ORIGINAL ARTICLE

A trim-loss minimization in a produce-handling vehicle production plant

Apichai Ritvirool[1]

Abstract

Ritvirool, A.

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How to cut out the required pieces from raw materials by minimizing waste is a trim-loss problem. The integer linear programming (ILP) model was developed to solve this problem. In addition, this ILP model could be used for planning an order over some future time period. Time horizon of ordering raw material including weekly, monthly, quarterly, and annually could be planned to reduce the trim loss. The numerical examples using an industrial case study of a produce-handling vehicle production plant were presented to illustrate how the proposed ILP model could be applied to actual systems and the types of information that was obtained relative to implementation. The results showed that the proposed ILP model can be used as a decision support tool for selecting time horizon of order planning and cutting patterns to decrease material cost and waste from cutting raw material.

Key words : trim-loss minimization, order-planning horizon, produce-handling vehicle

[1]Ph.D.(Industrial Engineering), Department of Industrial Engineering, Faculty of Engineering, Naresuan University, Muang, Phitsanulok, 65000 Thailand.
E-mail: apichairit@yahoo.com

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บทคัดย่อ

อภิชัย ฤตวิรุฬห์

การลดเศษวัสดุที่เหลือจากการตัดให้เหลือน้อยที่สุดในโรงงานผลิตรถบรรทุกเพื่อการเกษตร

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ปัญหาการตัดชิ้นส่วนต่าง ๆ จากวัสดุให้ได้จำนวนชิ้นตามความต้องการโดยให้มีเศษเหลือทิ้งจากการตัดน้อยที่สุดเรียกว่า trim loss แบบจำลองโปรแกรมจำนวนเต็มเชิงเส้นตรง (Integer Linear Programming, ILP) ถูกสร้างขึ้นเพื่อแก้ปัญหาดังกล่าว นอกจากนี้แบบจำลอง ILP นี้ยังสามารถนำมาใช้ในการวางแผนเวลาล่วงหน้าของการสั่งซื้อวัสดุ โดยจะเลือกสั่งซื้อในแบบใดแบบหนึ่งดังนี้คือ แบบรายสัปดาห์ รายเดือน รายสามเดือน หรือรายปี เพื่อที่จะลดปริมาณเศษวัสดุให้เหลือน้อยที่สุด ตัวอย่างกรณีศึกษาของการตัดเหล็กฉากซึ่งเป็นวัตถุดิบที่ใช้ในโรงงานผลิตรถบรรทุกเพื่อการเกษตร (รถอีแต๋น) ถูกนำมาศึกษาโดยการเก็บข้อมูลต่าง ๆ ป้อนให้กับแบบจำลอง ILP เพื่อแสดงให้เห็นถึงการประยุกต์ใช้แบบจำลองดังกล่าว และนำผลลัพธ์ที่เหมาะสมที่สุดไปเป็นแนวทางปฏิบัติ ผลของงานวิจัยแสดงให้เห็นว่าแบบจำลอง ILP ที่สร้างขึ้นสามารถนำมาเป็นเครื่องมือช่วยในการตัดสินใจเลือกช่วงเวลาของการวางแผนสั่งซื้อวัตถุดิบและเลือกรูปแบบในการตัดวัตถุดิบเพื่อทำให้ต้นทุนวัตถุดิบและเศษวัสดุที่เหลือจากการตัดลดลง

ภาควิชาวิศวกรรมอุตสาหการ คณะวิศวกรรมศาสตร์ มหาวิทยาลัยนเรศวร อำเภอเมือง จังหวัดพิษณุโลก 65000

SMEs (Small and Medium Enterprises) play an important role in increasing economic growth of Thailand. SME sector is typically categorized into sub-sectors of micro (up to 10 employees), small (10 to 49 employees), and medium size enterprises (50 to 249 employees). Small size enterprises that produce and sell produce-handling vehicles to customers, such as farmers, rarely apply material management, especially material utilization, in their factory. Raw-material usage is done based on experience of the worker without planning. A lot of wastes from cutting out the required pieces from raw materials exist on the shop floor. How to cut material to minimize waste is called cutting stock or trim loss problem.

Gilmore and Gomery (1961) firstly solved the problem of cutting out some paper products of different sizes to minimize the required number of paper rolls. The linear programming model for one-dimensional cutting stock problems was developed and the column generation approach has been proposed to solve the optimal solution. Dyckhoff (1990) classified traditional operations research approaches to these problems into two categories; heuristics and linear programming (LP)-based methods. Schilling and Georgiadis (2002) proposed a mixed integer linear programming model to maximize the profit of cutting out raw rolls of one or more standard types to obtain several product rolls. Several solution approaches based on algorithms; such as algorithm using column generation and genetic algorithm were proposed to solve the complex problems in various industries; such as construction (Shahin and Salem, 2004), automobile component manufacturing (Arbib *et al.*, 2002), paper (Harjunkoski and Westerlund, 1998), aluminium (Stadtler, 1990; Helmberg, 1995), steel (Carvalho and Rodrigues, 1995), wood products (Wagner, 1999), and cloth (Gradisar *et al.*, 1976) industries. However, most previous reports presented how to solve the complex and difficult combinatorial problems without considering an order-planning decision depending on time frame, which is very important for competitiveness in SME. The aim of this study was to develop a mathematical model that can be used to support decision making in cutting one-dimensional material stock and planning an order to be submitted to material supplier based on the appropriate time horizon to decrease material cost. The article is organized by first presenting assumption, notation, and generation of various cutting patterns as input data. Then, the integer linear programming model is developed. The numerical examples using an industrial case study of a produce-handling vehicle production plant are presented to illustrate how the proposed model can be applied to actual systems. Finally, model validation is presented.

Materials and Methods

The first step of mathematical modeling was to define the problem and gather data (Hiller and Lieberman, 2004). The research problem was how to cut raw materials while minimizing waste in a preparation process of producing front body of a specific model of a produce-handling vehicle. This study focused on cutting one-dimensional material, which was six-meter angle steel used as one of raw materials of front body of a produce-handling vehicle. There were 8 different parts in length of angle steel and each part was required in different number as shown in Table 1. Cutting the required part to satisfy demand was generated in many patterns. There were 659 cutting patterns which can be categorized as follows:

(1) The same part number = 8 patterns

(2) All of each part number = 1 pattern

(3) An increase with the same number of each part = 22 patterns

* length of trim loss (mm)

(4) Fixing the number of each part while increasing the others = 628 patterns

Part number	Number of patterns
Hf - 05	46
Hf - 06	52
Hu - 04	20
Hu - 05	107
Hu - 09	20
Hu - 10	71
Hu - 11	179
Hu - 15	133

The example of cutting patterns is shown in Table 1. The integer linear programming model was developed. Our goal was to minimize the total number of six-meter angle steel ordered from supplier to produce front body of a produce-handling vehicle. The number of parts cut from each pattern was used as a parameter of mathematical model. The constraints were that the number of steels was integer and the number of parts cut from each pattern was not less than number of parts required to produce the vehicle. This study assumed that (i) there was no human error of cutting material (ii) the machine used to cut angle steel was always accurate and (iii) demand of each period was deterministic.

Notation

Z = the total number of six-meter angle steels to be cut according to pattern i, $i = 1,2,...,m$, in period j, $j = 1,2,...,n$.

x_{ij} = the number of six-meter angle steels to be cut according to pattern i, $i = 1,2,...,m$, in period j, $j = 1,2,...,n$.

a_{ij} = the number of parts cut by pattern i in period j.

b_{jk} = the number of parts required by part number k, $k = 1,2,...,p$, in period j.

The trim-loss minimization and order planning problem can be formulated as an integer linear programming model as follows:

$$\text{Minimize } Z = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} \qquad (1)$$

subject to

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}x_{ij} \geq b_{jk}, \forall_j \forall_k \qquad (2)$$

$$x_{ij} \geq 0 \text{ and integer, } \forall_i \forall_j \qquad (3)$$

Results and Discussion

Numerical Example

To illustrate the use of the model, 8 different part numbers were cut from six-meter angle steel, which was one of materials used as shown in Figure 1. The total number of units needed to produce

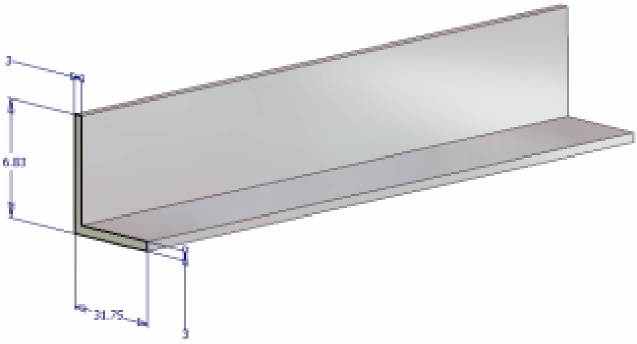

Figure 1. Six-meter angle steel drawing.

Table 1. The number of parts cut from various cutting patterns.

Part number	**Pattern # (Category #)**													
	1 (1)	**2 (1)**	**...**	**9 (2)**	**10 (3)**	**11 (3)**	**...**	**32 (4)**	**33 (4)**	**34 (4)**	**35 (4)**	**36 (4)**	**...**	**659 (4)**
Hf - 05	8	-	...	1	2	-	...	1	1	1	1	1	...	-
Hf - 06	-	9	...	1	2	-	...	8	-	-	-	-	...	-
Hu - 04	-	-	...	1	2	-	...	-	3	-	-	-	...	-
Hu - 05	-	-	...	1	-	2	...	-	-	15	-	-	...	-
Hu - 09	-	-	...	1	-	2	...	-	-	-	3	-	...	-
Hu - 10	-	-	...	1	-	2	...	-	-	-	-	10	...	-
Hu - 11	-	-	...	1	-	2	...	-	-	-	-	-	...	1
Hu - 15	-	-	...	1	-	2	...	-	-	-	-	-	...	21

Table 2. Demand of each part number per vehicle.

Part number	**Length (mm)**	**Demand per vehicle (units)**
Hf - 05	737	1
Hf - 06	648	2
Hu - 04	1473	2
Hu - 05	330	2
Hu - 09	1597	1
Hu - 10	489	4
Hu - 11	200	2
Hu - 15	267	2
Total	**5741**	**16**

one front body of a produce-handling vehicle was 16 as given in Table 2.

The demand for this type of vehicle was assumed to be 25 vehicles per month. Production engineer planned to produce 6, 7, 6, and 6 vehicles in weeks 1, 2, 3, and 4, respectively. The Integer Linear Programming (ILP) model was formulated and data from Tables 1 and 2 were used as input

Table 3. Optimal solutions of weekly ordering for the total demand of 25 vehicles.

Part number	Pattern							Demand	Total	Excess Demand
	40	64	112	155	205	3	187			
Hf - 05	1	-	-	-	-	-	-	25	25	-
Hf - 06	1	1	1	6	3	-	3	50	57	7
Hu - 04	1	1	2	-	2	4	1	50	52	2
Hu - 05	1	1	2	6	3	-	2	50	58	8
Hu - 09	1	-	-	-	-	-	-	25	25	-
Hu - 10	1	6	3	-	-	-	-	100	103	3
Hu - 11	2	-	-	-	-	-	-	50	50	-
Hu - 15	1	2	1	-	-	-	-	50	51	1
Trim Loss (mm/piece)	59	81	12	132	120	108	1923	2435		
Week 1 (pieces)	6	3	0	1	0	1	0	11		
Week 2 (pieces)	7	3	1	0	1	0	0	12		
Week 3 (pieces)	6	3	0	1	0	1	0	11		
Week 4 (pieces)	6	3	1	0	0	0	1	11		
Total (pieces)	25	12	2	2	2	2	1	45		
Trim Loss (mm)	1475	972	24	264	120	216	1923	4994		

Table 4. Optimal solutions of monthly ordering for the total demand of 25 vehicles.

Part number	Pattern					Demand	Total	Excess Demand
	40	64	112	155	205			
Hf - 05	1	-	-	-	-	25	25	-
Hf - 06	1	1	1	6	3	50	50	-
Hu - 04	1	1	2	-	2	50	50	-
Hu - 05	1	1	2	6	3	50	57	7
Hu - 09	1	-	-	-	-	25	25	-
Hu - 10	1	6	3	-	-	100	100	-
Hu - 11	2	-	-	-	-	50	50	-
Hu - 15	1	2	1	-	-	50	50	-
Trim Loss (mm/piece)	59	81	12	132	120	404		
Total (pieces)	25	9	7	1	1	43		
Trim Loss (mm)	1475	729	84	132	120	2540		

data of parameters for the model. The ILP model was solved by using commercial software, Solver, which is a tool added-in Microsoft Excel. Solver uses the simplex method with bounds on the variables and the branch-and-bound method for linear and integer problems, respectively. The optimal solutions are shown in Table 3.

Using the results from Table 3, production engineer weekly planned to order angle steel 11, 12, 11, and 11 pieces from supplier in weeks 1, 2, 3, and 4, respectively, with 4,944 mm of trim loss. Considering monthly ordering cycle, production engineer ordered only 43 pieces a month of angle steel with 2,540 mm of trim loss and excess demand was only 7 units of part Hu-05 as shown in Table 4.

The trim loss and the number of angle steels were decreased by 49.14% and 4.4%, respectively, for monthly ordering cycle compared with weekly

Table 5. Number of angle steels to be ordered for the total demand of 300 vehicles.

Ordering cycle	Demand (vehicles per cycle)	Angle steel (pieces per cycle)	Angle steel (pieces per year)	Trim loss (mm)
Weekly	6	11	550	59,928
Monthly	25	43	516	30,480
Quarterly	75	129	516	41,052
Yearly	300	513	513	37,158

Table 6. Number of angle steels to be ordered for the total demand of 600 vehicles.

Ordering cycle	Demand (vehicles per cycle)	Angle steel (pieces per cycle)	Angle steel (pieces per year)	Trim loss (mm)
Weekly	12	22	1,056	119,424
Monthly	50	86	1,032	67,872
Quarterly	150	257	1,028	74,018
Yearly	600	1,025	1,025	74,400

Table 7. Number of angle steels to be ordered for the total demand of 1200 vehicles.

Ordering cycle	Demand (vehicles per cycle)	Angle steel (pieces per cycle)	Angle steel (pieces per year)	Trim loss (mm)
Weekly	25	43	2064	148,740
Monthly	100	171	2052	149,064
Quarterly	300	513	2052	148,968
Yearly	1200	2050	2050	148,800

ordering cycles (Tables 3 and 4). In addition, the results of optimal number of angle steels to be ordered from supplier and trim loss for quarterly and annually time horizons based on demand of 25 vehicles per month are shown in Table 5.

As seen in Table 5, the minimum trim loss was found if ordering cycle of angle steel was monthly. However, the minimum number of angle steels to be ordered for producing 300 vehicles was 513, which was yearly ordering cycle as shown in Figure 2 (a). Moreover, the variation of demand was performed by doubling demand of 300 and 600 vehicles as shown in Tables 6 and 7. The ordering-time horizon associated with the minimum number of angle steels for producing 600 and 1,200 vehicles was yearly as shown in Figure 2 (b) and (c).

For the time frame less than a year, material-order planning can be decided depending on the number of angle steels. For the demand of 600 vehicles, quarterly horizon was selected because of the minimum number of steels. For the demand of 300 and 1,200 vehicles, either monthly or quarterly horizon was selected as shown in Figure 2 (a) and (c). However, monthly horizon was chosen for the demand of 300 vehicles because its amount of trim loss is lower than that of quarterly horizon as shown in Table 5. Quarterly horizon was chosen for the demand of 1,200 vehicles because its amount of trim loss is lower than that of monthly horizon as shown in Table 7.

Model validation

Hiller and Lieberman (2004) stated that the

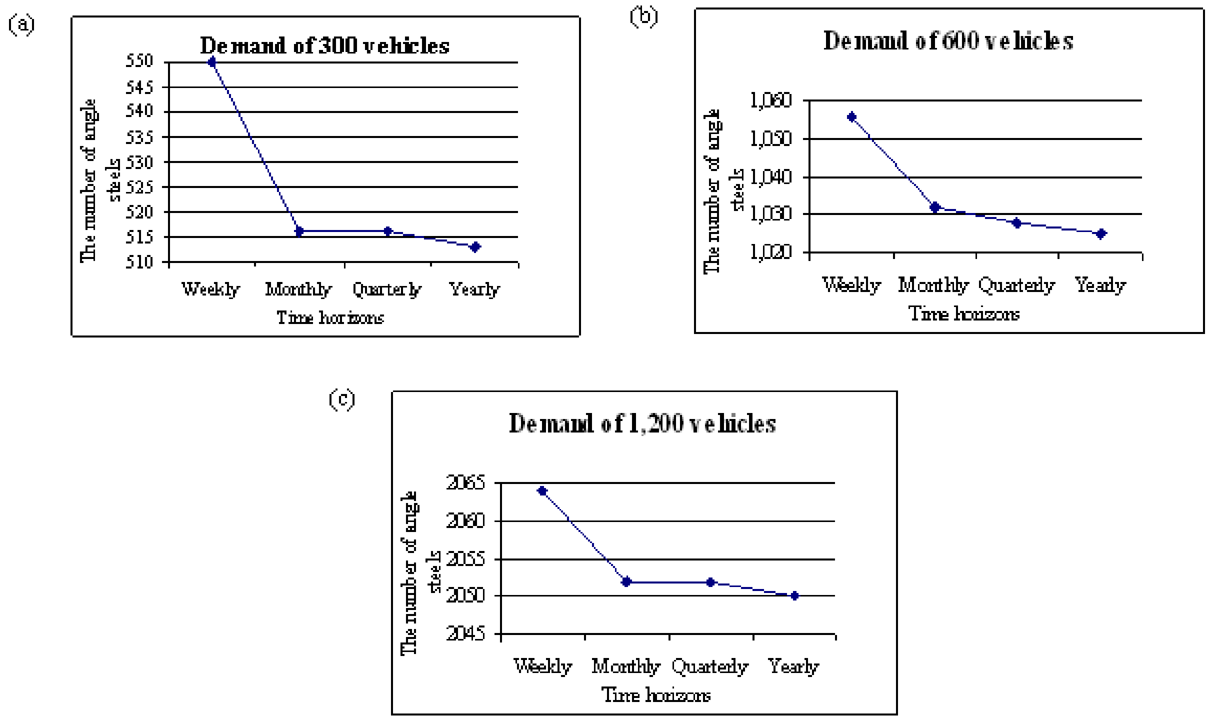

Figure 2. The variation of demand of vehicles.

process of validating a model depends on a situation of the nature of the problem and the model that were considered. They suggested a few general comments such as varying the values of the parameters and checking to see if the output from the model behaves in a plausible manner. Hence, parameterwas varied by doubling the demand of 300 and 600 vehicles. The optimal solutions from the model are shown in Column A of Table 8. To compare the output from the proposed model, we illustrated the ideal case as shown Column B of Table 8. The lengths of steel needed to satisfy demand of 25, 300, 600, and 1200 vehicles were 253,150, 3,037,800, 6,075,600, and 12,151,200 mm, respectively. The ideal case was supposed that the angle steels were ordered 4 pieces for the length of 258,000, 3,042,000, 6,078,000, and 12,156,000 mm, respectively, or equivalent to 43, 507, 1,013, and 2,026 pieces, respectively, for a standard-piece length of 6,000 mm sold in the market. The results of comparing the number of angle steels ordered from the model with the ideal case showed that the difference of output from the proposed model and ideal case is less than 2% as seen in Table 8.

Conclusions

A mathematical model was developed to determine how many angle steels should be ordered from a supplier while minimizing trim loss and when an order of angle steels will be submitted as an ordering cycle. There are potential economic savings in material cost and trim-loss reduction resulting from long-term ordering cycle and cutting plan. In addition to cutting patterns and ordering cycle horizon, costs, such as inventory and ordering costs, should be considered as key factors that might impact on making a decision of ordering raw materials from supplier. Short-term ordering cycle can decrease holding costs while increasing ordering cost. In turn, long-term ordering cycle can

Table 8. Varying the parameter of the model.

Demand (vehicles)	Proposed model (A)		Ideal case (B)				Comparison of steels used of A and B (%)
	steel* (pieces)	Trim loss (mm) to satisfy demand (mm)	Length of steel needed (mm/1 piece)	length of steel ordered	steel** (pieces)	Trim loss (mm)	
25	43	2,540	253,150	258,000	43	4,850	0
300	513	37,158	3,037,800	3,042,000	507	4,200	1.183
600	1,025	74,400	6,075,600	6,078,000	1,013	2,400	1.185
1200	2050	148,800	12,151,200	12,156,000	2,026	4,800	1.185

* each piece of angle steel length = 6,000 mm

** the number of angle steels = $\frac{\text{length of steel ordered (mm/1 piece)}}{\text{6,000 mm}}$

decrease ordering cost while increasing holding cost. To extend this work into a more realistic environment, the problems such as the limited storage space, demand fluctuations, and quality problems of raw materials can be added to the model.

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