OPTIMISATION OF MULTI-LEVEL SUPPLY CHAIN OF AUTOMATISED PRODUCTION SYSTEMS WITH HARMONY SEARCH ALGORITHM

Tamas Bányai

University of Miskolc, Hungary

Abstract: Supply chain processes of automatised production systems include the functions of procurement, collection, sales, distribution and recycling. The success of the operation of these functions is based on the optimal structure and strategy. The purpose of this paper is to describe a possible complex model of internal multi-level supply chain of production systems. The complexity of the purposed model is so high that sophisticated operation research heuristics has to be used to find the optimal solution of the optimisation problem, which is the minimisation of the operation costs. There are several heuristics algorithms to solve NP and hard NP problems. In this case as a suitable method the harmony search algorithm (HSA) was chosen.

Keywords: just-in-time, logistics, optimisation, warehousing

1. Introduction

The optimal design of the green supply chain is a knowledge intensive task because of the complexity of the system. The huge number of entities and the connections of them define the problem field, and there are several aspects to find the optimal solution. Within the frame of this work, the author focuses on the optimisation of the supply chain of manufacturer. Much literature has been published in the field of green supply chain (GSC) and some of them have included a comprehensive survey [15.]. The main stream of literature addressed the development of traditional purchasing – production – distribution logistics chain models into closed loop economy (purchasing – production – distribution – recycling) models. Some generalised terms were created and published in different research works: sustainable supply network management [1.]; supply and demand sustainability [7.]; supply chain environmental management [16.]; green purchasing [11.], environmental purchasing [17.], green logistics [13.], and sustainable supply chains [9.], JIT supply with virtual enterprises. The IT aspects of networking entities are very important and there are some research works summarising aspects that have to be considered during design and set-up of IT structure of large scale networks, such as green supply chain: aspects of connections through IP-based networks in industrial environments [6.], possibilities of information logistics utilisation [5.]. The economical growth can influence the efficiency, functionality and transparency of large systems based on a huge number of entities (end users), and therefore it is important to research the effects of the economical growth [3.]. The green supply chain has very high costs and one of the most important costs of these large scaled systems is the transportation cost. Therefore it is important to optimise the transportation processes of these systems from the point of view transportation technology and logistics [12.].

2. Mathematical modeling

During the optimisation of the above mentioned green supply chain model (see fig. 1.) the following assumptions have to be taken into consideration: (a) In the proposed model the multi-product condition is considered. (b) The manufacturer produce products from components purchased from either the component suppliers or the secondary material market. The proportion of new, used and refurbished products is given. (c) The manufacturer transports the products from the output warehouse to the users through distribution process. (d) The refuse ratio of products produced by the manufacturer depends on the quality of the purchased components; the refurbished components have higher refuse rate than new components. (e) The return ratio of used products from end users to collection system is given. (f) The direct return of used products from end users to recycling and disassembly plants is not allowed. (g) The specific warehousing cost depends on the type of the components (new, used or refurbished). The specific warehousing cost of used products is lower in the case of new components, because of the special warehousing conditions in the case of used products (e.g. wastes of electric and electronic components).

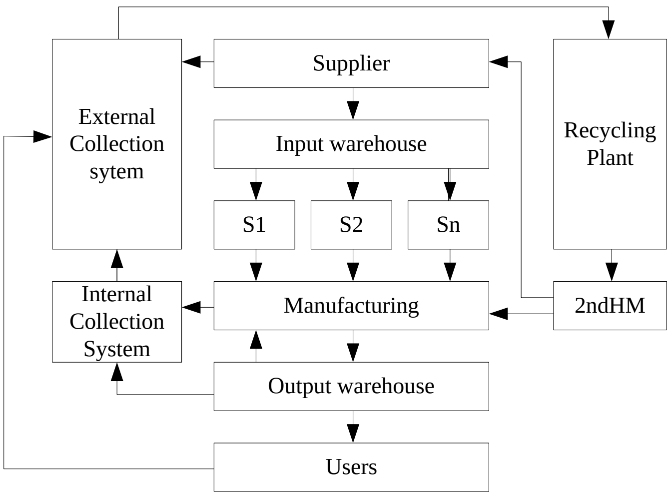

Figure 1. The model of supply system

The revenue of the manufacturer depends on the sold amount of products and the lot size of transportation:

$$R^{L1} = \sum_{i \in \Psi} Q_i^{L1} * \left(R_i^{L1,min} + \left(R_i^{L1,max} - R_i^{L1,min} \right) * \left(\frac{q_i^{L1,UB} - q_i^{L1}}{q_i^{L1,UB} - q_i^{L1,LB}} \right) \right) \qquad (1)$$

The warehousing cost of the manufacturer has two important parts: the warehousing costs of new components purchased from the components supplier and the warehousing cost of refurbished components purchased from the second material market:

$$WC^{L1} = WC_1^{L1} + WC_2^{L1} \qquad (2)$$

The warehousing cost at the manufacturers depends on the warehousing cost of final products and the warehousing cost of purchased components. The first term on the left handside of the Eq. (3) represents the warehousing cost of purchased components, which depends on the lot size of transportation of new components from component suppliers to manufacturers). The right handside of the same equation represents the warehousing cost of final products, which depends on the proportion of the number of purchased components from source p and the total number of components, the structure of the products and the unit warehousing cost of components from suppliers:

$$WC_1^{L1} = \sum_{j \in \Theta_i} \sum_{p \in \Phi} \left| \frac{q_j^{L1,p} * \tau}{2} - \sum_{i \in \Psi} \frac{\alpha_{i,j}^{p} * n_{i,j} * q_i^{L1}}{2} * \tau \right| * \kappa_j^{L1,W,p} \tag{3}$$

The warehousing cost of refurbished components depends on the sold amount of final products, the refuse rate of components, the amount of refused products transported to the collection system through internal collection system, the intensity of the transportation of refused products from the manufacturer to the collection system or to the recycling and disassembly plant and the unit warehousing cost of refused products:

$$WC_2^{L1} = \sum_{i \in \Psi} Q_i^{L1} * \left(\prod_{j \in \Theta_i} \left(1 + \eta_{i,j}^{L1,p}\right)^{n_{i,j}} - 1 \right) * \frac{\tau}{2} * \left(\frac{\beta_1}{z_1} + \frac{1-\beta_1}{z_2} \right) * \kappa_i^{L1,W,r} \tag{4}$$

The transportation cost of components from the component sources to the manufacturer consists of the cost of three different transportation relations: (1) the transportation cost of components from component sources to manufacturers; (2) the transportation cost of refused components and products from manufacturers to collection system and (3) the transportation cost of refused components and products from manufacturers to disassembly plant:

$$TC^{L1} = TC_1^{L1} + TC_2^{L1} \tag{5}$$

The transportation cost of components from component sources to manufacturers depends on the lot size of transportation of new components from component suppliers to manufacturers, the maximum load capacity of the truck from component source p to manufacturer, the specific transportation cost of components in the case of one truck from supplier p defined by a set, the total amount of components purchased by the manufacturer from component sources. This equation makes it possible to take into consideration the periodicity of the transportation cost depending on the number of trucks.

$$TC_1^{L1} = \sum_{j \epsilon \Theta_i} \sum_{p \in \Phi} \left(\frac{q_j^{L1,p}}{c_{truck}^{L1,p}} \right)_{int} * \frac{Q_j^{L1,p}}{q_j^{L1,p}} * \kappa_j^{L1,T,p} \tag{6}$$

The transportation cost of refused components and products from manufacturers to collection system through internal collection system depends on the sold amount of final products, the refuse rate of components, the amount of refused products transported to the collection system, the intensity of the transportation of refused products from the manufacturer to the collection system and the unit transportation cost of refused products:

$$TC_2^{L1} = \left(\sum_{i \in \Psi} Q_i^{L1} * \left(\prod_{j \in \Theta_i} \left(1 + \eta_{i,j}^{L1,p}\right)^{n_{i,j}} - 1 \right) * \frac{\beta_1}{z_1 * c_{truck}^{L1,r}} \right)_{int} * z_1 * \kappa_{i,1}^{L1,T,r} \tag{7}$$

The manufacturing process has a refuse rate depending on the refuse rate and number of built-in components. However the physical process of the recycling of refused final products means the transportation of refused products from the manufacturer to the collection system or to the recycling and disassembly plant, but the cost of this transportation belongs to the transportation cost. The recycling cost is the recycling fee paid by the manufacturer as a product fee, which depends on the on the refuse rate of components and the unit recycling cost of different products:

$$RC^{L1} = \sum_{i \in \Psi} Q_i^{L1} * rc_i^{L1} * \left(\prod_{j \in \Theta_i} \left(1 + \eta_{i,j}^{L1,p}\right)^{n_{i,j}} - 1 \right) \tag{8}$$

The production cost of manufacturers includes the aggregate assembly cost of components and depends on the number of build-in components, the sold amount of products and the refuse rate of components:

$$PC^{L1} = \sum_{i \in \Psi} \left(Q_i^{L1} * \prod_{j \in \Theta_i} \left(1 + \eta_{i,j}^{L1,p}\right)^{n_{i,j}} * \sum_{p \in \Phi} \sum_{j \in \Theta_i} n_{i,j} * \varepsilon_{i,j}^{L1,p} \right) \tag{9}$$

The price of components to be paid by the manufacturer to the component supplier and second material market depends on ratio of new and refurbished components, the amount and specific costs:

$$PR^{L1} = \sum_{p \in \Phi} \sum_{j \in \Theta_i} \varsigma_j * q_j^{L1,p} * pr_j^{L1,p,n} + \left(1 - \varsigma_j\right) * q_j^{L1,p} * pr_j^{L1,r} \tag{10}$$

From the above mentioned costs (warehousing, transportation, production or assembly, recycling and purchasing), the profit of the manufacturer is generated:

$$P^{man} = R^{L1} - WC^{L1} - TC^{L1} - PC^{L1} - RC^{L1} - PR^{L1} \tag{11}$$

3. Optimisation of the model with harmony search algorithm

Harmony search is a meta-heuristic algorithm, mimicking the improvisation process of music players. There are several parameters of the harmony search algorithm, which makes it more efficient and flexible, than other meta-heuristics: (a) there are fewer mathematical conditions; (b) the initial setting of decision variables is not necessary; (c) derivative information is not required; (d) the new solution vectors are created using the information on all of the existing possible solution vectors [8., 14.]. The harmony search process includes five steps: (a) initialisation of the mathematical problem and the initial value of algorithm parameters; (b) fill in the harmony memory matrix with randomly generated solutions of the objective function of the optimisation problem; (c) improvisation of the new harmony memory matrix using values of all existing harmony vectors; (d) update of harmony memory matrix; (e) repeat the above mentioned steps until termination criteria [4.]. However there are some research works to try to eliminate algorithm parameters of heuristic algorithms, such genetic algorithm, simulated annealing, tabu search, ant colony optimization, particle swarm optimization but within the frame of this research work the parameterised harmony search algorithm will be described and used to find the optimal solution of the problem of green supply chain [2.]. Eq. (11) represents the objective function of the optimisation.

The most important parameters of the algorithm are the harmony memory size (maximum number of solution vectors in the harmony memory matrix, HMS), harmony memory considering rate (HMCR), pitch adjusting rate (PAR) and of course the termination criteria. The aim of the harmony memory considering rate and the pitch adjusting rate is to improve the fitness of solutions in the harmony memory matrix. Harmony memory consideration rate is the rate of choosing a value from the vectors stored in the harmony memory matrix with probability HMCR. Pitch correction is the process of correcting the intonation of an audio signal without affecting other aspects of its sound. Every component is examined to determine whether it should be pitch corrected or pitch adjusted: pitch adjusting is necessary with probability PAR. The value of pitch adjustment means the band distance [10.]. The solution vector of this green supply chain problem consists of the different types of lots, for example the procurement lot of new components from component suppliers to manufacturers, the procurement lot of used and refurbished components from secondary material market to manufacturers, the transportation lot in the level of distribution (manufacturing – wholesaler – retailer – end user supply chain), the transportation lot of collected used products from entities of collection system to disassembly and recycling plant, transportation lot of used and refurbished products from disassembly and recycling plant to secondary material market and the lot of transportation of not refurbishable products, components and materials from disassembly and recycling plant of disposal plant. The solution vector includes the rate of new and refurbished components to be used to manufacture products. By the aid of the above mentioned harmony search algorithm it is possible to solve the optimisation problem of the described complex green supply chain model. The algorithm is flexible and makes it possible to find a “good” solution vector, by the aid of which the optimal parameters of the logistic processes can be defined.

4. Conclusion

The modeling and optimisation of supply chain is a very complex problem of the economy, but during the optimisation of these systems not only economical, but also logistic, aspects have to be taken into consideration. It is possible to build a complex model of internal supply chain of including “green sub-processes” called green supply chain, but the mathematical model is so complex, that the solution is not possible by the aid of analytical methods. There are several heuristic algorithms, which make it possible to solve such complex models and find the optimal logistic and economical parameters of the operation. The above mentioned harmony search algorithm makes it possible to find a “good solution” of the optimisation problem. In the case of implementation of the ideas presented in this article it would be possible to design more efficient green supply chain form the point of view logistics. The developed optimisation model and method would be more efficient in the case of integration into different enterprise systems. The future research direction is the development of the optimisation model to take into consideration more parameters of the real system.

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