THE IMPACT OF REPLENISHMENT FREQUENCY ON THE LOGISTICS COST-A SIMULATION APPROACH

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ABSTRACT
The aim of this research is to optimise logistics cost through fractal supply network by investigating the effect of different replenishment frequencies within fractal supply network. A new mathematical model is developed through which inventory holding cost and transportation cost can be integrated and measured at different sub-fractal of the fractal supply network. The proposed mathematical model is implemented through the hypothetical fractal supply network and validated using Supply Chain GURU Simulation Software. Application of the proposed mathematical model provides a systematic method through which practitioners should be able to decide upon replenishment frequency at different sub-fractal of the network. Moreover, it shows that the proposed fractal supply network and its capabilities have ability to optimise and achieve the lowest logistics cost through the supply network.

Keywords: Fractal supply network, Supply network modelling, Logistics cost optimisation.

1. INTRODUCTION

Logistics processes affect the customer satisfaction, product value, benefits and operating costs and it is important in two aspects; essential and costly (Aronsson et al 2003). Enhancing delivery performance and reduce costs which are caused by activities related to logistics of a company or a supply chain are aims of logistics management (Borgqvist and Hultkrantz, 2005).
The concept of total cost of logistics is very important because this criterion can be a good basis for cost-cutting analysis. Effective logistics cost reduction is very dependent on an integrated and systematic approach, while the focus on minimising the cost of each area separately may be offset by increasing costs in other areas (Stock and Lambert, 2001). Total logistics costs are often provided as a large part of total sales revenue (Min et al., 2009). The definitions of logistics costs are vary in different companies. In large number of companies, logistics costs reports are different even with similar business and there are different items at their own expense. However, the main activities of the operational logistics including transportation, handling, storage and maintenance of inventory make up the key logistics costs (Gudehus and Kotzab, 2009). In terms of logistics, inventory holding and transportation are the most important costs for strategic development of enterprises (Cesca, 2006). The result of a study was conducted in the America logistics costs in 2008 shows that transportation costs are the most important component with 50%, followed by inventory holding cost with 20%, warehousing with 20%; costs related to customer service / order processing with 7% and administrative costs was 3% of the total cost of logistics (Rushton, 2010).
Transportation costs include the cost of transportation equipment such as equipment depreciation and operating costs such as fuel costs, payroll, toll and insurance (Chao-yang et al., 2011). Rent and maintenance of vehicles are also part of the cost of transportation. Size and weight of transported goods, travelling distance, number of deliveries, hours of operation (Somuyiwa, 2010), loading capacity, transportation responsibility to the risk of product failure and accidents are drivers of transportation cost (Chao-yang et al., 2011).
Inventory holding costs include the cost of capital, risk, services related to inventory, and variable costs of warehouse space, because it depends on the level of inventory (Stock and Lambert, 2001). Most effective factors in inventory are purchase method, amount of demand, inventory turnover, changes in inventory levels, and types of warehouse and efficiency of data transmission system (Chao-yang et al., 2011).

2. FRACTAL SUPPLY NETWORK

Fractal supply network can be defined as a reconfigurable supply network which has the ability to present many different problem solving methods under the terms of various situations (Fan and Chen, 2008). Fractal supply network attracting many of industrialists because of its capabilities such as self-similarity, self-optimisation, self-organisation, goal orientation, and dynamics (Warnecke, 1993).
Self-similarity means each fractal unit is similar to another fractal unit while they can have their own structure (Attar and Kulkarni, 2014). Although, fractal units may have a different condition and internal

structure in comparison to another they can have a same target in the system. Therefore, in the fractal supply network, fractals are self-similar if they can achieve goals in the system with different internal structure while inputs and outputs are same (Ryu et al, 2013). Higher self-similarity in the supply network can increase the information sharing, operation coordination and degree of integration among the fractal units and decrease the complexity of the system and make supply network to be understood and managed clearly (He, 2010).

Self-optimisation means each fractal unit as independent unit has ability to improve its performance continuously. Fractals choose and use suitable methods to optimise operation and decision making processes with coordination of the whole system to achieve the goals (Attar and Kulkarni, 2014; He, 2010; Ryu et al., 2013).

Self-organisation (dynamic restructuring) refers to support the reconfiguration of network connections between fractals and the reorganisation of fractals in the system (Ryu and Jung, 2003). It means each fractal is free to make decision about the organisation dimension which is require for special performance with regards to environmental parameter and the goals (He 2010) without external intervention (Leitão and Restivo, 1999). In fact, self- organisation as a kind of supply chain organisation convert irregular condition into regular condition without outer monitoring and control to offer products and services to customers constantly (Fan and Chen, 2008).

Goal orientation enables the system goals to be achieved from the goals of individual fractals (Warnecke, 1993). Fractal units perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals and modifying goals if necessary (Ryu and Jung, 2003)

Dynamics refer to cooperation and coordination between self- organising fractals which are characterised by a high individual dynamics and an ability to restructure their processes to meet and adapt to the dynamically changing environment (Ryu and Jung, 2003).

3. LOGISTICS COST INTEGRATION

Nowadays, to provide value advantages in the supply chains companies try to decrease inventory with higher replenishment frequency. However, it may leads to increase in the transportation cost due to longer travel distances. In addition, inventory holding cost and transportation cost are independent to each other; both of them are function in replenishment frequency with inverse and direct relationship respectively.

Therefore, contrast between transportation cost and inventory holding cost has been focused for planning activities. Viau et al. (2007) used Decision Support Systems (DSS) model to integrate inventory control and transportation operation in the spread supply chain by considering delivery frequency and date of delivery to nodes (e.g. Friday and Monday) as variables. Moreover, mathematical models of inventory holding cost and transportation cost are created in order to reduce logistics cost. Qu et al. (1999) developed mathematical model to integrate inventory and transportation policies by considering a central warehouse and several suppliers under stochastic demand during a period time. Hong et al. (2012) presented a model to integrate inventory and transportation for ubiquitous supply chain management and developed mathematical model which demand of products assumed as linear, convex and concave function of price. Chen et al. (2012) used non-linear programing to minimise both inventory cost and transportation cost. They developed a model with one supplier and several retailers and compared the results with traditional approach which was based on Economic Order Quantity (EOQ). Kutanoglu and Lohiya (2008) built inventory model in terms of single-echelon and multi-facility and integrated with both transportation and service responsiveness. They use three alternate modes namely slow, medium and fast in the service parts logistics system. Hong Zhao et al. (2010) developed an algorithm to solve Markov decision process model which was applied to formulate ordering and delivery problems based on vary transportation modes, costs and inventory issues. Pei et al. (2012) used bi-level programming method to establish mathematics model in order to integrate and optimise inventory and transportation cost with probable demand and various products. Swenseth and Godfrey (2002) proposed a method to approximate the actual transportation cost with truckload freight rates into inventory replenishment decisions in order to minimise the total logistics cost. They claimed that the complexity arising from incorporating transportation cost into inventory replenishment policies does not affect the accuracy of decisions. Zhao et al. (2004) introduced the problem of minimising the production, inventory and transportation costs in a two- echelon system model. They made a trade-off among production, inventory and transportation costs and considered both the fixed cost and the variable cost of the vehicles.

There is some research focused on integration of inventory and transportation in order to minimise logistics costs. However, in terms of fractal supply network, there is very few technical research carried out in this area. The focus of this paper is to optimise logistics cost by investigating the different replenishment frequencies on both transportation and inventory holding through fractal supply network.

4. THE PROPOSED MATHEMATICAL MODEL

In order to achieve the lowest total logistics cost through each fractal in the fractal supply network, both inventory holding costs and transportation costs can be integrated to choose the best match and find the optimum amount of replenishment frequency. Through understanding the mathematical equations governing the problem of inventory holding costs (IHC) and transportation costs (T(c)); mathematical model is presented briefly as follows due to space limitation, which will be presented in details during the conference.

$$Min\left(\left\{\sum_{j}^{n} SS_j + DBR \times \left(\frac{\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j}{2T}\right) + \frac{\left(\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j\right) t}{T}\right\} \times C_{(v)}/P_{(v)} \times \frac{T}{365} \times I_{(cc)\%} + td \times \frac{\sum_{j=1}^{n} SS_j \sum_{j}^{n} TD_j}{DBR \times \mu_d} \times A_{(C)}\right),$$

$$DBR = 1, \dots, x$$

Where
SS =Safety stock
DBR = Days between replenishment
TD = Total demand of component/product j
j = Index number of different component/product
n= Number of different component/product
T = Time period
t= Transportation time
$C_{(v)}$ = Component value
$P_{(v)}$ = Product value
$I_{(cc)\%}$ =Inventory carrying cost percentage
td =Travel distance
μ_d = Average daily demand
$A_{(c)}$ = Average transportation cost per mile

5. MODEL VERIFICATION AND VALIDATION

The validity of the developed simulation model was evaluated by comparing the performance of the model to the conceptual system (manually calculated). Experiments were carried out, to investigate how robust the proposed model is, the output values obtained from the simulation model were not found significant difference (at most 10.8%) to the estimated values of the conceptual system. Therefore, this increases our confident in the proposed model and can be considered as a valid model for analysis and experimentation and the obtained results should be reliable within this percentage of error. The output values obtained will be presented at the conference.

6. APPLICATON OF THE PROPOSED MODEL

In this study, a simple hypothetical fractal supply network located in England with a core manufacturer (M) located in the Sheffield and deals with just one type of product (K) with value of £100 per product made from different components is considered. Due to long lead times from suppliers to manufacturer, a central supply hub (H) (12.04 miles from core manufacturer) built close to the manufacturer located in Chesterfield. Components are supplied from the following suppliers to Supply Hub (H):

- S_1 (Norwich) deals with a single component (c_1) with a value of £20 (141.2 miles from Supply Hub (H)).
- S_2 (Sunderland) deals with a single component (c_2) with a value of £10 (133.51 miles from Supply Hub (H)).
- S_3 (Swansea) deals with a single component (c_3) with a value of £30 (180.18 miles from Supply Hub (H)).
- S_4 (Southampton) deals with a single component (c_4) with a value of £40 (187.99 miles from Supply Hub (H)).

Moreover, there is a distribution centre (D) (75.19 miles from core manufacturer) dealing with finished product located in in Birmingham with five retailers, including Oxford (R_1) (67.15 miles from distribution centre), Cambridge (R_2) (101.94 miles from distribution centre), Cardiff (R_3) (103.5 miles from distribution centre), Leeds (R_4) (107.55 miles from distribution centre) and Liverpool (R_5) (91.84 miles from distribution centre). The proposed hypothetical fractal supply network is implemented in the Supply Chain Guru Simulation Software within which the proposed mathematical model mentioned in previous section is in-cooperated. Figure 1 displays a snap shot of the GURU model created for the hypothetical supply network.

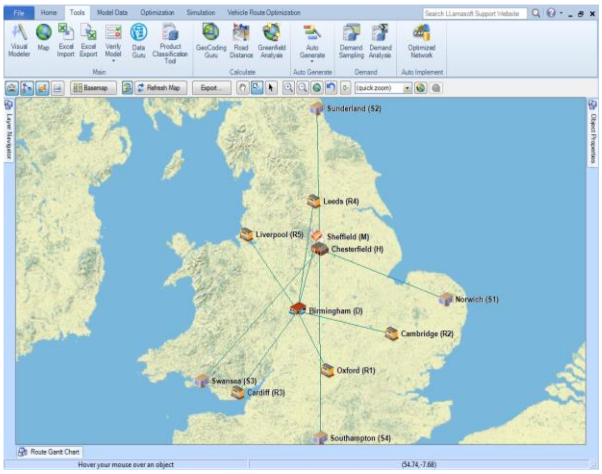

Figure 1: Supply Chain Guru Screen Shot of the Considered Fractal Supply Network

In accordance with fractal theory, each member of the supply network can be a fractal by itself, and also any combination of members can be a fractal as well. Figure 2 displays the composition of the of the considered hypothetical fractal supply network. The upstream stage deal with components (c_1,c_2,c_3 and c_4) and consists of three levels; the manufacturer (M) as top level, the supply hub (H) as middle level and suppliers (S_1,S_2,S_3 and S_4) as bottom level. The downstream stage deal with product (K) also consists of three levels; manufacturer (M) as top level, the distribution centre (D) as middle level and retailers (R_1, R_2, R_3, R_4, and R_5) as bottom level.

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In this study, the following compositions of the fractals in the both upstream and downstream stage are assumed and applied in the Supply Chain Guru Simulation Software:

- M in the upstream stage can be considered as a fractal named (Fr-M_1) with one sub fractal (H).
- H can be considered as a fractal named (Fr-H) with four sub fractals (S_1, S_2, S_3 and S_4).
- M in the in the downstream stage can be considered as a fractal named (Fr-M_2) with one sub fractal (D).
- D in the downstream stage can be considered as a fractal named (Fr-D) with five sub fractals (R_1, R_2, R_3, R_4, and R_5).

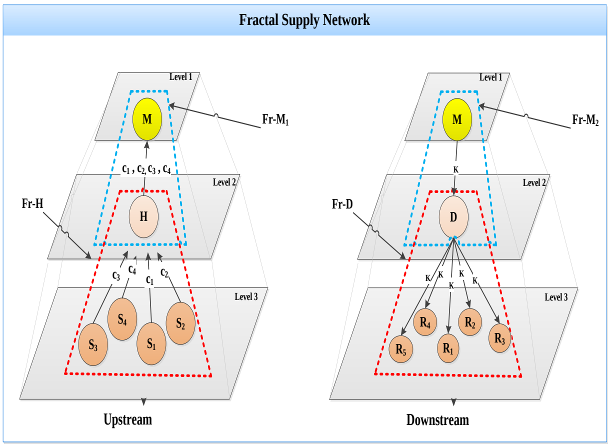

Figure 2: Composition of Fractals in Fractal Supply Network

Retailer's demand of one-month test period for the one type of product (K) has been recorded as shown in Table 1.

Table1: Retailers' Demand of one-month Test Period

	01/12/16	08/12/16	15/12/16	22/12/16	29/12/16
R_1	1000	1000	1000	1000	1000
R_2	N(1000,100)	N(1000, 100)	N(1000, 100)	N(1000, 100)	N(1000, 100)
R_3	N(1000,200)	N(1000, 200)	N(1000, 200)	N(1000, 200)	N(1000, 200)
R_4	N(1000,300)	N(1000, 300)	N(1000, 300)	N(1000, 300)	N(1000, 300)
R_5	N(1000,400)	N(1000, 400)	N(1000, 400)	N(1000, 400)	N(1000, 400)

Moreover, there are some other assumptions as follows:

- The lead time required for all components and product to be replenished from the source sites is assumed to be 1 day.
- The percentage of Inventory carrying cost is assumed to be 12 percent of total value of inventory. In practice, this percentage is identified by senior managers in the company.
- There is a transportation system from a third party with two types of transportation assets (no capacity limitation) to ship components and products from source sites to destination sites, namely; Full truck load (TL) which is assigned to the distance of more than fifty miles with average transportation cost per mile ($A_{(c)}$) of £1 and Less than truck load (LTL) which is assigned to the distance of less than fifty miles with average transportation cost per mile ($A_{(c)}$) of £2.
- Days between replenishment should not be more than 5 days.

With respect to fractal supply network capability each fractal unit as independent unit has ability to improve its performance continuously. Fractals choose and use suitable methods to optimise operation and decision making processes with coordination of the whole system to achieve the goals. Therefore, in this study each fractal investigated different days of replenishment from 1 day to 5 days aiming to minimise its logistics cost and whole network as well.

7. RESULT

As shown in figure 3 the results proved that during the demand of one-month test period for supplying components in the Fr-H, the lowest logistics cost can be achieved with day between replenishment of five days from each supplier (S_1, S_2, S_3 and S_4) to supply hub (H) . Moreover, in terms of Fr-M1, the results showed that during the demand of one-month test period for supplying components from supply hub (H) to Manufacture (M), the lowest logistics cost can be achieved with day between replenishment of 1 day.

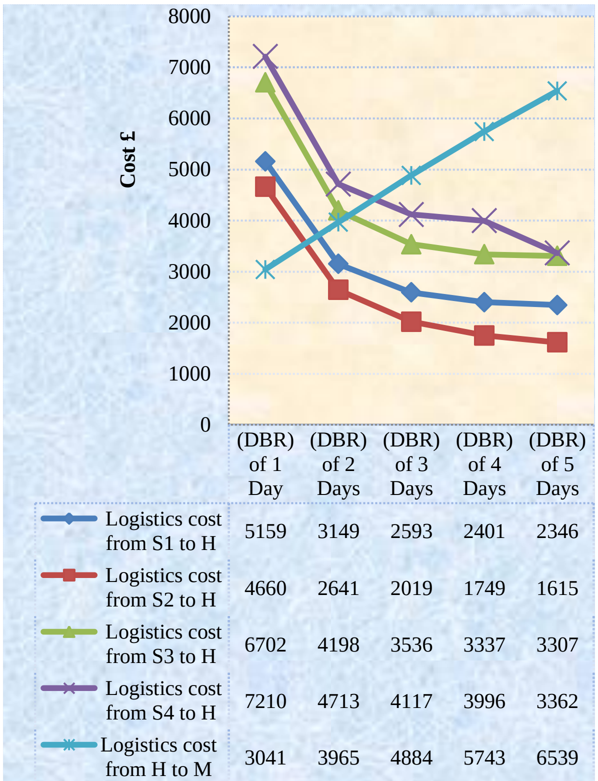

Figure 3: Logistics Cost at different DBR (1 day to 5 days) through Upstream Stage

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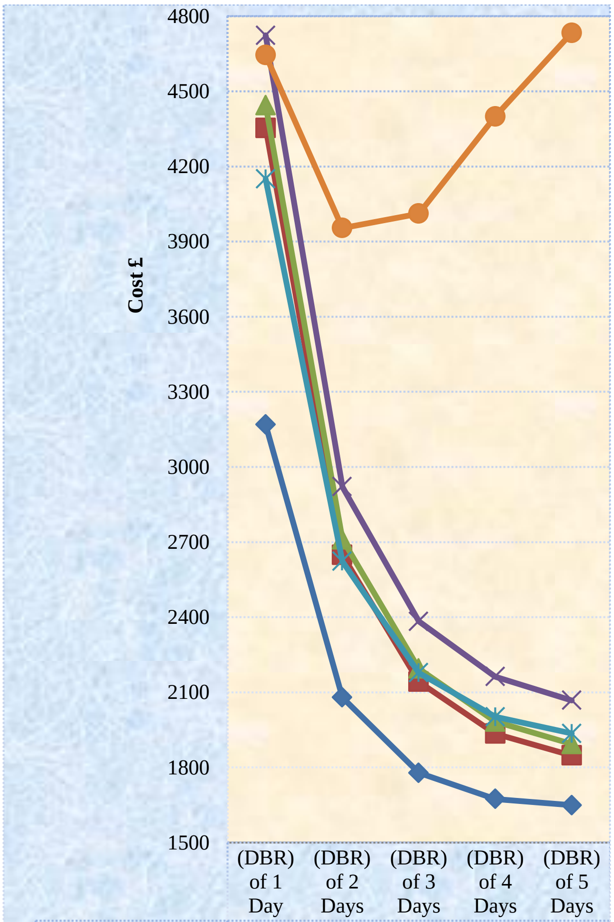
As shown in figure 4, the results proved that during the demand of one-month test period for distributing finished product (K) from Manufacture (M) to distribution centre (D) in the Fr-M_2, the lowest logistics cost can be achieved with day between replenishment of 2 days.

Finally, in terms of Fr-D, during the demand of one-month test period for supplying finished product (K) from distribution centre (D) to each retailer the lowest logistics cost can be achieved with day between replenishment of five days.



	(DBR) of 1 Day	(DBR) of 2 Days	(DBR) of 3 Days	(DBR) of 4 Days	(DBR) of 5 Days
Logistics time from D to R1	3169	2079	1778	1674	1649
Logistics time from D to R2	4354	2649	2142	1935	1848
Logistics time from D to R3	4445	2710	2194	1983	1893
Logistics time from D to R4	4723	2921	2383	2162	2068
Logistics time from D to R5	4150	2623	2178	2002	1935
Logistics cost from M to D	4645	3954	4012	4400	4734

Figure 4: Logistics Cost at different DBR (1 day to 5 days) through Downstream Stage

8. CONCLUSION

In this paper, a new mathematical model is proposed to measure logistics cost through the fractal supply network which inventory holding cost and transportation cost can be measured and integrated at different sub-fractal of the fractal supply network. The hypothetical fractal supply network located in England which is composited to different fractals is considered and implemented in the Supply Chain Guru Simulation Software within which the proposed mathematical model is in-cooperated. Logistics cost optimised by investigating different days between replenishment (from 1 day to 5 days) through each fractal during the period test of one month to choose the best match of inventory holding cost and transportation cost; in order to minimise the total logistics costs within sub-fractals and finally the whole fractal supply network.

Application of the proposed mathematical model provides a systematic method through which practitioners should be able to decide upon replenishment frequency at different sub-fractal of the network. Moreover, it shows that the proposed fractal supply network and its capabilities have ability to optimise and achieve the lowest logistics cost through the supply network.

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