ICIC Express Letters
Part B: Applications
Volume **1**, Number **1**, September **2010**

ICIC International ©2010 ISSN 2185-2766
pp. **85–91**

IMPROVEMENT RESEARCH OF DISCRETE MANUFACTURING ENTERPRISE'S RESOURCE CONSUMPTION QUOTA BASED ON INVERSE OPTIMIZATION

Yunfu Huo[1] and Lin Ma[2]

[1]Institute of E-Commerce and Logistics
Dalian University
No. 10, Xuefu Ave., Economic Technological Development Zone, Dalian 116622, P. R. China
huoyunfu@dlu.edu.cn

[2]Qi Ming Hai Tong Information Technology Co., Ltd
Dalian 116023, P. R. China

Received May 2010; accepted July 2010

Abstract. *This paper takes the enterprises' ultimate goal that profit-maximization as the starting point, combines inverse optimization with VA, creates a method of improvement resource consumption quota on the premise of meeting market demand and successfully completing production tasks, expects to integrate and optimize the enterprise resource, to ensure low-cost operation, according schedule and output to organize the production, to full play enterprises' resources and make them to maximum profits. The research results show that in the process of actual production, the method is able to guide enterprises to optimize resource allocation, improve resource consumption quota, lower production costs and make enterprise's profit space expanding.*
Keywords: Discrete manufacturing enterprise, Inverse optimization, VA (Value Analysis), Resource consumption quota

1. **Introduction.** Along with the advancement and development of the scientific and production technology, the manufacturing sector has gradually become the mainstay of the national economy. In the operation of the market economy mechanism, the manufacturing sector creates wealth, while consuming a large number of all kinds of social economic resources. From the macroscopic to say, no matter financing, land, labor or other factors of production are limited and scarce, so we must seriously consider how to make these limited and scarce resources reasonably allocated to the best options to use them in order to achieve the greatest economic benefits. From the microcosmic to say, the resource consumption of production process directly relate to costs and effect their competition, so in the case of meeting the market demand, according with the greatest efficiency and the principle of the lowest cost, using the optimization production plan, and guide the enterprises to optimize the resource allocation. Everyone knows, the purpose of enterprise is profit maximization. However, one side, in some countriesmanufacturing still use cheap labor or take "energy" to exchange "technology", so they lack the core competitiveness, which determines profit space will not be great. The other side, in the process of production, raw material costs account for 70% of overall production costs, while today the raw materials' constraints of global manufacturing has become increasingly prominent problem. Therefore, two ways that are able to reduce the cost: lower resource consumption and optimize the allocation of resources are particularly important.

At present, in the references of relating improve the resource consumption quotation under the premise of meeting the market demand, the manufacturing enterprise resource consumption quotas of the formulation and management had studied by a few scholarsthe results show two points, one is that from macro-qualitative to show it, did not give specific methods and quantitative model, the most of methods were given by the design drawings and process by hand [1,2], mainly; the other one is that in the references of resource consumption quota, the articles of relating the modeling did not refer to meet the market demand and successfully complete production tasks, and it is the management method [3], mainly.

About the issue of meeting the market demand, the best method is the inverse optimization. In 1992, the method was initiated by Burton and Toint [4]. In 1996, Zhang et al. had started to study the feasible solutions of LP become the optimal solution of inverse optimization, and they gave column generation and the ellipse method [5,6]. Currently, applications of the method more widely in the equilibrium of transportation flows, multi-criteria optimization and web site selection and other issues have made great achievements [7,8]. In the enterprise management, from the quantitative point of view, studied the management of innovation [9]. However, how to apply the inverse optimization to manage the manufacturing's resource consumption quota is still blank until now. The recent result is Zhang et al. (2007) gave mathematics model of inverse problem for optimal production plan that let some infeasible solution transform into feasible ones based on linear programming, according as complementary optimum condition [10], that made the inverse optimization theory further deepened in the field of production.

Based on this, this paper will take the profit-maximization as the starting point, create a method of improvement resource consumption quota on the premise of meeting marketing demand and successfully completing production tasks, expect to integrate and optimize the enterprise resource, to ensure low-cost operation, to full play enterprises' resources and make profits maximum.

The research frame of this paper is as in Figure 1.

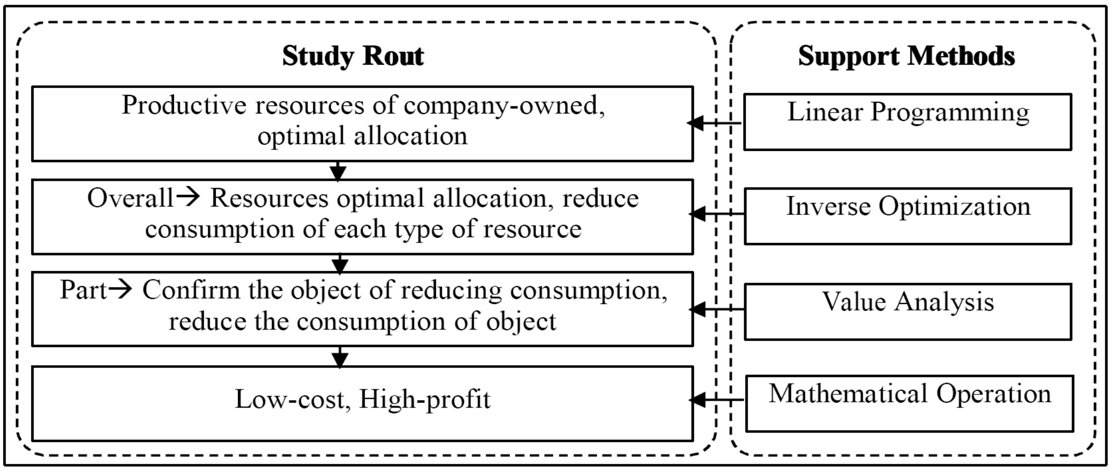

FIGURE 1. The research frame of this paper

This paper will divided four parts, Section 2 establish a resource optimal allocation model of the discrete manufacturing and an improvement mechanism of consumption quota, Section 3 is empirical analysis and Section 4 is conclusions.

2. Establish a Resource Optimal Allocation Model of the Discrete Manufacturing and an Improvement Mechanism of Consumption Quota.

2.1. **The inverse optimization-based optimal allocation model of overall resource.** Study the production general form of discrete manufacturing, in the planning period, n kinds of product need to produce, planned output is $x_1, x_2, \cdots, x_n$, production cost is $c_1, c_2, \cdots, c_n$, when the ith kind of product is produced, the jth kind of resource need to use a_{ij}, produce n kinds of product need m kinds of resource, the resource of enterprise-owned is b_1, b_2, $\cdots$, b_m. So, enterprise resource optimal allocation problem can be expressed as:

$$(LP)\begin{cases} \min & c^T x \\ s.t. & Ax \geq b \\ & x \geq 0 \end{cases} \tag{1}$$

The DP (Dual Problem) of (1) is:

$$(DP)\begin{cases} \max & wb \\ s.t. & wA \leq c \\ & w \geq 0 \end{cases} \tag{2}$$

hereinto, $x = (x_1, x_2, \cdots, x_n)^T$, $c = (c_1, c_2, \cdots, c_n)^T$, $b = (b_1, b_2, \cdots, b_m)^T$, $A = (a_{ij})_{m\times n}$.

With the development of market economy, individuation and diversification gradually replaced the planned production, most of companies will arrange a production plan based on market demand. It has become the focus that how to minimally adjust the allocation of resource and make the market demand become the optimal point of model (1).

When the target value of market expectation is given as $\bar{x}$, if want $\bar{x}$ become the optimal solution of (1), corresponding enterprise resource consumption coefficient $a_{i\bullet}$ or $a_{\bullet j}$ need change to $\bar{a}_{i\bullet}$ or $\bar{a}_{\bullet j}$, here, the optimal target is the least change of $\bar{a}_{i\bullet}$ or $\bar{a}_{\bullet j}$, the model is expressed as:

$$\begin{cases} \min & \|\bar{A} - A\| \\ s.t. & \bar{a}_{i\bullet} x^* \geq b_i,\ w_i = 0 \\ & \bar{a}_{i\bullet} x^* = b_i,\ w_i > 0 \end{cases} \tag{3}$$

Order $\bar{a}_{i\bullet} = a_{i\bullet} + \eta_i^* - \gamma_i^*$, $i = 1, 2, \cdots, n$, here, $\eta_i^* \geq 0$ and $\gamma_i^* \geq 0$ are increment and decrement of $a_{i\bullet}$, consider $\|\eta_i^* - \gamma_i^*\| \leq \|\eta_i^* + \gamma_i^*\|$, so we can rewrite (3) as:

$$\begin{cases} \min & \|\eta + \gamma\| \\ s.t. & (a_{i\bullet} + \eta_i^* - \gamma_i^*)x^* \leq b_i,\ w_i = 0 \\ & (a_{i\bullet} + \eta_i^* - \gamma_i^*)x^* = b_i,\ w_i > 0 \\ & \eta_i^*, \gamma_i^* \geq 0, i = 1, 2, \cdots, m \end{cases} \tag{4}$$

If the objective function is the vector norm in the inverse optimization model, so it can be express as L_1-Norm, at this time, the model is LP, the traditional simplex method can be used to solve it; if the objective function is the matrix norm, then no matter what norm is used that is not easy to solve. So, define the *abs*-norm of A as:

$$\|A\|_{abs} = \sum_{i=1}^{n} \sum_{j=1}^{m} |a_{ij}| \tag{5}$$

Thereby, the object function can be solved by simplex method, let the solution compare with the raw data, we can get the improved result.

2.2. **VA-based improvement mechanism of part resource consumption quota.** First, VA-based to find the object of reducing consumption. From raw materials to finished goods, each product has its own production technics, in that, there are many processes, focusing on the value of processes, it is the fundamental for finding the object of reducing resource consumption quota.

In the previous chapter, using the inverse optimization model of enterprise resource allocation has been got the overall decrement of each type resources consumption in the manufacturing process, but how to reduce the resource consumption quota of part process was unable to determine in the process of production technics.

Because the various products, complex processes and many processes consume the high ratio of resource, so, the first is apply ABC classification to select key processes, then, use VA to analyze every process, and confirm the improvement object. Model as shown in Table 1.

Table 1. The decrement model of resource consumption quota in process

<table>
<tr><td rowspan="4">The decrement of each process</td><td>Process 1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Process 2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>……</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Process n</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="2">Unknown / Known</td><td>Resource 1</td><td>Resource 2</td><td>……</td><td>Resource 3</td></tr>
<tr><td colspan="4">The overall decrement of each type resources</td></tr>
</table>

Confirm the object of reducing resource consumption, steps as: (1) According the actual situation, give the production technological process and the process; (2) Use VA to analyze and calculate the value coefficient of each process; (3) When the value coefficient of one process is less than 1, it is confirmed as the improvement object.

Then, establish the model to measure the consumption. By VA, we can get the value coefficient and make the coefficient which is less than 1 to normalize. Then, get part decrement of resource consumption quota by (6).

$$\text{Normalized coefficient} \times \text{overall decrement of one resources} = \text{part decrement} \tag{6}$$

Applying the above Formula (6) to calculate degree of reduction, to achieve improvement of the resource consumption quota and quota management purposes.

Finally, confirm the major work processes of the improvement mechanism for part resource consumption quota: (1) preparation stage. Materials collected, and determine the work flow; (2) analysis stage. Understanding of part technology and analyzing functional; (3) understanding the cost of product and each process; (4) calculate the value coefficient. Confirm the object of reducing resource consumption; (5) calculate the part decrement; (6) evaluation results. Evaluation indicators are annual savings amount and cost saving rate etc.

3. **Empirical Analysis.** In the crankshaft workshop of a automobile engine factory, there are two different models of crankshaft need to produce, mark them as CI and CII, the production parameters as follow:

Production program: annual production capacity is 120 000 units for CI and CII;

Production system: 3 shifts, 8 hours/shifts;

Work days: 251 days/year;

Production efficiency: 70%.

According above conditions, the enterprise equipment capacity:

$$8 \times 3 \times 251 \times 60 \times 70\% \approx 248000(\text{min}).$$

Now, the resource consumption quota of CI and CII as Table 2.

Table 2. Two kinds of resource consumption quota parameter of crankshaft

Consumption Quota	**CI**	**CII**	**Available Resource**
Raw material (kg/root)	50.00	100.00	1000000.00 (kg)
Labor cost (yuan/root)	0.50	1.20	11600.00 (yuan)
Working-hour (min/root)	16.00	20.00	248000.00 (min)
Single profit of product (yuan/root)	225.00	460.00	

At present, the market expectations are the CI: 4500 root, CII: 8500 root. The enterprise wish to optimize the allocation of available resources and meet market demand by improving resource consumption quota.

3.1. **Resources optimal allocation, reduce consumption of each type of resource.** Assuming that in the plan period, the enterprise plan to produce CI: root, CII: root. So, profit-maximizing model as follows:

$$(LP)\max z = 225.00x_1 + 460.00x_2$$
$$s.t.\begin{cases} 50.00x_1 + 100.00x_2 \le 1000000.00 \\ 0.50x_1 + 1.2x_2 \le 11600.00 \\ 16.00x_1 + 20.00x_2 \le 248000.00 \\ x_1, x_2 \ge 0 \end{cases} \tag{7}$$

The optimal solution of (7) is $x^* = (4000, 8000)^T$, so $\max z = 4580000$ yuan, that is when CI and CII is produced 4000 root and 8000 root, the profits could reach to 4.58 million yuan.

According present quota level to evaluate the equipment capacity, if increase production to market demand, then $16.00 \times 4500 + 20.00 \times 8500 = 242000$(min), it is less than 248000 min, so, the enterprise capacity is sufficient

By (1) and (2), we can get

$$\min \sum_{i=1}^{3}\sum_{j=1}^{2}\eta_{ij} + \sum_{i=1}^{3}\sum_{j=1}^{2}\eta_{ij}$$
$$s.t.\begin{cases} 4500\eta_{11} - 4500\gamma_{11} + 8500\eta_{12} - 8500\gamma_{12} = -75000.00 \\ 4500\eta_{21} - 4500\gamma_{21} + 8500\eta_{22} - 8500\gamma_{22} = -850.00 \\ 4500\eta_{31} - 4500\gamma_{31} + 8500\eta_{32} - 8500\gamma_{32} \ge -19500.00 \\ \eta_{ij}, \gamma_{ij} \ge 0,\ i = (1,2,3);\ j = (1,2) \end{cases} \tag{8}$$

The optimal solution of (8) is: $(\eta_{11}, \eta_{12}, \eta_{21}, \eta_{22}, \eta_{31}, \eta_{32}, \gamma_{11}, \gamma_{12}, \gamma_{21}, \gamma_{22}, \gamma_{31}, \gamma_{32})^T = (0, 0, 0, 0, 0, 0, 0, 8.82, 0, 0.10, 0, 2.29)^T$.

By the results of solution, we know that the resource consumption quota of CI is unchanged and quota of CII for each resource is changed and the initial quota and the optimal one as shown in Table 3.

TABLE 3. The initial quota and optimization quota of each resource

CII	Initial Quota	Decrement of resource quota	Optimal Quota
Raw material (kg/root)	100.00	8.82	91.18
Labor cost (yuan/root)	1.20	0.10	1.10
Working-hour (min/root)	20.00	2.29	17.71

3.2. **Confirm the object of reducing consumption, reduce the consumption of object.** (1) Materials collected. Use the method of ABC to analyze the 40 process of CII, and confirm main processes. (2) Confirm the object of reducing consumption. By expert estimation and BOM of product, we can get function coefficients, cost coefficients and value coefficients, the result as shown in Table 4. Here, the value coefficient of less than 1 process is the improvement object. (3) Determine decrement of resource consumption quota of the object process, calculate the profit space, as shown in Table 4. (4) Evaluation results. One side, predigest process. Make the major processes from 20 reduce to 18 operations, and working-hour quota from 20 minutes/root reduce to 18 minutes/root; the other side, economic benefits. Carry out the emendatory resource consumption quota, the CII's cost saves about 84.00 yuan. Cost savings rate is 10.5%, the annual savings amount is 678,000 yuan.

Table 4. CII's coefficients of function, cost and value, as well as decrement of resource consumption quota and profits space

NO.	Main Process of CII	Function coefficient	Cost coefficients			Value coefficients			Decrement of Equipment (s)	Decrement of labor (yuan)	Decrement of Material (kg)	Profit space (yuan)	Annual economic benefits (yuan)
			Material	Labor	Equipment	Material	Labor	Equipment					
1	Blank marking	0.0837	—	0.1334	0.0107	—	0.6273	7.8297	—	0.011	—	0.01	90.36
2	Rough machining	0.0251	0.16	0.0073	0.0702	0.1569	3.4577	0.3578	11	—	0.23	2.85	24246.99
3	Quenched: stable temper	0.0586	—	0.0053	0.2223	—	10.9533	0.2635	8	—	—	6.15	52304.68
4	Marking	0.0126	—	0.0522	0.0049	—	0.2404	2.5726	—	—	—	—	—
5	Semi finishing	0.0126	0.08	0.0046	0.0554	0.1569	2.7288	0.2267	7	—	0.23	2.30	19570.84
6	Marking	0.0126	—	0.0715	0.0036	—	0.1756	3.5234	—	—	—	—	—
7	Crude drilling: Center Bore	0	0.12	0.0083	0.0049	0	0	0	8	0.01	3	17.98	152838.50
8	Aging	0	—	0.0167	0.0331	—	0	0	24	0.02	—	7.96	67632.83
9	Marking	0.0209	—	0.1192	0.0036	—	0.1756	5.8723	—	—	—	—	—
10	Finishing	0.0837	0.12	0.0188	0.0904	0.6974	4.4538	0.9259	30	—	1.02	9.77	83074.06
11	Marking	0.0167	—	0.041	0.0083	—	0.4084	2.0196	—	0.007	—	0.01	58.82
12	Drilling	0.0837	0.1	0.1433	0.0118	0.8368	0.5839	7.0621	—	0.01	1.23	6.88	58479.81
13	Quenching	0.0837	—	0.0108	0.1567	—	7.7207	0.5341	17	—	—	8.79	74720.97
14	Dynamic balance, counter-balance, ridding unbalance	0.0628	0.14	0.0765	0.0167	0.4483	0.8205	3.7692	—	0.014	0.66	3.69	31401.60
15	Finishing	0.0837	0.08	0.022	0.0773	1.046	3.8088	1.0827	—	—	—	—	—
16	Marking	0.0251	—	0.0477	0.0107	—	0.5267	2.3489	—	0.009	—	0.01	75.86
17	Drilling, attack, milling	0.0837	0.1	0.0198	0.0856	0.8368	4.2172	0.9778	31	—	1.23	11.14	94718.40
18	Cleaning	0.0837	—	0.0274	0.0619	—	3.0494	1.3523	—	—	—	—	—
19	Finally diagnostic	0.0837	—	0.1462	0.0116	—	0.5725	7.2033	—	0.01	—	0.01	82.46
20	Assembly product	0.0837	0.1	0.028	0.0606	0.8368	2.9883	1.38	—	—	1.23	6.87	58395.70
$\sum$		1	1	1	1	3.9699	4.1308	3.2858	137.00	0.10	8.82	84.44	717691.90

4. **Conclusions.** This paper takes the profit-maximization as the starting point, create a method of improvement resource consumption quota on the premise of meeting market demand and successfully completing production tasks. The main features of this study are: applying the method of inverse optimization to improve enterprise quota management mechanism; at the same time, this paper combines VA with inverse optimization to solve the issue of reducing resource consumption quotas. The study results show that in the process of actual production, this method is able to guide enterprises to optimize resource allocation, is good for improving resource consumption quota, lower production costs and make enterprise's profit space expanding.

REFERENCES

[1] A. Liu and B. Shen, The analysis of working hour's rational establishment, *Technology*, vol.10, pp.26, 2009.

[2] X. Chen, *Manufacturing System Model of Resource Consumption and Resource Consumption Analysis of the Situation*, Chongqing University, Chongqing, 1999.

[3] Q. Sun, Discussion on application of material consumption quota management in the production enterprise, *Shanxi Coking Coal Science and Technology*, vol.11, pp.33-34, 2008.

[4] D. Burton and Ph. L. Toint, On an instance of the inverse shortest paths problem, *Mathematical Programming*, vol.53, pp.46-61, 1992.

[5] C. Yang and J. Zhang, Two general methods for inverse optimization problems, *Applied Mathematics Letters*, vol.12, pp.69-72, 1999.

[6] J. Zhang and Z. Ma, A network flow method for solving some inverse combinatorial optimization problems, *Optimization*, vol.37, pp.59-72, 1996.

[7] C. Heuberger, Inverse combinatorial optimization: A survey on problem, methods, and result, *Journal of Combinatorial Optimization*, vol.8, pp.329-361, 2004.

[8] R. K. Ahuja and J. B. Orlin, Inverse optimization, *Operations Research*, vol.49, pp.771-783, 2001.

[9] D. Gao, *Inverse Linear Optimization Problems for the Quantitative Analysis of Management Innovation*, Dalian University of Technology, Dalian, 2005.

[10] X. Zhang, X. Song and P. Liang, Generalized inverse optimal models of linear programming for enterprise optimal production plan, *Systems Engineering – Theory and Practice*, vol.6, pp.80-85, 2007.