Applied Mathematics & Information Sciences
An International Journal

A Genetic Algorithm Approach for TOC-based Supply Chain Coordination

Kaijun Leng[1] *and Xiangjun Chen*[2]

[1] Research Center of Hubei Logistics development, Hubei University of Economics, Wuhan 430205, China
[2] School of Business Administration, Hubei University of Economics, Wuhan 430205, China

Abstract: A supply chain is a network of retailers, distributors, manufacturers, and suppliers cooperating to satisfy customers demands. In traditional business environments, each business tries to minimize its costs based on its own cost structure, regardless of other SC participants. However, most decisions made by each SC members are based on the profitability of their own. In this paper, we consider a two-level supply chain in which retailer orders exceeds the suppliers capacity. To balance supply and demand, we proposed a coordination mechanism based on Theory of Constraints (TOC) in face of meeting peak demand in certain period for the whole system, and Genetic algorithm(GA) has been selected in solving the optimal model. Furthermore, a numerical example has been implemented to demonstrate the efficiency of our method.

Keywords: Genetic algorithm, Supply chain coordination, Theory of constraints

1. INTRODUCTION

Intensifying competition in todays business environment has highlighted the need to optimize the design and management of supply chains. Starting with effective product design, the selection of suppliers, facility location decisions, inventory management, distribution strategies, information technology, and finally the coordination and integration activities are critical factors for an effective supply chain [1].

Supply chains generally consist of multiple agents, such as suppliers, manufacturers, warehouses, and distribution centers. In a supply chain, if there is a single decision maker who tries to optimize the overall system, the structure is referred to as centralized [2]. However, generally the various agents have conflicting objectives even when they belong to the same entity. For instance, manufacturers would prefer to produce in large lot sizes in order to reduce setup costs. This would increase inventory amounts, and hence holding costs, which contradicts the objectives of the warehouses. On the other hand, a supply chain in which each agent tries to optimize its own system is referred to as decentralized.

Consider a supply chain in which one supplier sells to multiple retailers and suppose that the sum of retailer orders exceeds the suppliers fixed capacity. To balance supply and demand, the supplier must employ an allocation mechanism, an algorithm for converting an infeasible set of orders into a feasible set of capacity assignments.

During the last decade, there has been a growing interest using genetic algorithms (GA) to solve a variety of single and multi-objective problems in production and operations management that are combinatorial and NP-hard [12]-[15]. GA is heuristic search techniques inspired from the principles of survival-of-the-fittest in natural evolution and genetics. However, GAs are generally slow, and the average time that a well-configured GA would need to search for a satisfactory solution of the entire supply-chain problem may be too high for practical use in a real industrial context, where the decision algorithm must provide a solution in relatively short times. Namely,we use the GA to perform demand-to-production center assignment, and the production sequencing at each center, while the remaining part of the whole scheduling problem is handled by constructive heuristic algorithms. This approach leads to a hybrid evolutionary algorithm in which the GA constitutes the core of the search strategy, while multiple heuristic rules called in specific circumstances contribute to reconstruct a feasible solution that satisfies all the constraints and objectives.

In this paper, we investigate a two echelon supply chain system consist of multi-manufacturers and multi-distributors,

* Corresponding author: e-mail: Kaiijunlen@yahoo.com.cn

we proposed a optimal production allocation mechanism based on Theory of Constraints(TOC) in face of meeting peak demand in certain period for the whole system. The TOC is a global managerial methodology that helps the manager to concentrate on the most critical issues. It has been applied to a wide range of fields including Operation (Production), Finance and Measures, Project, Distribution and Supply Chain, Marketing, Sales, Managing People, and Strategy and Tactics[3][4], The TOC-based strategy has being implemented by a growing number of companies. The performance reported by the implemented companies includes reduction of inventory level, lead-time and transportation costs and increasing forecast accuracy and customer service levels[5]-[11] As the programming model we set up for the system is a NP-hard problem, Genetic algorithm (GA) has been selected in solving the optimal model in our work.

2. LITERATURE REVIEW

2.1. The literature on supply chain coordination

The contracting literature on supply chains with stochastic demand can be mainly divided into two categories. Most of the research is on the coordination of supply chains in a single-period setting, i.e. the newsvendor model and its extensions. There are also relatively fewer studies on the coordination of supply chains in an infinite horizon setting.

The scope of this paper is the stochastic models in an infinite horizon setting that investigates the coordination of the inventory policies in a decentralized supply chain. The literature in this area can be mainly analyzed in two groups. Some of the studies consider an uncapacitated supply system (Lee and Whang, 1999; Chen, 1999; Cachon and Zipkin, 1999; Cachon, 2001) and some of them deal with capacitated supply chains (Cachon, 1999; Caldentey and Wein, 2003; Jema and Karaesmen, 2004; Gupta and Weerawat, 2006; Hennet and Arda, 2008). It is worthful to note that the key distinction in the studies considering uncapacitated and capacitated supply chains is that inventory theory is used in the former, whereas queuing theory is used in the latter. Since our study deals with a capacitated supply chain, the studies falling into this area are described in more detail below. See Cachon (2003) for a more thorough review of the related literature.

All the studies investigating a capacitated supply chain consider a two-stage system with a single member at each stage. The other similarities between these studies are as follows: the base stock policy is used as the inventory control policy; a game theoretical framework is used in the models; and the capacitated member or members are modeled using queuing theory. Among these studies, different contracts are investigated to coordinate the supply chain.

Cachon (1999) develops several contracts that contain one or more of the following elements: retailer holding cost subsidy, lost sales transfer payment, and inventory holding cost sharing. Caldentey and Wein (2003) examine a linear transfer payment scheme that induces a cost sharing agreement. Jemai and Karaesmen (2004) develop a set of simple linear contracts, such as the holding cost subsidy contract. Gupta and Weerawat (2006) investigate three different contracts for the coordination of the decentralized system: fixed-markup contract, simple revenue sharing contract, and two part revenue sharing contract. Finally, Hennet and Arda (2008) develop price-only contracts, backorder cost sharing through transfer payments, and capacity reservation to assure supply.

The distinctive features of the studies mentioned in this part and our model are summarized in Table 1. The system examined in our study is similar to that of Gupta and Weerawat (2006) since both studies consider a manufacture-to-order system. However, the most important feature that distinguishes our study from those in the literature is that our system consists of multiple suppliers at the first stage. Accordingly, while Gupta and Weerawat (2006) approximate the manufacturer as an M/M/1 queue, we have modeled the manufacturer as a GI/M/1 queue, which makes our model more complicated. In addition, the objective functions differ in both studies. Gupta and Weerawat (2006) try to maximize the expected profit per unit time, which consists of the average revenue, minus the average holding cost and production costs per unit time. However, in our study, the objective is to minimize the average backorder and holding costs per unit time as in Jemai and Karaesmen (2004).

2.2. The literature on supply chain scheduling

Here we review the literature of supply chain scheduling. Lee,Jeong, and Moon (2002) studied the notion of advance planning and scheduling in a supply chain. They considered both outsourcing and precedence constraints between the operations. Their model of production involved both fabrication and assembly stages. They presented a mathematical model of the problem and developed a genetic algorithm based heuristic to solve it. Moon, Kim, and Hur (2002) discuss an integrated process planning and sequence dependent scheduling model for multi-plant supply chain. They decided that all the plants would behave like a single company, through strong coordination and cooperation in furtherance of mutual goals. The researchers assumed that an appropriate objective function would involve minimizing total tardiness. Gnoni, Iavagnilio, Mossa, Mummolo, and DiLeva (2003) discuss production planning in the context of a multi-site automotive manufacturing system, with capacity constraints and uncertain multi-product and multi-period demands. To solve this problem, the researchers integrated a mixed integer linear programming model and a simulation model.

Ryu, Dua, and Pistikopoulos (2004) propose a bi-level programming approach for integration, production and distribution. Their goal was to determine the level of production and inventory in plants and distribution centers that would minimize the production, transportation and warehousing costs. They assumed that plants would share available resources. Bredstrom, Lundgren, Ronnqvist, Carlsson, and Mason (2004) integrate production and distribution planning in the context of a large international pulp producer with five pulp mills located in Scandinavia. Their objective function minimizes production and distribution costs by determining the level of inventory, production and transformation across various time periods. They propose two mixed integer programming models that describe daily supply chain decisions for their scenario.

Chang and Lee (2004) study a two-stage supply chain scheduling problem. The first stage involves production, while the second stage involves the transportation of products and the distribution of orders to customers. The jobs require different amounts of storage space during delivery. These researchers present three scenarios for problem modeling. In the first scenario, jobs are processed on a single machine and delivered by a single vehicle to a specified area. They provide a heuristic with worst-case performance ratio equal to 5/3 for this case. In the second case, the jobs are processed by one of two parallel machines and are delivered by a single vehicle to a given area. Their choice of heuristic leads to a 100% error metric under worst-case conditions. Finally, in the third scenario, they assume that all jobs are processed by a single machine and are delivered by a single vehicle to two different areas. Jetlund and Karimi (2004) study ways to improve the logistic chemicals manufacturing and delivery. Their hypothetical transportation fleet comprises several ships that carry cargos to harbors. The goal is to assign each cargo to each ship and to select an optimal route for each ship so as to achieve maximum profit. At first, they assumed the existence of only one ship. They subsequently extended their model to multi-ship environments. They propose a mixed integer model for the original case and two different heuristics for the extended case. Berning et al. (2004) discuss ways to minimize production and tardiness costs in the chemical industry supply chain, with a specific focus on resource constraints. They consider batches with setup and cleanup times in the context of a network of companies.

Chan, Chung, and Chan (2005) discussed distributed scheduling problems in multi-factory and multi-product environments. Lejeune (2006) studies ways to minimize costs in a three-stage supply chain that includes supplier, production and distribution phases. After modeling the problem using a mixed integer programming approach, they develop an algorithm based on variable neighborhood decomposition search. Selvarajah and Steiner (2006) study how to minimize inventory holding and delivery costs in a supply chain for given batches of products. In addition, changing from one production to another is required a setup time. They present an algorithm that exhibits polynomial complexity time that underlies the optimal solution. Agnetis, Hall, and Pacciarelli (2006) study scheduling in a two-stage supply chain. They consider a supplier at the first stage and several manufacturers at the second stage, with an intermediate storage buffer between the two stages. Averbakh and Xue (2007) focus on on-line supply chain scheduling problems with preemption. Their goal is to minimize the total cost, calculated as the sum of the total flow time and the total delivery cost. In their scenario, no information is available at any time regarding the number, release times and processing times of future jobs. The processing time of a job is known only when the job is released by the customers. Processed jobs are grouped into batches for subsequent customer deliveries.

Naso, Surico, Turchiano, and Kaymak (2007) discuss supply chain scheduling using a real-world case study in the ready-mixed concrete industry. They propose a hybrid genetic algorithm combined with constructive heuristics. Karabuk (2007) studies the assignment of jobs to suppliers and aims to determine optimal production scheduling that can minimize the makespan. Each supplier may require a different length of time to process each job. To solve this problem, an adaptive genetic algorithm with a new mechanism named dominated gene crossover is proposed. Chauhan, Gordon, and Proth (2007) examined a supply chain involving multiple shops that together comprise an assembly system. They consider two cases with objective of minimizing the makespan. In the first case, they assume that only one assembly operation is necessary.In the second case, multiple assembly operations are allowed. They proposed a heuristic for each case. Lin, Cheng, and Chou (2007) studied ways to minimize the makespan in a two-stage supply chain. They assumed the existence of two parallel suppliers at the first stage and a single company at the second stage. Jobs would arrive in batches, and the researchers assumed that a constant setup time was required for each batch. Roghanian, Sadjadi, and Aryanezhad (2007) consider a probabilistic bi-level linear multi-objective programming problem to explore supply chain planning using fuzzy programming techniques. Nishi, Konishi, and Ago (2007) proposed a distributed decision-making system for the integrated optimization of production scheduling and distribution in the context of an aluminum rolling processing line. Lapierre and Ruiz (2007) present a tabu search scheme that allows the scheduling of logistics activities as a means of improving supply operations at health care institutions. Ko and Evans (2007) propose an integrated logistics network for third party logistics providers that simultaneously takes into account both forward and reverse flows. They propose a GA-based heuristic that comprises both genetic operations and a simplex transshipment algorithm. Moon, Lee, Jeong, and Yun (2008) integrate process planning and scheduling problems in a supply chain model that takes into account finite resources and precedence constraints with the goal of minimizing the makespan. Each job can be assigned to different resources, and each job may be associated with a different and possibly resourcedependent processing time. Erera, Karack, and Savelsbergh (2008) propose a heuristic in which greedy search and enumeration are combined to determine cost-effective solutions for solving driver scheduling and load dispatching problems. In a recent study, Mazdeh, Sarhadi, and Hindi (2008) use a branch-and-bound algorithm to minimize the sum of flow times and delivery costs in the context of a single machine, considering a batch delivery system. They mention in their manuscript that an extension of their problem would be applicable to supply chain networks.

Certain of the aforementioned publications have considered transportation fleets. Chang and Lee (2004) bear the most relevance to our research. In both two problems, two-stage supply chain scenario is considered in which jobs have different sizes, suppliers are located in a geographical zone, and vehicle travel time is taken into account.

However, Chang and Lee assume that there exists only one vehicle in the transportation fleet and they do not consider more than two suppliers of identical production speed. Obviously, it is unrealistic to assume that there is only one vehicle to deliver the jobs since the manufacturer can easily reinforce their delivery transportation fleet by adding more vehicles. In this study, we will extend the problem by assuming that the supply chain comprises m production companies that act as suppliers in the first stage and l vehicles that perform deliveries in the second stage. Moreover, we allow variation in the production speed of the suppliers, and in the speed and capacity of the delivery vehicles.

3. DESCRIPTION AND FORMULATION

The model we investigate in this paper is a two-echelon production-distribution supply chain system consists of M manufacturers and N retailers. Normally, we assume that $M \geq N$, as shown in Fig 1.

In the system, all manufacturers are belonged to the same enterprise which can not only produce products with its own brand but also capable of dealing with the ODM (Original Design Manufacture) order for other companies, so each of the these manufacturer may have the choice to either focus on the internal business or other manufacturing outsourcing services, and each manufacturer pursuit the maximization of its own performance, however, still they have to follow the direct instruction from the headquarters of the company, the limitation of the manufacturers capacity will not be considered in the model. We assume that different manufacturer produce certain product of different type, hence, we note $i = 1, 2, L, t, L, r, L, w, LM$ for the manufacturers which produce three types of products which are A, B and C separately, and W_i stand for the maximum capacity of the manufacturer.

Meanwhile, the manufacturing enterprise distributes its product via certain distributors. In regular sales seasons, the distributors order the product from the manufacturers, we note them as $D_j, j = 1, 2, L, N$, and the production schedule are made based on the sales information provided by the distributors, and its obviously that the accuracy of information are far more different from each other among those distributors for the profit consideration of their own.

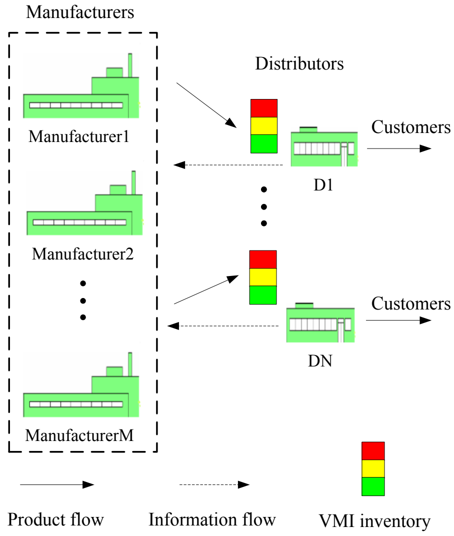

Figure 1 A Production-distribution supply chain system

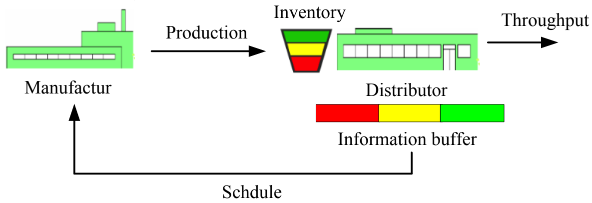

Figure 2 Allocation mechanism based on TOC

The inaccuracy information would lead to overstock for the manufacturers and heavily jeopardize the profitability of whole supply chain system. However, in particular sales period such as Christmas or spring festival, shortage of products would appear inevitably, even with overtime working strategy for the manufacturers, it is still hardly satisfy the peak demand in the period due to the constraints of funds available F and production capacity, although the distributor believe that the more inventories they have the higher profit they would achieve. Hence the main issue in this period is how to optimal the production allocation to maximize the profit of the entire supply chain system.

Though the amount of the order is often considered as a main factor in priority decision, the information accuracy remains a leading concern for the manufacturer. Thus, we proposed an allocation mechanism based on TOC which use the information accuracy level as a buffer to schedule the production allocation in the system as shown in Fig 2.

In contrast with the amount-oriented schedule, TOC-based mechanism emphasis the information accuracy of each distributor in daily operation. With different information accuracy level U_j, the higher value of the index the more product those distributor could have. By doing so, it will not only be a schedule mechanism but also an incentive for the whole supply chain system to be more cooperative.

The objective function of our optimal model is to maximize the profit of the supply chain system:

$$max \sum_{j=1}^{N} U_j[(1 - \prod_{i=1}^{M}(1 - p_{ij}))^{x_{ij}}] \quad (1)$$

In which p_{ij} stands for the possibility of the demand be satisfied when one batch of overtime production work be allocated to a certain manufacturer for a certain distributor.

According to the TOC-based mechanism, it is necessary to satisfy minimum requirement of each distributor:

$$\sum_{i=1}^{M} x_{ij} \geq U_j \dot{\sigma} (\sum_{i=1}^{M} W_i) \quad (2)$$

σ is the flexible coefficient that the production capacity been put into use for the basic needs of the distributors, and represent the number of batches of overtime work be allocated to manufacturer i for distributor j. While the amount-oriented schedule focus on the amount of distributors need:

$$\sum_{i=1}^{M} x_{ij} \geq Max\{D_j, D_{j-1}, \ldots, D_1\} \quad (3)$$

However, the schedule process has been limited to certain constraints, first of all is the funds that could be put into production, which often be used in material procurement, labourage etc.:

$$\sum_{j=1}^{N} \sum_{i=1}^{M} c_{ij} x_{ij} \leq F \beta_\theta \quad (4)$$

c_{ij} is the overtime production cost of each batch that manufacturer i be allocated to distributor j; β stands for the proportion of each kind of product that satisfy the distributors basic needs. And of course the schedule process will also be limited by the capacity constraint:

$$\sum_{j=1}^{N} x_{ij} \leq W_i \quad (5)$$

4. A GA-BASED PROCEDURE

Model (1) is a typical target allocation mathematical problem which has been researched by many scholars. And various methods have been proposed in various literatures [16]-[18].However, because of the large amount of manufacturers and retailers exist in a real supply chain system and the efficiency of the Genetic algorithm in solving analogous issues, we choose an improved genetic algorithm in our research.

Prior to the application of GA, it is important to define an encoding strategy to transform a generic solution of the problem into a string of symbols suitable to the application of genetic operators. In GA literature, an encoded solution is generally referred to as chromosome, and a single parameter of the solution vector is called a gene. Designing a more suitable chromosomal representation of a solution is a key issue for successful implementation of GA. For the problem under study, binary system is selected in chromosome coding, meanwhile the chromosome structure shown in Fig 3 is selected, each chromosomal is a $M \times N$ matrix, and each gene x_{ij} represent the number of batches of overtime work be allocated to manufacturer i for distributor j in the schedule process:

	Distributors			
Manufacturers	x_{11}	x_{12}	...	x_{1N}
	...	...	...	...
	x_{M1}	x_{M2}	...	x_{MN}

Figure 3 Chromosomal representation of solution

Different from the traditional GA, we set a brand new race quality examination and rectify procedure in the GA program, which consists of three modules, as shown in Fig 4.

Module1 is used to adjust row vector of the chromosomal, the main function is to make sure that the production batch would not exceed the max capacity of the manufacturers, and:

$$CalM[i] = \sum_{j=1}^{N} x_{ij} \quad (6)$$

Module2 is used to adjust column vector of the chromosomal, and its main function is to assure that the basic requirement of the distributors could be satisfied, and:

$$CalN[j] = \sum_{i=1}^{N} x_{ij} \quad (7)$$

Module3 is the last adjust procedure to the chromosomal, with the command:

$$i' = rand\{I_k\}, j' = rand(1, N), flag = 0 \quad (8)$$

Manufacturer who produce different type of product will be separated with each other, and then the procedure will adjust the chromosomal with the proportion of the funds be put into different type of products, and:

$$CalC[k] = \sum_{I_k} \sum_{j=1}^{N} c_{ij} x_{ij} \quad (9)$$

Then following the trational GA procedure, we shall have the optimal prodcution allocation schedule of the supply chain system.

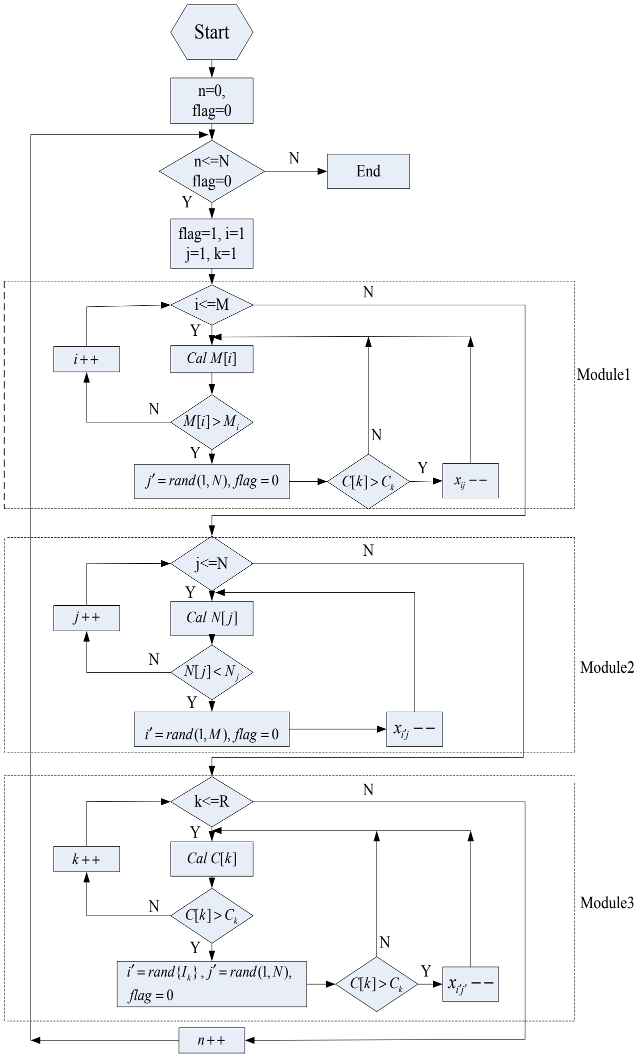

Figure 4 Structure of the race quality examination and rectify procedure

5. NUMERICAL EXAMPLE

In this section we use practical data as numerical example to demonstrate the efficiency of our proposed model. The data were provided by a traditional manufacturing SME (small and medium enterprise) located in Henan province, China. The company owns seven manufacturing plants located in different places and each plants pursuit its own profitability although they have to follow the direction of the headquarters of the company.

The company distributes its products 4 main distributors, and by the year 2009, it owns 15 plants which produce 3 main goods, 7 produce A, 2 for B, and 6 for C. When face the peak demand sales period, the production funds in hand is $F = 7500000$ yuan, and the proportion for each kind of product is $\beta_A = 55\%, \beta_B = 15\%, \beta_C = 25\%$ separately. The possibility of demand satisfaction of each production allocation process is given in Table 1:

Table 1 Possibility of satisfaction for the peak demand

	A1	A2	A3	A4	A5	A6	A7	B1	B2
S1	0.31	0.35	0.19	0.07	0.13	0.24	0.09	0.39	0.24
S2	0.15	0.24	0.04	0.26	0.19	0.20	0.21	0.17	0.31
S3	0.25	0.12	0.03	0.19	0.25	0.22	0.18	0.47	0.14
S4	0.29	0.07	0.19	0.13	0.05	0.19	0.28	0.09	0.43
	C1	C2	C3	C4	C5	C6			
S1	0.1	0.12	0.32	0.32	0.23	0.29			
S2	0.23	0.11	0.23	0.1	0.12	0.07			
S3	0.13	0.23	0.19	0.28	0.13	0.15			
S4	0.35	0.09	0.21	0.02	0.03	0.32			

And other production cost and information accuracy level are shown in Table 2:

Table 2 Production cost and information level

	S1	S2	S3	S4	Max Capacity
A1	0.140	0.120	0.140	0.150	8
A2	0.110	0.130	0.150	0.100	7
A3	0.100	0.043	0.100	0.085	9
A4	0.130	0.130	0.130	0.125	5
A5	0.130	0.135	0.140	0.140	6
A6	0.150	0.130	0.150	0.110	8
A7	0.130	0.130	0.130	0.130	3
B1	0.015	0.010	0.010	0.010	10
B2	0.025	0.020	0.020	0.027	15
C1	0.050	0.050	0.050	0.065	12
C2	0.100	0.100	0.100	0.100	8
C3	0.060	0.060	0.060	0.060	4
C4	0.096	0.096	0.096	0.096	4
C5	0.020	0.020	0.020	0.020	4
C6	0.080	0.080	0.080	0.080	4
Distributor demands	20	30	25	15	
Information level	30	40	10	20	
Buffer level	18	25	10	16	

The final solutions with different mechanism are shown in Table 3 and Table 4, and the variations of the solution for different mechanism are shown in Fig 5 and Fig 6:

Table 3 Optiaml schedule based on TOC mechanism

	A1	A2	A3	A4	A5	A6	A7	
S1	5	7	0	0	0	0	0	
S2	0	0	0	5	0	2	3	
S3	2	0	0	0	4	0	0	
S4	0	0	6	0	0	0	0	
	B1	B1	C1	C2	C3	C4	C5	C6
S1	0	0	0	0	2	4	4	0
S2	0	7	9	0	2	0	0	0
S3	10	0	0	2	0	0	0	0
S4	0	8	3	0	0	0	0	4
Optimal fitness value		3.999070				Throughput	99.97504	

Table 4 Optiaml schedule based on amount-oriented mechanism

	A1	A2	A3	A4	A5	A6	A7	
S1	6	7	0	0	0	0	0	
S2	0	0	4	5	0	4	2	
S3	1	0	5	0	1	0	1	
S4	0	0	0	0	0	0	0	
	B1	B1	C1	C2	C3	C4	C5	C6
S1	0	0	0	0	4	3	0	0
S2	0	6	9	0	0	0	0	0
S3	10	0	0	2	0	1	4	0
S4	0	9	3	0	0	0	0	4
Optimal fitness value		3.998607				Throughput	99.94798	

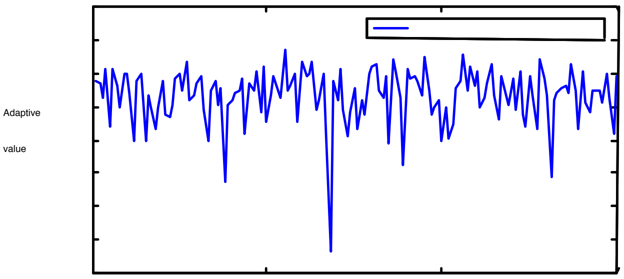

Figure 5 TOC-based mechanism Variation

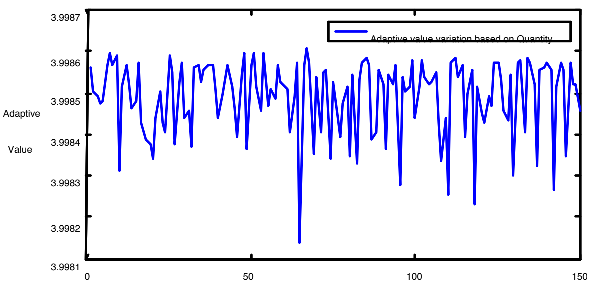

Figure 6 Amount-oriented mechanism Variation

6. CONCLUSIONS

In this paper, we investigate the supply chain coordination mechanism in a two echelon supply chain system consist of multi-manufacturers and multi-distributors, in order to deal with the information variation in the system such as bullwhip effect, we proposed a optimal production allocation mechanism based on Theory of Constraints (TOC) in face of meeting peak demand in certain period for the whole system. And through a numerical example, weve shown the efficiency of our method in contrast with the traditional amount-oriented mechanism.

ACKNOWLEDGEMENTS

This paper is sponsored by the National Natural Science Funds (serial number: 71101047), the Ministry of Education of PRC Humanities Social Sciences Youth Fund Projects (serial number: 12YJC630292), Educational Commission of Hubei Province (serial number: Q20112201) and Research Center of Hubei Logistics development (serial number: 2011A12).

References

[1] J. C Hennet., Y.Arda, Supply chain coordination: A game-theory approach, ngineering Applications of AI.21 **3**, 399-405 (2008).
[2] T. Peral, U .Fusun, Coordination in a two-stage capacitated supply chain with multiple suppliers, EJOR. 21 **2**, 43-53(2011).
[3] T. M Simatupang., A. C. Wright, N. Sridharan, Applying the theory of constraints to supply chain collaboration, SCM: An International Journal. 9 **1**, 57-70(2004).
[4] D. A. Smith, Linking the supply chain using the theory of constraints logistical applications and a new understanding of the role of inventory/buffer management, n 2001 constraints management technical conference proceedings, (San Antonio, Texas, USA, 2001).
[5] D. Naso, M. Surico, B. Turchiano, Genetic algorithms for supply-chain scheduling: A case study in the distribution of ready-mixed concrete, EJOR. 177, 2069-2099(2007).
[6] Torabi S., Ghomi S., Karimi B., A bybrid genetic algorithm for the finite horizon economic lot and delivery scheduling in supply chains, EJOR. 173, 173-189(2006).
[7] Y. Lee, , C. Jeong, C. Moon, Advanced planning and scheduling with outsourcing in manufacturing supply chain, CIE.43, 351-374(2002).
[8] V. Belvedere, A. Grando, Implementing a pull system in batch/mix processindustry through theory of constraints: A case-study, HSM.24 **1** 3-12(2005).
[9] A. Bhattacharya, P. Vasant, Soft-sensing of level of satisfaction in TOC product-mix decision heuristic using robust fuzzy-LP, EJOR.177 **1**, 55-70(2007).
[10] J. H. Blackstone, Theory of constraints - A status report, IJRP.39 **6** 1053-1080(2001).
[11] H. Cole, D. Jacob, Introduction to TOC supply chain, AGI Institute, (2002).
[12] J. R. Holt, TOC in supply chain management, In 1999 constraints management symposium proceedings, (Phoenix, AZ, USA, 1999).
[13] G. I. Kendall, Viable vision, Heliopolis Culture Group/SAGA Culture Publishing Co, (2006).
[14] Luebbe, R., Finch, B., Theory of constraints and linear programming: A comparison, IJPR.30 **6** 1471-1478(1992).
[15] N. H. Patnode, Providing responsive logistics support: Applying lean thinking to logistics, In 1999 constraints management symposium proceedings, (Phoenix, AZ, USA, 1999).
[16] R .K. Ahuja, A. Kumar, J. Krishna, J. B. Orlin, Exact and heuristic methods for the weapon target assignent problem, MIT Sloan School of Management, 1-20(WorkingPaper, 2003).

[17] Z. Lee, C. Lee, S. Su, An immunity based ant colony optimization algorithm for solving weapon target assignment problem, ASC.2, 39-47(2002).
[18] W.L.Winston, Operations Research: Application and Algorithms, fourth ed., Brooks/Cole, (Belmont, 2004).

Kaijun Leng is an Associate professor who works in school of logistics and engineering management, Hubei University of Economics, China. He obtained his PhD in Huazhong University of Science and Technology. And his research direction focuses on logistics and supply chain management, constraint theory. In recent years he has emceed and attended a number of national natural science foundation of China, the ministry of education funding in key projects, the Hubei province and abroad research project by the university research project. And he has published many academic research papers in many international journals and conferences, most of which are included by SCI, EI, ISTP.

Xiangjun Chen is a Professor, master tutor, who works in Hubei University of Economics. He obtained his PhD in Huazhong university of science and technology. and he also works in Hubei province business economic association secretary-general, wuhan jiangxia district industry and been awarded as commerce joint vice President,The Chinese market association, member of wuhan university of technology, ZhongShang group operating management college guest professor. He has published many papers in domestic and international journals. Many research results of him have been adopted by the state council development research center. His research are focus on private scientific and technological enterprise research, and have made abundant achievements