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Responsiveness Optimisation in the Fractal Supply Network

Sameh M SAAD and Ramin BAHADORI
Department of Engineering and Mathematics, Sheffield Hallam University
Sheffield S1 2NU, UK

Abstract. Responsiveness is one of the significant performance measures in today's market based on which organisations can measure their success in seizing markets opportunities within Fractal Supply Chain. This paper aims to present this fractal supply network and also proposes a new mathematical model through which replenishment; transportation, production and handling time can be optimised at different stages of the fractal supply network. Both the proposed Fractal Supply Network and the mathematical model are implemented and validated using Supply Chain GURU Software. Application of the proposed mathematical model has led to a reduction in the total replenishment time and enables practitioners to systematically decide upon the optimum replenishment time at different stage of the network.

Keywords. Fractal supply networks, replenishment time, supply network optimisation.

1. Introduction

For customer satisfaction and better understanding of the market, companies are trying to achieve the best performance using different supply chain parameters including accurate prediction of demand, inventory, responsiveness and etc. Today supply chain responsiveness is an important issue in the supply chain management. Lead time is an important indicator for measuring the responsiveness which means period of time where the final products reach to the target customers. Lead time in the supply chain can be divided to manufacture lead time and distribution lead time [1]. Shortening the lead time in the supply chain is very important, because its changes between sequential stages of the supply chain is often has much impact on supply chain coordination and can provide order winner for the firms. It can be achieved by decreasing in the order transmission, production time, handling time in the warehouses, and traveling time. Therefore, this research tried to measure and optimises replenishment time between each node in order to decrease lead time in the whole fractal supply network.

Fractal supply network can be defined as a reconfigurable supply network which has the ability to present problem solving methods under the terms of various variables. Each part in the fractal supply network has the ability to optimize itself continuously [2]. Fractal Supply network attracting many of industrialists because of its capabilities such as self-similarity, self-optimization, self-organization, goal orientation, and dynamics [3]. An optimal structural representation of the fractal manufacturing partnership (FMP) which facilitates achievement of flexibility and swift response to uncertainties in the manufacturing environment was proposed by [4]. A framework of collaborative in terms of supply chains based on fractal concept was presented by [5] and also analysed a trust model for production planning in automotive industry. Fractal manufacturing systems (FrMS) including its concepts, architecture, and major characteristics have been defined and developed by [6] using IDEF0, Petri-net, and UML. Another framework of e-biz Company in terms of fractal concept in the network supply chain was developed by [7] by using "unified modelling language (UML)".

In terms of responsiveness in the fractal supply network, the literature review indicated there is very few technical research carried out in this area. The focus of this paper is to optimise the replenishment time in the fractal supply network in order to improve responsiveness. The fractal supply network features are introduced to enhance the practitioners understanding of this type of relationship. In addition, the proposed model provided an appropriate method to recognising of bottlenecks in order to optimise the replenishment time and decompose of a complicated supply network into smaller entities (i.e. fractals) with a unified goal to achieve and ability to adapt to the dynamically nature of today's markets.

2. The proposed mathematical model and optimisation planning

Figure 1 displays a framework of a fractal supply network which is used to present the mathematical model of replenishment time. Whole supply network considered as a fractal with chains as sub-fractals (e.g. Fr-chain (n)). Each chain divided in to upstream and downstream stages (e.g. Fr-Upstream (n), Fr-Downstream (n)). Upstream stage consists of suppliers, hubs and manufactures based on raw materials and the downstream stage consists of manufactures, distribution centres and retailers based on finished products. Each node and combination of them is also considered as fractal (e.g. Fr-S x (n)). As a fractal features, Due to self-similarity, duplicate models were applied in the framework which can decrease complexity of system and each fractal has its own structure while they have same inputs and outputs. Therefore, system can be understood and managed clearly. Abilities to use appropriate methods to optimise responsiveness and recognition of bottlenecks in the each node, chains and whole supply network by itself and divided large problem to small problems, perform a goal-formation process to generate their own goal by coordinating process with the participating fractals and modifying goals if necessary, and finally each fractal has ability to adapt to the dynamically environment changing.

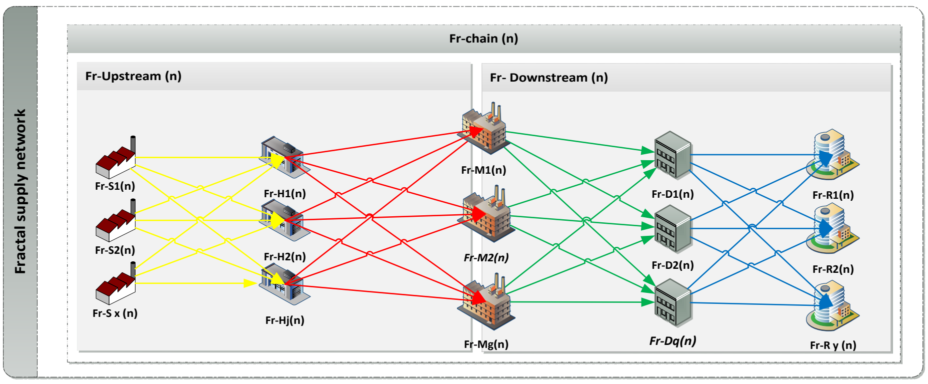

Figure 1. Fractal supply network framework

According to the fractal supply network framework presented and through understanding the mathematical equations governing the problem of replenishment time, a new mathematical model to measure replenishment times in the fractal supply network is presented as follows and Table 1 displays all the notations used in the proposed mathematical model.

Table 1. Mathematical notations

Notation	Description	Notation	Description
S	Supplier	L	Transportation distance
H	Hub	V	Transportation velocity
M	Manufacture	$L_{i\rightarrow r}(n)$	Transportation distance from source to destination in the chain (n)
D	Distribution Centre	$V_{i\rightarrow r}(n)$	Transportation velocity from sour to destination in the chain (n)
R	Retailer	Q	Order quantity
i	Source	z	Index name of different node
r	Destination	$l_{(t)}$	Loading time
(n)	Index name of different chain	$l_{(t)z}(n)$	Loading time of node z in the chain (n)
x	Index number of different Suppliers	$u_{(t)}$	Unloading time
$S_x(n)$	Supplier number x in the chain (n)	$u_{(t)z}(n)$	Unloading time of node z in the cha (n)
y	Index number of different Retailers	$Tr_{(t)}$	Traveling time
$R_y(n)$	Retailer number y in the chain (n)	$Tr_{(t)i\rightarrow r}(n)$	Traveling time from destination to source in the chain (n)
j	Index number of different hubs	$di_{(t)}$	Dispatch Time
H j (n)	Hub number j in the chain (n)	$di_{(t)i\rightarrow r}(n)$	Dispatch Time from destination to source in the chain (n)
g	Index number of different manufactures	$P_{(t)}$	Production time
Mg (n)	Manufacture number g in the chain (n)	$P_{(t)z}$	Production time in the node z
q	Index number of different distribution centres	$P_{(t)\,K_e z}$	Production time of product number e in the node z
D q (n)	Distribution centre number q in the chain (n)	$p_{(t)}$	Production time per unit of product
e	Index number of different products and components	$p_{(t)K_e z}$	Production time per unit of product number e in the node z
c_e	Components number e	$p_{r\,(t)}$	Production preparation time
K_e	Product number e	$p_{r\,(t)z}$	Production preparation time in the node z
$R_{(t)network}$	Total supply network replenishment time	$p_{r\,(t)K_e z}$	Production preparation time of product number e in the node z
$R_{(t)}$	Replenishment time	$L_{r\rightarrow i}(n)$	Transportation distance from destination to source in the chain (ı
$R_{(t)\,i\rightarrow r}(n)$	Replenishment time from source to destination in the chain (n)	$V_{r\rightarrow i}(n)$	Transportation velocity frc destination to source in the chain (n
$R_{(t)\,chain}(n)$	Replenishment time in the chain (n)	$fs_{(t)}$	Fixed service time
$\mathbf{T}_{i\rightarrow r}(n)$	Transportation time from source to destination in the chain (n)	$fs_{(t)z}$	Fixed service time in the node z
$vs_{(t)}$	Variable service time	$h_{(t)}$	Handling time
$vs_{(t)z}$	Variable service time in the node z	$h_{(t)z}$	Handling time in the node z

Replenishment time ($R_{(t)}$) in the whole fractal supply network is equal to the sum of the $R_{(t)}$ in the different chains which deal with $R_{(t)}$ in the own chain. As mentioned before, each chain is divided in to upstream and downstream stages. Replenishment time of a chain is equal to the sum of the $R_{(t)}$ in the upstream and downstream stages. Upstream stage deals with $R_{(t)}$ from suppliers to hubs and from hubs to manufactures and downstream stage deals with replenishment time from manufactures to the distribution centre and from distribution centre to retailer in the chain (n). Therefore, $R_{(t)}$ in the whole supply network can be calculated as follows:

$$R_{(t)network}=\frac{L_{Hj\to S_x}(n)}{V_{Hj\to S_x}(n)}+l_{(t)S_x}(n)+\frac{L_{S_x\to Hj}(n)}{V_{S_x\to Hj}(n)}+u_{(t)Hj}(n)+fs_{(t)Hj}(n)+\left(vs_{(t)Hj}(n)\times Q\right)+\frac{L_{Mg\to Hj}(n)}{V_{Mg\to Hj}(n)}+$$
$$l_{(t)Hj}(n)+\frac{L_{Hj\to Mg}(n)}{V_{Hj\to Mg}(n)}+u_{(t)Mg}(n)+pr_{(t)K_eMg}(n)+\left(p_{(t)K_eMg}(n)\times Q\right)+\frac{L_{Dq\to Mg}(n)}{V_{Dq\to Mg}(n)}(n)+l_{(t)Mg}(n)+$$
$$\frac{L_{Mg\to Dq}(n)}{V_{Mg\to Dq}(n)}+u_{(t)Dq}(n)+fs_{(t)Dq}(n)+\left(vs_{(t)Dq}(n)\times Q\right)+\frac{L_{R_y\to Dq}(n)}{V_{R_y\to Dq}(n)}(n)+l_{(t)Dq}(n)+\frac{L_{Dq\to R_y}(n)}{V_{Dq\to R_y}(n)}+u_{(t)R_y}(n)$$

Figure 2 displays the proposed optimisation planning in the fractal supply network to improve responsiveness in which each fractal try to optimise itself with own decision and methods.

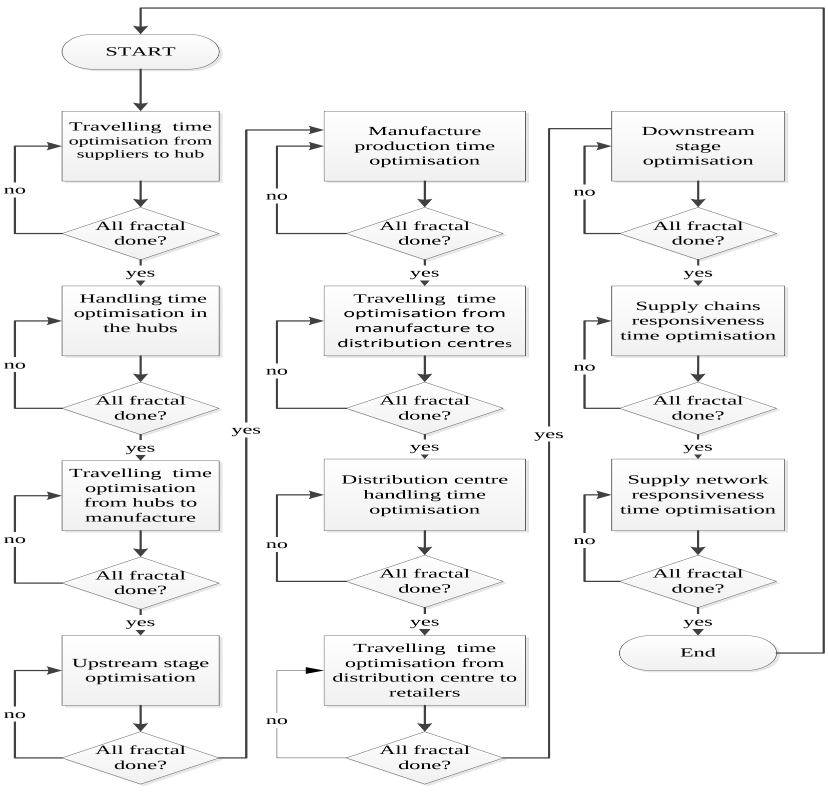

Figure 2. Optimisation planning in the fractal supply network

3. Application of the proposed model

In this paper we assumed a fractal supply network with two chains named Fr-chain (A) and Fr-chain (B). Fr-Chain (A) includes three suppliers Fr-S_1(A) , Fr-S_2(A), Fr-S_3(A), one hub Fr-H(A), one manufacture Fr-M, one distribution centre Fr-D (A), and three retailers Fr-R_1(A), Fr-R_2(A), and Fr-R_3(A). Fr-chain (B) includes two suppliers Fr-S_1(B), Fr-S_2(B), one hub Fr-H(B), one manufacture Fr-M which is common with Fr-chain (A), one distribution centre Fr-D(B), and three retailers Fr-R_1(B), Fr-R_2(B), and Fr-R_3(B). Fr-Chain (A) deals with product K_1 made from three different components (c_1, c_2 and c_3) and are supplied from three different suppliers in the Fr-chain (A). While Fr-Chain (B) deals with product K_2 which made from two different components (c_3 and c_4) which are the responsibility of another two suppliers in the Fr-chain (B).

Each supplier considered as a fractal deals with replenishment to the hub in their chain and each hub considered as a fractal deals with replenishment to the manufacture. Moreover, manufacture as a fractal deals with replenishment to the both distribution centres in the chains A and B. In addition, distribution centre in each chain considered as fractal deals with replenishment to the retailers in their own chain which each retailers considered as a fractal as well. On the other hand, direct routes applied in the baseline model:

Vehicles start from hubs in the Fr-chain A&B and pickup components from Fr-S_1(A), Fr-S_2(A), Fr-S_3(A), Fr-S_1(B) and Fr-S_2(B) respectively and deliver to hubs To replenish manufacture, vehicles start from manufacture and pickup components from hub in the Fr-chain (A) and from hub in the Fr-chain (B) and deliver to manufacture. To replenish distribution centres, vehicles start from distribution centres in the Fr-chain (A) & (B) and pickup products and deliver to distribution centres. Vehicles start from retailers Fr-R_1(A), Fr-R_2(A), Fr-R_3(A), in the Fr-chain (A) and Fr-R_1(B), Fr-R_2(B), Fr-R_3(B), in the Fr-chain (B) and pickup products and deliver to retailers.

According to the propose mathematical model, replenishment time in the whole supply network was 55.28 hours which is equal to the sum of the replenishment time in chain (A) & (B) with 28.77and 26.51 hours respectively. Replenishment time in the chain (A), including replenishment time from suppliers to hub, hub to manufacture and manufacture to distribution centre was longer in comparison to chain (B) except from distribution centre to retailers. Replenishment time in downstream stage was 17.61 hours in the chain (A) and 18.35 hours in the chain (B). On the other hand, replenishment time in upstream stage was 11.16 hours in the chain (A) and 8.16 hours in chain (B). In terms of constituent elements of the supply network replenishment time, traveling time was leading with 33.28 hours, followed by production time and handling time close behind with 12 hours and 10 hours respectively.

Since, in the baseline model traveling time had significant amount among the constituent elements of the supply network replenishment time, based on optimisation planning its optimisation has been focused. Therefore, fractals in each stage of the supply network are tried to use own suitable routing approach in order to optimise the baseline model aiming to reduce route lengths:

To replenish components to hubs, vehicle starts from Fr-H (A) and pickup components from Fr-S_3(A), Fr-S_1(A), and Fr-S_2(A) respectively and come back to

Fr-H (A). On the other hand, vehicle starts from Fr-H (B), pickup components from Fr-S_2 (B), Fr-S_1 (B) respectively and come back to Fr-H (B).To replenish components to manufacture from hubs, vehicle starts from Fr-M and pickup components from Fr-H (A) and Fr-H (B) respectively and come back to Fr-M. To replenish product K_1 to retailers, vehicle start from Fr-D (A) and deliver to Fr-R_3(A), Fr-R_1(A), and Fr-R_2(A) respectively then pickup product K_1 from Fr-M to replenish Fr-D (A). On the other hand, for replenishing product K_2 vehicle start from Fr-D (B) and deliver to Fr-R_1(B), Fr-R_2(B), and Fr-R_3(B) respectively then pickup product $K_2$from Fr-M and delivery to Fr-D (B).

In the optimised model, replenishment time of whole supply network was 40.77 hours and replenishment time of the downstream stage was about twice of replenishment time of the upstream stage. Moreover, in terms of constituent elements of the supply network replenishment time, traveling time still was the first with 23.77, followed by production time with 12 hours and handling time with 10 hours.

Due to space restriction, the graphical presentations of both the direct routes and the multi stop transportation routes will be presented at the conference.

4. Conclusion

In this paper, a new framework of the fractal supply network and its mathematical model of replenishment time were proposed to analyse and measure responsiveness in the supply network in terms of time. The hypothetical fractal supply network as the baseline model was implemented and validated using Supply Chain GURU Software. Traveling time recognised as a bottleneck in the baseline model and multi stop transportation routes were used to optimise the situation between nodes. Thus, in comparison to the baseline model, replenishment time in the whole fractal supply network dropped from 55.28 hours to 45.77 hours in the optimised model. Application of the proposed mathematical model has led to a reduction in the total replenishment time. Most importantly, the novelty of the new proposed framework will enable practitioners to systematically decide upon the optimum replenishment time at different stages of the supply network, which is hardly found in the literature.

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