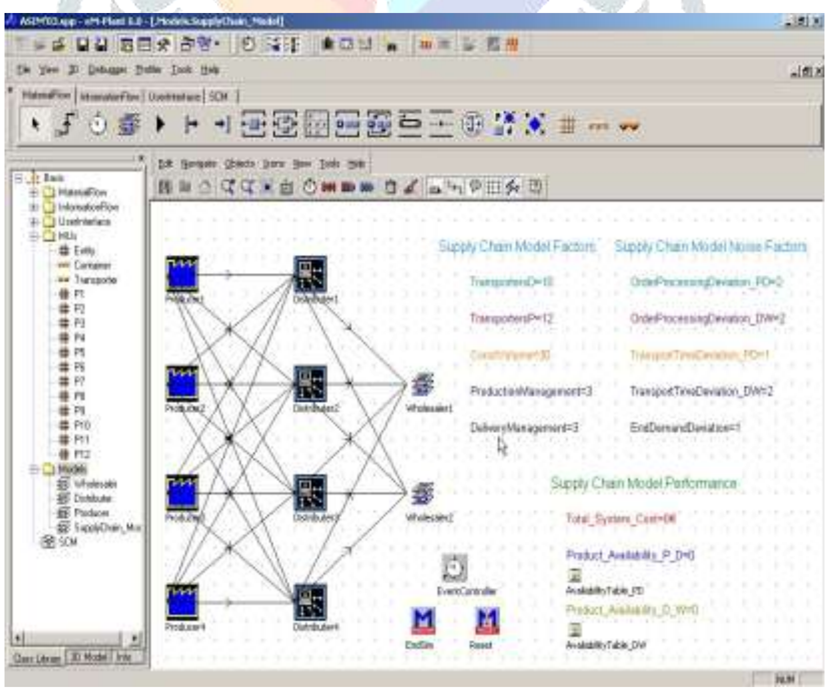

Figure 2: The model of supply chain

The producers produce 12 different kinds of product that are ordered by the distributors. Two wholesalers order from the distributors. Each of the four producers produces only six of the before mentioned products that are characterized with different specifications (product volume and production time). Transport times between different tiers in the supply chain are presented in table 2 and are expressed in hours.

Table 2: Transport times

	P1	P2	P3	P4	W1	W2
D1	14	20	20	12	8	12
D2	18	16	13	19	10	11
D3	14	16	20	17	14	6
D4	20	12	14	20	16	8

The supply chain model is characterized as:

- Wholesalers W1 and W2 place an order at the ninth day of simulation where the quantity of ordered products follows the uniform distribution U (1, 5). A wholesaler randomly chooses the distributor and this is also modelled as uniform distribution U (1, 4). The time between two consecutive orders of a wholesaler is described with the negative exponential distribution NegExp (4), where 4, expressed in hours, represents an average time between two orders.
- The distributors hold at their storages some amount of products (each of the 12 products). At the eighth day of simulation the distributors forward the orders of 50 pieces of each product to producers. If the ordered amount can be shipped, which depends of current storage capacity of a product and transporters availability, it is shipped, and if not only the part of the order is shipped and the rest is backordered. An order is defined as realized only if it the whole quantity of products ordered is shipped.
- The producers make products for seven days until the first order of a distributor. The P1 and P3 make products 1-6 and P2 and P4 products 7-12. The D1 and D2 order products at P1 and P2, while D3 and D4 order at P3 and P4. If a producer can deliver the whole amount of products ordered by a distributor (that depends of current product and transporters availability) it delivers it and if not it delivers only the amount that can be delivered at the moment. An order is defined as realized only if it the whole amount of products ordered is shipped.
- The performance metrics of the supply chain are: the total system cost and average product availability (number of realized orders/total number of orders) between the two tiers, i.e. between the producers and distributors (P-D) and distributors and wholesalers (D-W).
- Total system cost consists of: storage and transport costs, of producers and distributors, and penalty costs due to backorders between the involved tiers in the supply chain.
- The simulation time of the model is three months.

Table 3: The control factors of the supply chain model

Factor	Level		
A - Num. of distributors' transporters	10	12	14
B - Num. of producers' transporters	8	10	12
C - The order of distributor	10pcs.	20 pcs.	30 pcs.
D - Production volume	5 pcs.	10 pcs.	20 pcs.
E - Accumulation of orders	9h	6h	3h

The response of the model is already defined in the model characteristics: total system cost and average product availability and they are smaller-the-better and larger-the better type respectively. The control ***(z)*** and noise factors ***(x)*** of the model are represented in tables 2 and 3.
Design of experiments for the model is determined by choosing the orthogonal arrays, among the standard ones [2] that could accommodate the control and noise factors. The L_{18} standard array and L_8 standard array has been chosen for the control and noise factors respectively. By knowing the orthogonal array the plan of experiments is explicitly defined. The experiments are conducted according to L_{18} array on which the effects of noise factors are simulated by L_8 array.

Table 4: The noise factors of the supply chain model

Factor	Level	
Order time deviation P-D	1h	2h
Order time deviation D-W	30min.	1h
Transport time deviation P-D	3h	5h

Transport time deviation D-W	2h	4h
End demand deviation	30% lower	30% higher

.
In this specific situation this means that for every of 18 control factor combinations the effect of noise factors is simulated through 8 noises factor combinations. Also, every control/noise factor combination is replicated 3 times so the total number of experiments resulted in: $432=18 \cdot 8 \cdot 3$.

Table 5: The relative effects of control factors

Factor	Level	Total cost (S/N)	Total cost	P-D availability (S/N)	P-D availability	D-W availability (S/N)	D-W availability
A	10	-131.92	3651648.25	-5.28	0.68	-24.81	0.23
	12	-132.02	3675747.00	-2.44	0.78	-24.88	0.23
	14	-131.91	3649622.00	-2.62	0.77	-25.66	0.24
B	8	-132.02	3676580.75	-4.69	0.68	-26.88	0.23
	10	-131.94	3655807.00	-2.20	0.80	-24.28	0.24
	12	-131.89	3644629.00	-3.46	0.75	-24.20	0.22
C	10pcs.	-133.88	4224864.50	-0.12	0.99	-34.78	0.05
	20pcs.	-128.06	1937987.00	-1.67	0.83	-24.40	0.36
	30pcs.	-133.91	4814165.50	-8.56	0.41	-16.18	0.28
D	5pcs.	-131.93	3656292.75	-2.44	0.78	-24.64	0.24
	10pcs.	-131.92	3652803.25	-2.39	0.79	-24.62	0.22
	20pcs.	-132.00	3667921.75	-5.51	0.66	-26.10	0.24
E	9h	-131.96	3654499.25	-2.44	0.78	-26.54	0.19
	6h	-131.90	3653938.00	-3.98	0.74	-25.39	0.23
	3h	-131.99	3668580.00	-3.92	0.71	-23.42	0.28

Table 5 presents the relative effects of control factors, according to the results of experiments, expressed in the system's metrics (total system cost and product availability).
The optimal combination of control factors can be found by observing their relative effects. Generally for the S/N metric the larger value is desired (not absolutely larger value). By analyzing the relative effects from table 5 the optimal combination of control factors that should result in the greatest insensitivity to noises is: $\mathbf{A_2\ B_2\ C_2\ D_2\ E_1}$.
The optimal combination is verified by comparing it with the randomly chosen control factor combination: $\mathbf{A_2\ B_1\ C_3\ D_3\ E_3}$. The results of this comparison are presented in table 6.

Table 6: Optimal vs. random control factor combination

Combination	Total cost (S/N)	Total cost	P-D availability (S/N)	P-D availability	D-W Availability (S/N)	D-W availability
$\mathbf{A_2\ B_1\ C_3\ D_3\ E_3}$	-133.43	4847914.43	-16.03	0.158	-11.84	0.32
$\mathbf{A_2\ B_2\ C_2\ D_2\ E_1}$	-120.39	1919121.49	-1.2	0.87	-16.45	0.29

III. CONCLUSION

In the paper the use of Taguchi method for supply chain optimization has been presented. The efficiency of the method was presented on a supply chain model that consists of four producers, four distributors and two wholesalers. Even the presented model is relatively complex one, real potential of the method could be observed on a more complex model, e.g. model in which more entities are involved that on the other hand results in larger number of relevant control and noise factors. Results in table 6 present enough evidence about the appropriateness of the method for supply chain optimization.

The major benefit of Taguchi method is its ability to implement the effects of a supply chain environment while searching for optimal configuration. In this way the resulted supply chain is insensitive on variations generated in its internal and external environment.

Taguchi method is conducted in two stages: parameter and tolerance design. Former has been presented in the paper. The parameter design is conducted until the greatest insensitivity on variations in achieved. So it is an iterative process. On the other hand the reason of tolerance design study is to identify which noise factors are the largest drivers of decrease of a system's variation insensitivity. By identifying those noise factors the appropriate activities (or boundaries in which the noise factors are controlled) for the reduction or elimination of their effects could be set. The future research of the use of Taguchi method in a supply chain optimization will involve the application of tolerance design.

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