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Order Optimization of a Telecommunication Distribution Center through Service Lead Time

Tamás Hartványi, Ferenc Tóth

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***Abstract*—**European telecommunication distribution center performance is measured by service lead time and quality. Operation model is CTO (customized to order) namely, a high mix customization of telecommunication network equipment and parts. CTO operation contains material receiving, warehousing, network and server assembly to order and configure based on customer specifications. Variety of the product and orders does not support mass production structure. One of the success factors to satisfy customer is to have a proper aggregated planning method for the operation in order to have optimized human resources and highly efficient asset utilization. Research will investigate several methods and find proper way to have an order book simulation where practical optimization problem may contain thousands of variables and the simulation running times of developed algorithms were taken into account with high importance. There are two operation research models that were developed, customer demand is given in orders, no change over time, customer demands are given for product types, and changeover time is constant.

***Keywords*—**CTO, aggregated planning, demand simulation, changeover time.

I. Introduction

THIS study will present a model for improving the upstream and downstream distribution center of a European telecommunication company. The company with a manufacturing base in the Far East has developed a European sales channel for network equipment and parts. Companies based in the US or in the Far East often find European sales activities difficult. Both in America and in Asia, configuration (assembly instruction and uploading test software) for the end user is a standard process and there is no signification variation between customers in remote locations. These customers work along identical guidelines and system requirements. Thus, manufacturers implement a production model with small serial numbers and high volume production. For high volume manufacturing, it is much easier to build a supplier network, to operate it smoothly and provide for a stable production capacity Standardization of customer demands makes it possible to store end products which ensure that changes in demand are covered within the sales channel. When inventory is increased, capital invested therein also increases which could be compensated by high volume in sales. When production capacity is low and the company is able to sell products at a reasonable price and quantity, the company may have a competitive advantage. Nevertheless, inventory accuracy and proper control is required to prevent product shelf life problems. If market regulations are standard, production capacity is available, the supplier base is able to provide parts in good quality at a low price, and inventory is properly monitored, everything is given for efficient operations and strengthening market position.

The telecommunication company that has strengthened its position in the Far East develops new sales channels in Western and Central Eastern Europe. At the beginning, products manufactured in the Far East at a low price generated high sales volume. Operating a sales network with 45 European countries has its difficulties [1]. One of the biggest challenges is that each country has its own rules, regulations and service level. Telecommunication service providers build their networks in accordance with the regulations of the countries, respectively. Products from the Far East are shipped on sea with 2-3 months of delivery time. If delivery is urgent, airfreight is a significantly more expensive solution. During delivery, customers may not customize their orders as packaged products may not be opened due to customs regulations, only after customs clearance at the customers' location. This poses a great difficulty as the market is constantly changing and customers maintain the right of change [2]. Authorities may request modifications or marketing campaigns may require running a different software for the network units. One of the specialties of the European market is that customers tend to modify their orders. Here is a particular example taken from buying a new car. The customer goes to a dealership, selects the car and chooses from the available extras so that the car suits his taste and preferences. It makes it difficult for the car manufacturers, if the selected configuration is not available yet. The customer shall wait for a longer period until delivery. If he does not select any extras, he could easily choose from the stock available at the dealership. In case of a shipment from the Far East, the dealer can only offer cars delivered by sea freight, the customer can usually choose from only two colors, and no extras are available. In such a case, the customer is likely to look for another car and a different dealership to select extras. After a period of successful expansion, a Far Eastern supplier base is not able to manage manufacturing with high complexity and volume efficiently. European suppliers have a competitive advantage over their Far Eastern counterparts in terms of delivery time. Shipment by sea takes several months whereas manufacturing companies with a European base can manage a 2-week lead time. Expensive airfreight is also an option;

Tamás Hartványi PhD is with the Department of Logistics and Forwarding, Széchenyi István University, Győr, H-9026, Hungary (phone: 003696503400; fax: 003696503498; e-mail: hartvanyi@sze.hu.uni.sze.hu).

Ferenc Tóth (PhD Candidate) is with the Flex LTD., M1 Business Park, Páty, H-2071, Hungary (phone: 0036306099885, e-mail: peoplesmart@outlook.hu).

however, sales prices are not so favorable compared to the competitor's.

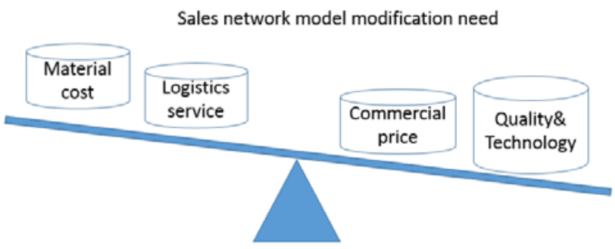

Fig. 1 Sales network model modification need

Increased costs mean less profit and it is less attractive to the customer. Consequently, the company either exits the market or modifies the sales network model. For a dynamically developing company, exiting a market means a loss of reputation. A successful way of handling the situation is to modify the sales network model. The model should conform to the following requirements: low price, short delivery time of maximum 2 weeks, option for change during ordering, good quality and fast response time.

The new sales network model is difficult to implement due to the mix of good quality, short delivery time and low price. If the product is of high quality, the manufacturer or the service provider shall secure the processes so that no error occurs during manufacturing or data management, which entails higher costs. The same applies to delivery time; shorter delivery time means better service level at a higher price.

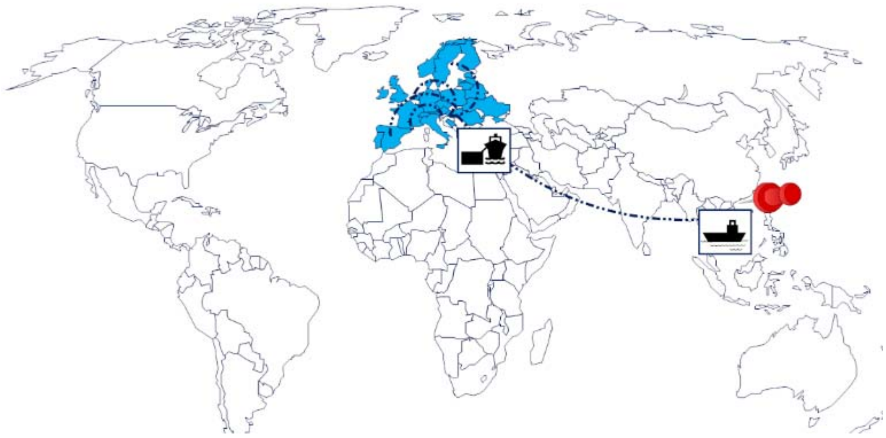

Fig. 2 European CTO operations

A European sales network model with CTO manufacturing units is a good solution. In the Far East, the original manufacturing company produces the basic parts that are shipped to Europe in containers. Therefore, cost savings resulting from serial production could be realized in case of basic product families. If the manufacturer in the Far East produces basic products in high volume, production costs are decreased. However, higher volume might increase inventory value whereas unit price of basic parts is low. Thus, inventory value does not reach the total value of products with the added effect of decreasing total cash at same time. With strict inventory planning and control, manufacturers from the Far East are able to ship basic products to CTO units on sea at a low price. The selected CTO partner completes assembly of products and software upload in accordance with the final specifications. After receiving and warehousing the containers, the CTO manufacturer is able to assemble and test units, upload the required software and thus create the configuration. Delivery time in Europe does not exceed 24 hours. A European CTO unit can reach any customer within 24 hours of road delivery. This works well not only in theory but in practice as well. Referring back to our car-purchasing example, European customers tend to request a number of changes on the products. In addition, it often happens that the CTO manufacturer performs the changes on the products during production or when the product is ready to be shipped. Obviously, manufacturers do not like these types of changes; however, the industry has to conform to these requirements and customer expectations.

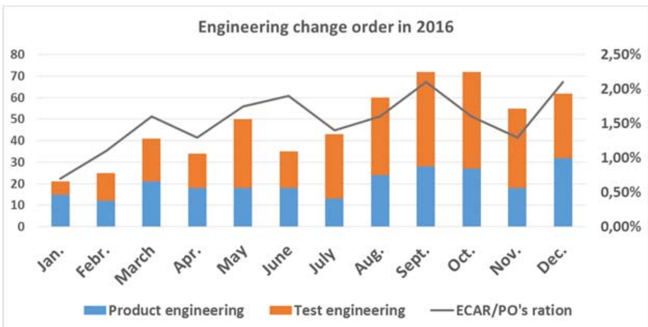

Fig. 3 Customer specification changes in production

Fig. 3 shows the number of engineering changes received

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for products already in production. There are 60-70 such changes during a month, which is considered a significant amount. Customer satisfaction is of paramount importance, fast response time is crucial here. The solution is to develop and implement a CTO supplier network. CTO manufacturing involves receiving raw materials from the Far East, producing finished goods in short lead time and shipping them to the European final customers. In case of end customer orders, CTO plants manufacture products in accordance with the specifications. The product includes empty racks, PCBs, panels and accessories and is assembled in accordance with the customer specifications. When hardware is completed, consulting with the customer and using the final specifications software is also uploaded. Software development and upload may happen everywhere due to cloud technology with which any virtual computer could be accessed from anywhere in the world and large data transmission could be managed. The most essential part of the process is that the hardware configuration is prepared within two days and the final software version as per the customer order could be uploaded. Afterwards, the CTO manufacturer starts the packaging process and arranging the shipment. Orders might also include parts or spare parts. Telecommunication service providers need spare parts, installation units and units that they could transfer to other locations, towers and control units. This means that CTO manufacturers do not only ship assembled products but also units in original packaging or smaller units than those received in bulk. For example, the shipment unit of a frequency filter is 10,000 pcs. The customer places an order of 100x3 pcs. In this case, the bulk material is used and 100 packages including three pieces each are to be prepared for dispatch. For the customer it is very similar to ordering from a catalogue. CTO manufacturers have to implement a robust control on production scheduling, as units arriving from different production areas have to be transferred to the loading area. This requires a very detailed and precise planning.

CTO manufacturers should manage a business environment with the following specifics:

- 2 500 m^3 inbound and outbound per week
- 2 800 packing list per week
- 5 550 customer purchase order per month
- 17 350 production order per month
- 7 000 order remark per month
- 250 order remark variation per month
- 4,5 days lead time
- 1,5 days production lead time

A telecommunication customer wants to improve delivery time and defines new targets for the CTO manufacturer by reducing this KPI from two days to one day. In case of one-day lead time, a well-defined and fast production scheduling is required. Production is able to handle one-day production time. However, decreasing the lead time to one day needs an advanced planning process so that all parts are received at the same time at the shipping area. In an environment with diverse lead times and production capacities, planning should be developed to achieve a very short time for production capacity simulation. This is essential because there are general production problems: one can never be sure which test will not run properly or if there will quality problems with any product. A dynamic capacity planning needs to be created so that calculations are performed fast using complex data. In case of modifications, changeover time should be considered as well. In such case, the customer shall be notified so that it could be communicated to their end users. In what follows, two models will be analyzed in detail.

- Model 1: Customer demands are given in orders, no changeover time.
- Model 2: Customer demands are given for product types, changeover time is constant.

II. Model 1: Customer Demands Are Given in Order no Change Over Time

A. Product Type, Workstations and Time Frame

- Vector of product types

$$p = (p_1, p_2, \dots, p_m)$$

$m =$ is the number of product types

- Vector of workstations (resources)

$$w = (w_1, w_2, \dots, w_n)$$

$n =$ is the number of workstations

- T is the network time, the time period supposed to be optimized for the operation

B. Product-Workstation Matrix

$$S = \begin{array}{c} \\ p_1 \\ p_2 \\ \vdots \\ p_m \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & \cdots & w_n \end{array} \\ \begin{bmatrix} s_{1,1} & s_{1,2} & \cdots & s_{1,n} \\ s_{2,1} & s_{2,2} & & s_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m,1} & s_{m,2} & \cdots & s_{m,n} \end{bmatrix} \end{array}$$

$$s_{i,j} = \begin{cases} 1, \text{if product } p_i \text{ can be produced at workstation } w_j \\ 0, \text{if product } p_i \text{ cannot be produced at workstation } w_j \end{cases}$$

$$i = 1, 2, \dots, \mathrm{m};\ \ j = 1, 2, \dots, \mathrm{n}$$

C. Order Matrix

$$O = \begin{array}{c} \\ p_1 \\ p_2 \\ \vdots \\ p_m \end{array} \begin{array}{c} \begin{array}{cccc} o_1 & o_2 & \cdots & o_k \end{array} \\ \begin{bmatrix} o_{1,1} & o_{1,2} & \cdots & o_{1,n} \\ o_{2,1} & o_{2,2} & & o_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ o_{m,1} & o_{m,2} & \cdots & o_{m,n} \end{bmatrix} \end{array}$$

$o_{i,j} =$ demand for product p_i in the order j for time period T

$i = 1, 2, \dots, \mathrm{m}$;

$j = 1, 2, \dots, \mathrm{k}, k$ is the number of orders for time period T

Process time vector of product type

$$(t)^T = (t_1, t_2, \dots, t_m)$$

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D. Assignment Matrix (Variable Matrix)

$$X = \begin{array}{c} \\ o_1, p_1 \\ \vdots \\ o_1, p_m \\ \vdots \\ o_k, p_1 \\ \vdots \\ o_k, p_m \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & \cdots & w_n \end{array} \\ \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m,1} & x_{m,1} & \cdots & x_{m,n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{(k-1)m+1,1} & x_{(k-1)m+1,2} & \cdots & x_{(k-1)m+1,n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{km,1} & x_{km,2} & \cdots & x_{km,n} \end{bmatrix} \end{array}$$

$x_{i,j}$ = quantity of product p_i of the o_i^{th} order to be processed at workstation w_j, $i = 1, 2, \dots, \text{km}$; $j = 1, 2, \dots, \text{n}$;

- Integer programming [4].

$$x_{i,j} \in N; (i = 1, 2, \dots, km; \quad j = 1, 2, \dots, n)$$

E. Constraints

- Fulfillment of each order $\forall_i$:

$$\sum_{j=1}^{n} x_{i,j} s_{p(i),j} = o_{p(i),o(i)}$$

- Optional constraint on station load (capacity) $\forall_j$:

$$\sum_{i=1}^{km} x_{i,j} s_{p(i),j} t_{p(i)} \leq T$$

F. Objective:

- Objective function (maximum of workstation loads)

$$\text{F(X)} = \max_{j=1,2,\dots,n} \left(\sum_{i=1}^{km} x_{i,j} s_{p(i),j} t_{p(i)} \right)$$

- Goal: $\text{F(X)} \rightarrow min.$

Note that if the optional constraint is not applied, then the criterion $\text{F(X)} \leq \text{T}$ can be used to decide if the solution is acceptable in practice.

$$p(i) = \begin{cases} i - \lfloor i/m \rfloor m, & \text{if } i - \lfloor i/m \rfloor m \neq 0 \\ m, & \text{if } i - \lfloor i/m \rfloor m = 0 \end{cases}$$

$$o(i) = \begin{cases} \lfloor i/m \rfloor + 1, & \text{if } i - \lfloor i/m \rfloor m \neq 0 \\ \lfloor i/m \rfloor, & \text{if } i - \lfloor i/m \rfloor m = 0 \end{cases}$$

G. Practical Consideration

- The order of magnitude k of orders, product types and workstations are as follows (n = 10k):
- Orders: k = 1
- Product types (in one planning session): k = 2
- Workstations: k = 1

The order of magnitude of number of variables is 1+2+1 = 4; that is, the optimization problem may include ten thousands of variables.

H.Developed Methods

Nonlinear optimization with relaxation and interior point method [3]

- Firstly, the interior point method (fmincon in MATLAB) is used to solve the relaxed problem in which $x_{i,j}$ [0, 1]
- Secondly, a heuristic is used to turn the solution of the relaxed problem to an integer solution of the original problem
- The solution is nearly optimal
- It runs rather in exponential time than in polynomial time

1. Weighted Balancing Heuristic

- Firstly, the relaxed problem, in which $x_{i,j}$ [0, 1], is solved by our weighted balancing technique
- The weighted balancing heuristic attempts to equalize the load of workstations in distribution of each order. It utilizes a fuzzy dissimilarity metric to generate the weights [5].
- Secondly, a heuristic is used to turn the solution of the relaxed problem to an integer solution of the original problem
- The solution is nearly optimal
- It runs in $O(n^2)$ time [6]

I. Running Time and Flexibility

1. Nonlinear Optimization with Relaxation and Interior Point Method

- The running time for a problem with 8000 variables is approx.23 minutes

2. Weighted Balancing Heuristic

- The running time for the mentioned problem with 8000 variables is approx. 0.2 seconds

The model construction allows us to use the solution in various ways:

- Sort the rows of matrix X by order priority to ensure an appropriate sequence of order fulfillments
- Sort the rows of matrix X by product type to ensure minimal
- changeovers on workstations
- Other considerations

III. Model 2 Demand Are Given for Product Type, Change Over Time Is Constant

A. Product Type, Workstations and Time Frame

- Vector of product types

$$p = (p_1, p_2, \dots, p_m)$$

m = is the number of product types

- Vector of workstations (resources)

$$w = (w_1, w_2, \dots, w_n)$$

n = is the number of workstations

- T is the network time, the time period supposed to be optimized for the operation.

B. Product-Workstation Matrix

$$S = \begin{array}{c} \\ p_1 \\ p_2 \\ \vdots \\ p_m \end{array} \begin{array}{c} \begin{array}{cccc} w_1 & w_2 & \cdots & w_n \end{array} \\ \begin{bmatrix} s_{1,1} & s_{1,2} & \cdots & s_{1,n} \\ s_{2,1} & s_{2,2} & & s_{2,n} \\ & \vdots & \ddots & \vdots \\ s_{m,1} & s_{m,2} & \cdots & s_{m,n} \end{bmatrix} \end{array}$$

$$s_{i,j} = \begin{cases} 1, \text{if product } p_i \text{ can be produced at workstation } w_j \\ 0, \text{if product } p_i \text{ cannot be produced at workstation } w_j \end{cases}$$

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$$i = 1, 2, \dots, \text{m}; \; j = 1, 2, \dots, \text{n}$$

C. Demand Vector

$$d = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_m \end{bmatrix}$$

$$d_i = \text{demand for product } p_i \text{ for time period } T$$

Vector of product type process times:

$$t^T = (t_1, t_2, \dots, t_m)$$

The change over time has a constant value of c, c ≥ 0.

D. Assignment Matrix (Variable Matrix)

$$X = \begin{matrix} & w_1 & w_2 & \cdots & w_n \\ p_1 & x_{1,1} & x_{1,2} & \cdots & x_{1,n} \\ p_2 & x_{2,1} & x_{2,2} & & x_{2,n} \\ \vdots & \vdots & & \ddots & \vdots \\ p_m & x_{m,1} & x_{m,2} & \cdots & x_{m,n} \end{matrix}$$

$x_{i,j}$ = quantity of product p_i to be processed at workstation w_j $i = 1, 2, \dots, \text{m}; \; j = 1, 2, \dots, \text{n}$. Note that here the customer demands are for product types. This is considered to be aggregating needs. This approach, on the one hand, considerably decreases the number of variables compared to Model 1, and on the other hand, gives a solution that is suitable for the practical applications.

- Integer programming [4]

$$x_{i,j} \in N; (i = 1, 2, \dots, m; \; j = 1, 2, \dots, n)$$

E. Constraints

Fulfillment of each demand $\forall_i$:

$$\sum_{j=1}^{n} x_{i,j} s_{i,j} = d_i$$

Optional constraint on station load (capacity) $\forall_j$:

$$\sum_{i=1}^{m} x_{i,j} s_{i,j} t_i \leq T$$

F. Objective

- Objective function (maximum of workstation loads)

$$\text{F(X)} = \max_{j=1,2,\dots,n} \left(\sum_{i=1}^{m} x_{i,j} s_{i,j} t_i + n_{c,j} c \right)$$

where $n_{c,j} = |C_j| - 1$,

$$\mathbf{C}j = \{x_{i,j} : x_{i,j} \, 6{=}0, \, i \in \{1, 2, \dots, m\}\};$$

that is, $n_{c,j}$ is the number of changeovers on workstation j.

- Goal: F(X) → min. Note that if the optional constraint is not applied, then the criterion F(X) ≤ T can be used to decide if the solution is acceptable in practice.

G. Practical Consideration

The order of magnitude k of product types and workstations are as ($n = 10^k$):

- Product types (in one planning session): k = 2
- Workstations: k = 1

The order of magnitude of number of variables is 1+2 = 3; that is, the optimization problem may include thousands of variables.

H. The Developed Method

1. Nonlinear Optimization with Relaxation and Interior Point Method

Firstly, the interior point method (fmincon in MATLAB) is used to solve the relaxed problem in which $x_{i,j}$ [0, 1]. Secondly, a heuristic is used to turn the solution of the relaxed problem to an integer solution of the original problem. The solution is nearly optimal. It runs rather in exponential time than in polynomial time.

2. Greedy Heuristic

In every iteration, one product of a given product type is assigned to a workstation so that the assignment results in minimal increase of the objective function. The solution is not optimal, just nearly optimal. It runs in O(n^3) time [6]. It suits the practical needs.

I. Running Times and Flexibility

1. Nonlinear Optimization with Relaxation and Interior Point Method

- The running time for a problem with 3000 variables is approx. 11 minutes.

2. Greedy Heuristic

- The running time for the mentioned problem with 3000 variables is approx. 2.3 seconds.

Since the greedy method runs quickly, it can be used for simulation purposes.

IV. Conclusion

The fastest software coded in MATLAB was selected for planning purposes. Runtime of the simulation model is critical for reducing CTO service lead time. [7] A one-day lead time is only feasible if proper planning and implementation is provided. Based on the available data, a model is selected which has the shortest runtime to ensure simulation for running production which provides for continuous production scheduling and the targeted one-day lead time [8].

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