Disney, S.M., Lalwani, C.S. and Naim, M.M., (2002), "Dynamic Design and Risk Assessment of Logistics Distribution Networks" Proceedings of the 7th International Symposium of Logistics and the 2nd International Symposium on Operations Strategy, Edited by Sadler, I., Power, D. and Dapiran, G.P., 14-17 July, Melbourne, Australia, 2002, pp437-444, ISBN 0-9281275-0-6.

Dynamic Design and Risk Assessment of Logistics Distribution Networks

S. M. Disney, C. S. Lalwani*, & M. M. Naim
* Corresponding Author: Logistics Systems Dynamics Group,
Cardiff Business School,
Cardiff University,
Aberconway Building, Colum Drive,
Cardiff – UK, CF10 3EU.
Lalwani@cf.ac.uk
Tel: +44(0) 29 2087 6083
Fax: +44(0) 29 2087 4301

ABSTRACT

The structures of supply chains are affected by various factors that change over time. These factors influence the location and number of stockholding locations in a distribution network, the inventory holding costs and the transportation costs. In this paper a systematic approach has been developed to ensure that the future supply chain scenario is robust to the changing operating environment that is used to highlight when it is important to redesign the distribution network. The Taguchi method and simulation was used on case study data from the automotive industry. The generic methodology developed in this paper suggests that for our case study, the capital holding charge for inventory is the most important factor affecting the structure of the distribution network. Thus, if the companies are aligning their capital holding charge with the expectations of the shareholders (or linking it to bank loans) then this needs to be monitored closely in order to judge when the supply chain needs to be redesigned.

INTRODUCTION

Companies who have a large number of suppliers and a large customer base and whose value proposition is stockholding and delivery of goods are often in doubt over the optimality of their distribution network. It is possible that these companies may make an attempt to redesign the network when it is not necessary thus incurring unnecessary costs. Alternatively the companies could fail to recognise the need for redesigning the network and therefore run an inefficient operation or fail to offer the service levels customers demand.

In this paper an attempt has been made to identify the factors that affect the structure of a distribution network. An approach utilizing simulation and the Taguchi Method has been used to analyse the sensitivity of the distribution network design to eight factors identified by managers in our case study as important. The simulation model is based on real case study data of a European after-sales business in the automotive industry. Using the Taguchi method, the percentage contribution of the factors affecting the design of the distribution network has been calculated. We show that the cost of capital associated with the inventory holding is the most important factor in the design of a distribution network. Companies, to identify when to make changes to a distribution network to ensure that it remains competitive and optimal, can use the methodology presented in this paper to achieve this aim.

METHODOLOGY

Our methodology follows five major steps; identifying the current supply chain state, adapting the current state to a likely future scenario, identifying important uncontrollable factors and a suitable experimental design, running the experiments and analysing the results.

In the first stage we developed a CAST-dpm model of the transport, warehouses operations and the customer and supplier base of a Europe Aftermarket business in the automotive sector. The collection of information on the current business environment e.g. customers, suppliers, warehouses, inventory and transport costs has been previously been described in Disney, et al (1997) and Hammant et al (1999).

BRAINSTORMING WORKSHOPS

An important consideration in the design of logistics distribution network is the suitability to the future-operating environment. A study was conducted to determine how the supply chain is expected evolve over time and this was incorporated into the modelling data set. This data was obtained through brainstorming workshops run for business managers. An example of the outputs from such workshops for a particular UK industrial sector is shown in Figure 1 and Table 1. Our case study on automotive sector has been previously reported by Hammant et al (1999) and we exploited the work of Hill (1993), Johansson et al (1993) and Harland (1990) in this study.

From / To	Systems Manufacturer	OE/Aftermarket Operator	Strategically Aligned Distributo	National Wholesalers	Inter Factor	Central Stores	Independant Wholesalers	Fitters	Retailers	End User	Specialist
Systems Manufacturer											
OE/Aftermarket Operator	1,2,3										
Strategically Aligned Distributor		3			3	3					
National Wholesalers		1,2			2,3	2					
Inter Factor		1,2,3									
Central Stores		2,3									
Independant Wholesalers				1,2,3	3						
Fitters		3	3	1	1	3	1,2,3				2,3
Retailers		1					1,2,3				
End User			3					1,2,3	1,2,3		2,3
Specialist		2,3			3						

Figure 1. Matrix representation of the 1990 (1), 1997 (2) and 2005 (3) automotive aftermarket supply chain structures of material flow channels, (1990 values adapted from Harland et al (1993))

Measures of Performance	1990	1997	2005
Quality	Market Qualifier	Order Winner	Market Qualifier
Order Cycle Time	Market Qualifier	Market Qualifier	Order Winner
Service Level (availability)	Market Qualifier	Market Qualifier	Market Qualifier
Cost	Order Winner	Market Qualifier	Market Qualifier

Table 1. Perceived change in importance of the aftermarket sector measures of performance

DESIGN OF EXPERIMENTS USING TAGUCHI METHOD

Through brainstorming sessions various factors that affect the network design were identified. The purpose of this stage in the methodology is to identify a limited number of simulation experiments to determine the sensitivity of the network design without excess experiments. This was achieved by a sensitivity analysis to determine how the network design changes with different company policies and market conditions. This sensitivity analysis or robustness test was performed using the Taguchi Method (see Figure 2). Importantly, here we have used the Taguchi Methodology at this stage to identify a set of simulation experiments to conduct in a CAST-dpm model of our warehouse, transportation and customer and supply base.

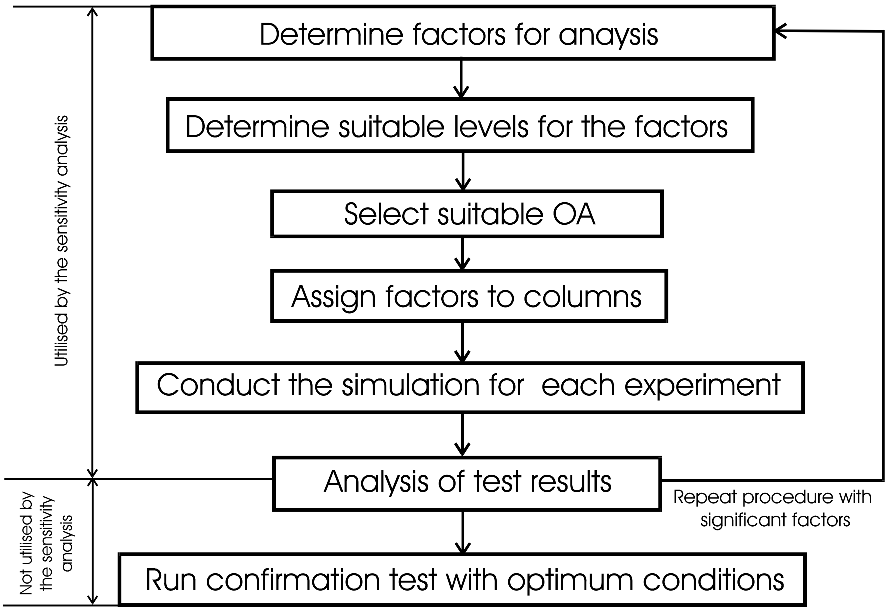

Figure 2. Outline of the Taguchi Method utilised

During the brainstorming session we identified eight uncontrollable factors and levels of those factors that could be part of a future scenario. The *first* factor was the inventory holding costs that was calculated as a percentage of the inventory value. The *second* factor was the transport tariffs.

A commercially important sensitivity analysis that can be conducted is the robustness of the network to changing market shares in different European regions. For example, what if the company's market share in Spain was to increase/ decrease and as a result the demand for the company's products was to increase/ decrease by a factor of 25%? The *next five* factors represent these changes to the UK, France, Germany, Spain and Italy market regions (case study countries). The *final factor* included was the delivery frequency to each individual customer.

The sensitivity analysis considers the effect of the eight selected factors on the design of the network. To determine the main effects of each of these eight factors an analysis was conducted using Taguchi's Orthogonal Arrays (OA). To determine how each of the five main regional market shares affects the solution (Spain, Italy, France, Germany and the UK), each individual customer demand was altered by a factor of 0.75, 1 or 1.25 within each region. The corresponding supply base was also scaled across the board to make supply equal demand as appropriate. Inventory carrying costs were subjected to a capital holding cost of 6%, 20% and 40% to reflect shareholder expectation via the EVA framework that our case study company had adopted (Young 1997). Transportation costs were scaled by a factor of 1, 1.25 and 1.5 as they were expected only to rise, rather then fluctuate around a nominal value. Finally the delivery frequency to the customer was multiplied by a factor of 1 and 2 on a customer by customer basis. These are used as the three levels in the experimental design and orthogonal arrays.

SIMULATION OF THE EXPERIMENTS AS DEFINED BY THE OA

The eight factors have two main influences; firstly on the optimum number of facilities (distribution centres/depots) in a network, and secondly, the total logistics costs (inventory and transportation costs) involved. Hence, for each of the simulations that were required, we optimised the network, by finding the optimum number and location of the DCs in the network and simulated the network performance to determine the inventory and transportation costs.

DATA ANALYSIS AND THE RESULTS

Taguchi's methodology as outlined in Figure 2 and succulently described in Ranjit (1990) was used to estimate the contribution of each factor with the least number of analytical investigations, significantly reducing computer time in the simulation environment. The use of the L18 OA allows the full factorial design of 4374 experiments (which would have been time consuming with present day computing power) to be examined with just 18 experiments. This is a significant saving of computer analysis time.

An L18 OA was chosen for the first analysis. It consists of one, two level factor and seven three level factors. The two level factor (column 1) was assigned to the delivery frequency (normal or increased by a factor of 2), to reflect the need to be robust to increased customer demands. The rest of the (seven) factors where assigned to the remaining three level columns. The experimental results of this analysis are shown in Table 2.

Level 3	na	1.50	0.40	1.25	1.25	1.25	1	1		
Level 2	2.00	1.25	0.20	1.00	1.00	1.00	1	1		
Level 1	1.00	1.00	0.06	0.75	0.75	0.75	1	1		
Expt	Delivery Frequency	Transport Costs	Inventory Costs	UK Demand	French Demand	Germany Demand	Italy Demand	Spain Demand	Depots	Total Costs
1	1	1	1	1	1	1	1	1	5	20812
2	1	1	2	2	2	2	2	2	1	28630
3	1	1	3	3	3	3	3	3	1	37130
4	1	2	1	1	2	2	3	3	5	26018
5	1	2	2	2	3	3	1	1	1	34244
6	1	2	3	3	1	1	2	2	1	41974
7	1	3	1	2	1	3	2	3	5	30241
8	1	3	2	3	2	1	3	1	4	26018
9	1	3	3	1	3	2	1	2	1	46960
10	2	1	1	3	3	2	2	1	5	29285
11	2	1	2	1	1	3	3	2	2	40611
12	2	1	3	2	2	1	1	3	1	49991
13	2	2	1	2	3	1	3	2	5	33137
14	2	2	2	3	1	2	1	3	2	46674
15	2	2	3	1	2	3	2	1	2	58481
16	2	3	1	3	2	3	1	2	5	40891
17	2	3	2	1	3	1	2	3	3	53018
18	2	3	3	2	1	2	3	1	2	66219

Table 2. The L18 orthogonal array and experimental results

Table 2 shows the three levels of each of the eight factors included in the analysis allocated to L18 OA based on the Taguchi method. Based on this experimental design the analysis of variance (ANOVA) was carried out to determine the percentage contribution of each factor to the simulation outputs of the total costs and number of depots in the logistics distribution network. The ANOVA results are shown in Table 3.

Factor	% contribution to total logistics costs	% contribution to the number of DC's in the network
Delivery Frequency	34.36	0.95
Transport Costs	10.59	4.44
Inventory Costs	47.39	84.44
UK Demand	2.16	1.9
French Demand	0.96	0.63
Germany Demand	1.37	1.9
Italy Demand	0.58	2.53
Spain Demand	0.41	2.52
Error	2.15	0.63

Table 3. ANOVA results for the L18 experimental design

The results show that 84% of the influence on the optimum number of distribution centres in a network is due to the percentage interest rate chosen by a company for inventory carrying costs. However, it only makes a 47% contribution to the total logistics costs.

Table 3 show shows the contribution of the demand profile in different countries was relatively insignificant on both the number of DCs and costs in the distribution network. Taguchi recommends that the ANOVA procedure is repeated with insignificant factors removed. This was conducted using the L9 orthogonal array in the design of experiments. The significant factors (see Table 1) studied in this revised analysis are the delivery frequency, the transport costs and the inventory costs. All other factors were held at the nominal state. The orthogonal array and experimental results are shown in Table 4. The ANOVA for the total logistics costs and the optimal distribution centres in the network are also shown in Table 5.

Level 3	0.50	1.50	0.40		
Level 2	2.00	1.25	0.20		
Level 1	1.00	1.00	0.06		
Expt	Delivery Frequency	Transport Costs	Inventory Costs	Depots	Total Costs
1	1	1	1	5	20036
2	1	2	2	3	34557
3	1	3	3	2	50853
4	2	1	2	3	43455
5	2	2	3	2	64022
6	2	3	1	5	44538
7	3	1	3	1	32477
8	3	2	1	5	16403
9	3	3	2	2	29394

Table 4. The L9 orthogonal array and experimental results

Factor	% contribution to total logistics costs	% contribution to the number of DC on the network
Delivery Frequency	50.98	3.52
Transport Costs	7.81	0
Inventory Costs	40.92	91.76
Error	0.29	4.71

Table 5. ANOVA results for the L9 OA

The results from the L9 array tests support the L18 analysis, with the delivery frequency accounting for 51% of the total costs, but the inventory costs are determining 92% of the decision for the number of distribution centres in a distribution network. From this analysis it can be concluded that the main influence on the design is the cost of capital.

Table 5 also shows that the most influential factor of the total logistics costs is the delivery frequency, accounting for half of the contribution. This is intuitively due to the economies of scale in the transport cost structure. The inventory costs are accounting for 40% of the total logistics costs. Interestingly, the distribution network design is quite robust to transport cost changes, as they account for approximately only a 10% contribution. Table 5 shows that the major influence on the number of distribution centres in the network is the capital cost.

RESEARCH IMPLICATIONS AND CONCLUSIONS

It was surprising that our research has shown that the transport costs and the demand profile of the different market regions were relevantly unimportant in terms of affecting the design of the distribution network. Looking closely at the results of the analysis on total logistics costs the delivery frequency came out as an important factor but inventory holding costs had the biggest effect on both number of DC's and logistics costs. In a company with products with high hidden inventory costs such as obsolescence and short product life issues, there may be a need to reduce the number of DC's.

The analysis indicates that the when developing the network careful consideration has to be given to reliably estimating inventory holding costs and the mechanism for determining the capital holding charge. The model is sensitive to these variables and hence we are prone to higher risk of designing the wrong network if these variables are incorrectly estimated.

Furthermore, our analysis suggests that higher customer expectations on delivery frequency have an impact on total logistics costs and therefore companies should consider charging customers different rates for different levels of customer service.

A useful generic method has been presented in this paper for investigating the sensitivity of a scenario without incurring expensive analysis costs such as endless simulation. This novel approach combines the use of simulation, Taguchi method and ANOVA with the distribution design modelling using the software CAST-dpm with the case study data in automotive industry.

REFERENCES

Disney, S.M., Childerhouse, P. and Naim, M.M., 1997, "The Development Of Supply Chain Structures In The Automotive Aftermarket Sector", Proceedings of the Logistics Research Network Conference, Huddersfield, 16-17 September.

Hammant, J., Disney S.M., Childerhouse, P. & Naim, M.M., 1999, "Modelling The Consequences Of A Strategic Supply Chain Initiative Of An Automotive Aftermarket Operation", International Journal of Physical Distribution and Logistics Management, Vol. 29, No. 9, pp535-551.

Hill, T., 1993, "Manufacturing Strategy: The Strategic Management of the Manufacturing Function", Macmillan, London.

Harland, C., Williams, D. and Fitzgerald, L., 1993, "Supply chain methodology", Human Systems Management, Vol. 12, pp17-23.

Johansson, H. J., McHugh, P., Pendlebury, A. J. and Wheeler III, W. A., 1993, "Business Process Re-engineering", John Wiley and Sons Ltd, Chichester.

Ranjit, K. R., 1990, "A Primer on the Taguchi Method", Van Nostrand Reinhold, New York.

Young, D., 1997, "Economic Value Added: A Primer for European Managers", European Management Journal, Vol. 15, No. 4, pp335-43.