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# The Transport Problem utilized for Machines Optimal Allocation

*The present paper presents an optimal allocation mode of the machines in a manner to maximize the profit. Starting from provided data – time standard, technical itineraries, production volume, working regime and continuing with the determined ones – duration, necessary number of machines, unit profit, the problem became a maximization transport problem*

***Keywords****: transportation problem, time standard, optimal solution, alternative solution, machining.*

## 1. Introduction

**The economic model of the transport problem**. One transports from m supplying centers, $F_1, F_2, ..., F_m$ representing the places of merchandise were loaded on the means of transport, a type of merchandise demanded by certain destination points, which can be *n* retail centers, consumption centers (beneficiaries) $B_1, B_2, ..., B_n$, the places where the merchandise is unloaded and thus the transportation process is completed [5],[9].

We know:

- The matrix of the unitary transport costs:

$$C = (c_{ij})_{\substack{i=\overline{1,m} \\ j=1,n}} \quad (1)$$

- The quantities available at each supplier:

$$(a_i)_m, i = \overline{1, m} \quad (2)$$

- The quantities necessary at each beneficiary:

$$(b_j)_n, j = \overline{1, n} \quad (3)$$

- The matrix of the transported quantities:

$$X = \left(x_{ij}\right)_{\substack{i=\overline{1,m} \\ j=\overline{1,n}}} \quad (4)$$

- Delivery is made by direct transportation without transboarding points.

We have to determine the optimum transportation plan in a manner that the total transportation costs to be minimum [6].

A problem of linear programming associated to a transportation problem becomes a problem of maximum if instead of transportation costs $c_{ij}$, in the objective function (1), it uses the profits earned by the transport firm by moving one merchandise unit from point *i* to point *j* under the same restrictions regarding the availability, the necessary and the non-negative of solutions [5], [9].

## 2. Case Study

From the gang range analysis of the production program [3] proposed inside a research program, it selects for the present paper only the parts selected in Table 1, parts realized inside a manufacturing cell.

**Table 1.**

| Crt. Nr. | Product | Part symbol | Production volume Q [buc/an] | $N_T$ [min/part] | Material |
|---|---|---|---|---|---|
| 1. | Screw bolt 1 | P1 | 3520 | 64 | OLC35N |
| 2. | Screw bolt 2 | P2 | 23040 | 35 | OL35CR |
| 3. | Screw bolt 3 | P3 | 1280 | 128 | OL50 |
| 4. | Bolt | P4 | 1280 | 85 | OL50 |

The working regime of the atelier is:

- no. working days: 5 days/week;
- no. of shifts: 2 shifts/day;
- no. of working hours: 8 hours/shift.

The available time (Fd) is given by the formula:

$$\begin{aligned} Fd &= [n_{zc} - (n_{zs} + n_{zn} + n_{zrp} + n_{zia})] \text{ x } (n_s \text{ x } d_s) = \\ &= [365 - (11 + 104 + 10 + 0)] \text{ x } (2 \text{ x } 8) = 3840 \text{ [hours/year]} = \\ &= 230400 \text{ min/year} \end{aligned} \quad (5)$$

in which:

$n_{zc}$ – no. of calendar days

$n_{sl}$ – no. of legal holydays

$n_{zn}$ – no. of nonworking days

$n_{zrp}$ – no. of days for maintenance

$n_{zia}$ – no. of days with announced disconnections
$n_s$ – no. of shifts
$d_s$ – shift duration [ore].

Determining the necessary number of machines [8] from each type *i* is realised applying formula (2), the results being presented in Table 2.

$$m_{i\ calc} = \frac{\sum_{i=1}^{p}\left(Q_j \times t_{uij}\right)}{60 \times F_{di} \times K} \quad [pieces] \qquad (6)$$

**Table 2.**

| Crt. Nr. | Activity Symbol | Activity | Part symbol | $Q_i$ [parts / year] | $t_{uij}$ [min/ part] | Calculated number of machines $m_{i\ calc}$ [pieces] | Adopted number of machines $m_{ia}$ [pieces] |
|---|---|---|---|---|---|---|---|
| 1. | A | Cutting | P1 | 3520 | 10 | $m_1$ = 0,89 | 1 |
| | | | P2 | 23040 | 5 | | |
| | | | P3 | 1280 | 8 | | |
| | | | P4 | 1280 | 10 | | |
| 2. | B | Frontal turning | P1 | 3520 | 7 | $m_2$ = 0,3 | 1 |
| | | | P3 | 1280 | 15 | | |
| | | | P4 | 1280 | 15 | | |
| 3. | C | Centering | P1 | 3520 | 5 | $m_3$ = 0,1 | 1 |
| | | | P3 | 1280 | 5 | | |
| 4. | D | Rough Turning, Finishing | P1 | 3520 | 20 | $m_4$ = 0,5 | 1 |
| | | | P3 | 1280 | 20 | | |
| | | | P4 | 1280 | 15 | | |
| 5. | E | Rough Turning, Finishing | P3 | 1280 | 45 | $m_5$ = 0,5 | 1 |
| | | | P4 | 1280 | 35 | | |
| 6. | F | Thread rolling | P2 | 23040 | 10 | $m_6$ = 1,1 | 2 |
| | | | P3 | 1280 | 15 | | |
| 7. | G | Chamfering | P3 | 1280 | 5 | $m_7$ = 0,09 | 1 |
| | | | P4 | 1280 | 10 | | |
| 8. | H | Threading | P1 | 3520 | 22 | $m_8$ = 2,5 | 3 |
| | | | P2 | 23040 | 20 | | |
| | | | P3 | 1280 | 15 | | |

in which:

$j$ = 1, 2,..., p - parts gang range;
$Q_j$ = predicted yearly production volume [parts/year];
$t_{uij}$ = unit allowed time for manufacturing part *j* on *i* machine [min/part];
$F_{di}$ = available time of each machine type [min/year];
k = usage coefficient of the production capacity (k = 0,85…0,95).

According to Table 2, the necessary number of machines is 11. In Table 3 are presented the available machines and the activity grouping mode. After activity grouping, the number of machines is reduced from 11 to 7.

**Table 3.**

| Crt. Nr. | Activity Symbol | Equipment | Machine symbol | Number of machines |
|---|---|---|---|---|
| 1. | A+C | Centre Lathe (560x2000) | M1 | 1 |
| 2. | B+H | Centre Lathe (630x1000) | M2 | 3 |
| 3. | D+F | Centre Lathe (710x2000) | M3 | 2 |
| 4. | E+G | Centre Lathe (1000x2800) | M4 | 1 |

The need is to allocate the four products ($P_i$, $i=\overline{1,4}$) on the four machine types ($M_J$, $j=\overline{1,4}$), in order to obtain maximal profit. The data from Table 4 will become thus data for a transport problem, having a maxim objective function (Table 5). The other components of Table 4 are:

- Market demand [parts/year] – $b_1$=3520; $b_2$=23040; $b_3$=1280; $b_4$=1280;
- Unit allowed time for parts [parts/year] – $t_1$=64; $t_2$=35; $t_3$=128; $t_4$=85.
- Unit price [m.u.] – $p_1$=270; $p_2$=250; $p_3$=190; $p_4$=300.
- Number of necessary machines [pieces] – $a_1$=1; $a_2$=3; $a_3$=2; $a_4$=1.
- Transport Costs [m.u] – $c_{11}$=4; $c_{12}$=6; $c_{13}$=3; $c_{14}$=8; $c_{21}$=5; $c_{22}$=8; $c_{23}$=1; $c_{24}$=5; $c_{31}$=3; $c_{32}$=7; $c_{33}$=2; $c_{34}$=4; $c_{41}$=0; $c_{42}$=0; $c_{43}$=1; $c_{44}$=3.

**Table 4.**

| | P1 | P2 | P3 | P4 | No. M.U. – $a_i$ [buc] |
|---|---|---|---|---|---|
| M1 | 4 | 6 | 3 | 8 | 1 |
| M2 | 5 | 8 | 1 | 5 | 3 |
| M3 | 3 | 7 | 2 | 4 | 2 |
| M4 | 0 | 0 | 1 | 3 | 1 |
| Demand - $b_j$ [parts/year] | 3520 | 23040 | 1280 | 1280 | |
| Unit allowed time - $t_j$ [parts/year] | 64 | 35 | 128 | 85 | |
| Unit price - $p_j$ [m.u.] | 270 | 250 | 190 | 300 | |

To transform the problem in a maximization transport problem is necessary to calculate the profit per minute, using the relation (3):

$$Pr_{ij} = \frac{p_j - c_{ij}}{t_j} \text{ [m.u./min]} \tag{7}$$

The available quantities, in this case – minutes of utilization of each type of machine, is calculated with formula (4), and the necessary quantities, more exact the offer expressed in available minutes for each machine type, with formula (5).

$$a'_i = F_d \cdot a_i \text{ [min]} \quad (8)$$

$$b'_j = b_j \cdot t_j \text{ [min]} \quad (9)$$

The maximization transport problem which has the input data presented in Figure 2 can be solved using the WinQSB software. It must be highlighted the fact that in this case we can not count on a certain profitability and it can not take in consideration the order for production launch of the parts.

| From \ To | P1 | P2 | P3 | P4 | Supply |
|---|---|---|---|---|---|
| M1 | 4.15 | 6.98 | 1.46 | 3.44 | 230400 |
| M2 | 4.14 | 6.91 | 1.48 | 3.47 | 691200 |
| M3 | 4.17 | 6.94 | 1.47 | 3.48 | 460800 |
| M4 | | | 1.48 | 3.49 | 230400 |
| Demand | 225280 | 806400 | 163840 | 108800 | |

**Figure 1.** Transport problem input data

In Figure 2 is presented the optimal transport plan in order to obtain the maxim profit. Results a maxim profit of 7.157.030,5 m.u. when:

- Part P1 is manufactured on M1 for 225.280 [min/year], meaning 3.520 [parts/year];
- Part P2 is produced on M1 for 230.400 [min/year], on M2 for 340.480 [min/year] and on M3 for 235.520 [min/year], namely 6.582 [parts/year] on M1, 9.728 [parts/year] on M2 and 6.729 [parts/year] on M3 ;
- Part P3 is manufactured on M2 for 163.840 [min/year], meaning 1.280 [parts/year];
- Part P1 is produced on M4 for 108.800 [min/year], namely 850 [parts/year];

It observes that M2 and M4 are inactive for 186.880[min/year], respectively 121.600 [min/year].

| 06-21-2015 | From | To | Shipment | Unit Profit | Total Profit | Reduced Cost |
|---|---|---|---|---|---|---|
| 1 | M1 | P2 | 230400 | 6,98 | 1608192 | 0 |
| 2 | M2 | P2 | 340480 | 6,91 | 2.352.716,75 | 0 |
| 3 | M2 | P3 | 163840 | 1,48 | 242.483,20 | 0 |
| 4 | M2 | Unused_Supply | 186880 | 0 | 0 | 0 |
| 5 | M3 | P1 | 225280 | 4,17 | 939.417,63 | 0 |
| 6 | M3 | P2 | 235520 | 6,94 | 1.634.508,88 | 0 |
| 7 | M4 | P4 | 108800 | 3,49 | 379712 | 0 |
| 8 | M4 | Unused_Supply | 121600 | 0 | 0 | 0 |
| | Total | Objective | Function | Value = | 7.157.030,50 | |

**Figure 2.** Optimal solution on matrix form

There is also an alternative solution, presented in Figure 3, which is not to different from the solution presented above. Appears just a modification of the P2 parts number manufactured on M2 machine from 9.728 la 3.291 [parts/year] and M3 machine from 6.729 la 13.165 [parts/year].

| 06-21-2015 | From | To | Shipment | Unit Profit | Total Profit | Reduced Cost |
|---|---|---|---|---|---|---|
| 1 | M1 | P2 | 230400 | 6,98 | 1608192 | 0 |
| 2 | M2 | P1 | 225280 | 4,14 | 932.659,19 | 0 |
| 3 | M2 | P2 | 115200 | 6,91 | 796032 | 0 |
| 4 | M2 | P3 | 163840 | 1,48 | 242.483,20 | 0 |
| 5 | M2 | Unused_Supply | 186880 | 0 | 0 | 0 |
| 6 | M3 | P2 | 460800 | 6,94 | 3197952 | 0 |
| 7 | M4 | P4 | 108800 | 3,49 | 379712 | 0 |
| 8 | M4 | Unused_Supply | 121600 | 0 | 0 | 0 |
| | Total | Objective | Function | Value = | 7.157.030,50 | |

**Figure 3.** Alternative solution on matrix form

Because M2 and M4 are used just in proportion of 73%, respectively 48%, is tried the insertion of M1 type machine, obtaining the results from Figure 4. Denotes a profit diminishing with 16.128 m.u.

| 06-21-2015 | From | To | Shipment | Unit Profit | Total Profit | Reduced Cost |
|---|---|---|---|---|---|---|
| 1 | M1 | P2 | 460800 | 6,98 | 3216384 | 0 |
| 2 | M2 | P2 | 110080 | 6,91 | 760.652,81 | 0 |
| 3 | M2 | P3 | 163840 | 1,48 | 242.483,20 | 0 |
| 4 | M2 | Unused_Supply | 417280 | 0 | 0 | 0 |
| 5 | M3 | P1 | 225280 | 4,17 | 939.417,63 | 0 |
| 6 | M3 | P2 | 235520 | 6,94 | 1.634.508,88 | 0 |
| 7 | M4 | P4 | 108800 | 3,49 | 379712 | 0 |
| 8 | M4 | Unused_Supply | 121600 | 0 | 0 | 0 |
| | Total | Objective | Function | Value = | 7.173.158,50 | |

**Figure 4.** Obtained solution for M1 machine insertion.

The most unfavorable solution is obtained by optimization criteria changing, presented in Figure 5, bringing to the company a profit of 7.127.782 m.u.

| 06-21-2015 | From | To | Shipment | Unit Cost | Total Cost | Reduced Cost |
|---|---|---|---|---|---|---|
| 1 | M1 | P1 | 121600 | 4,15 | 504640 | 0 |
| 2 | M1 | P4 | 108800 | 3,44 | 374272 | 0 |
| 3 | M2 | P1 | 103680 | 4,14 | 429.235,19 | 0 |
| 4 | M2 | P2 | 587520 | 6,91 | 4059763 | 0 |
| 5 | M3 | P2 | 218880 | 6,94 | 1.519.027,25 | 0 |
| 6 | M3 | P3 | 163840 | 1,47 | 240.844,81 | 0 |
| 7 | M3 | Unused_Supply | 78080 | 0 | 0 | 0 |
| 8 | M4 | Unused_Supply | 230400 | 0 | 0 | 0 |
| | Total | Objective | Function | Value = | 7127782 | |

**Figure 5.** Transport problem non-optimal solution

As in the first analyzed case, there is an alternative solution, presented in Figure 6.

| 06-21-2015 | From | To | Shipment | Unit Cost | Total Cost | Reduced Cost |
|---|---|---|---|---|---|---|
| 1 | M1 | P1 | 121600 | 4,15 | 504640 | 0 |
| 2 | M1 | P4 | 108800 | 3,44 | 374272 | 0 |
| 3 | M2 | P2 | 691200 | 6,91 | 4776192 | 0 |
| 4 | M3 | P1 | 103680 | 4,17 | 432.345,59 | 0 |
| 5 | M3 | P2 | 115200 | 6,94 | 799488 | 0 |
| 6 | M3 | P3 | 163840 | 1,47 | 240.844,81 | 0 |
| 7 | M3 | Unused_Supply | 78080 | 0 | 0 | 0 |
| 8 | M4 | Unused_Supply | 230400 | 0 | 0 | 0 |
| | Total | Objective | Function | Value = | 7.127.782,50 | |

**Figure 6.** Non-optimal alternative solution on matrix form

## 3. Conclusion

At the beginning of the optimal allocation study for the machines were known the following data: allowed times, technological itineraries, production volume, working regime. It was calculated afterwards available time, necessary number of machines, unit profit, necessary and available time. All these data were used inside the maximization transport problem, using WinQSB software. The results showed a maxim profit of 7.157.030,5 m.u., when the minim profit was calculated as 7.127.782 m.u.

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