An Application of Goal Programming Technique for Reconfiguration of Transfer Lines

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Abstract: In this paper, the reconfiguration problem of transfer machining lines is addressed. This problem appears when an existing line has to be adapted for the production of a new or modified product. The objective is to minimize the reconfiguration line cost. The compatibility constraints between old and new operations have to be taken into account. Therefore, a compromise between introducing new equipment and reusing old one is to be found. A goal programming model for this optimization problem is developed. This mathematical model minimizes the reconfiguration cost of transfer line as the primary objective and maximizes the reusability of old equipment as the second objective.

1 INTRODUCTION

Transfer machining lines are widely used in mechanical industry for mass production (Dolgui et al., 2006). This type of production line consists of a sequence of stations such that, for each product item, one subset of the required operations is executed on the first station, then another subset on the second, and so on until all the operations are executed. Each station can be equipped with a number of multi-spindle heads (Guschinskaya et al., 2008). These heads will be called blocks. Each block performs a set of operations. All blocks of the same station are executed sequentially. An example of such a line is presented in Figure 1.

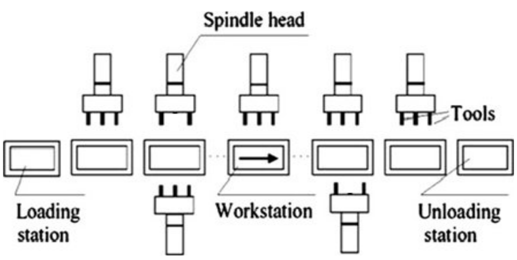

Figure 1: An example of transfer line.

Transfer lines are designed for a long exploitation time and need high investments. However, currently, because of excessive production capability and economic globalization it becomes more and more important for companies to respond to the changeable market demands faster and with less cost. A wide variety of modifications may require the reconfiguration of an existing transfer line, for example:

- changes in the product characteristics;
- modifications of the cycle time due to changes in market demand or sales; and
- introducing new models or modification on models (Gamberini et al., 2006; Boysen et al., 2008).

The reconfiguration of manufacturing systems was studied in several works (Abdi and Labib, 2003; Merhabi et al., 2000; Merhabi et al., 2002; Koren et al., 1999, Spiceret al., 2002; Youssef and ElMaraghy, 2008). Reconfiguration allows adding, removing, or modifying specific process capabilities, controls, software, or machine structure to adjust production capacity in response to changing market demands.

Generally, manufacturing systems reconfiguration activities are divided into two types: hard and soft. Examples of hard reconfiguration activities include adding or removing of machines, machine modules and changing material handling systems. Examples of soft reconfiguration activities include re-programming of machines, re-planning,

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re-scheduling and increasing or decreasing of shifts or number of workers.

Even if previously studied for different manufacturing systems, the reconfiguration problem, to the best of our knowledge, has not been formulated for transfer lines yet. The objective of this paper is to formulate this problem and then apply one of the techniques of multiple-objective programming (goal programming) to solve it.

In the formulation of goal programming, the objectives are written in the form of goals restrictions where each goal represents the value that intends to be reached. Deviation variables are introduced in each objective function, d^+ and d^-, indicating how much the objective was surpasses or was lacked by that value, respectively. Goal programming searches a form of reaching the goals as close as possible; the objective of this technique is to minimize the sum of the deviations for all the objective functions.

This method has been already successfully applied for solving optimisation problems appearing while designing assembly lines, see for example (Deckro and Rangachari, 1990; Gökçen and Erdal, 1997; Gökçen and Agpak, 2006; Özcanand Toklu, 2009).

In the next section, the problem of the reconfiguration of transfer lines is described in detail and its mathematical model is presented.

2 PROBLEM FORMULATION

The reconfiguration problem appears when an existing transfer line has to be chnaged in order to suit the new manufacturing requirements. In order to reduce the reconfiguration costs, the new equipment should be reused as more as possible, but the investment in new equipment has to be minimized as well.

2.1 Input Data

The following information about the product to be manufactured and the characteristics of the line are assumed to be known at the reconfiguration step.

Part characteristics:

- N is the set of operations necessary for machining the new part;
- $Pred(i)$ is the set of direct predecessors of $i \in N$;
- t_i operational time for operation i ($i = 1,\ldots, |N|$);
- IS is a family of subsets of N representing the inclusion constraints among operations: all operations belonging to the same subset have to be assigned to the same station;
- ES is a family of subsets of N representing the station exclusion constraints: all operations belonging to the same subset cannot be assigned to the same station together;
- EB is a family of subsets of N representing the block exclusion constraints: all operations belonging to the same subset cannot be assigned to the same block together;

Line characteristics:

- $N' \in N$ set of 'old' operations in the initial line;
- n_0 maximum number of blocks on a station;
- m_0 maximum number of stations;
- T_0 objective line cycle time;
- τ^b is an auxiliary time needed for activation of a block (spindle head);
- τ^s is an auxiliary time needed for loading/unloading the part on a station;
- C_1 is the cost of a station;
- C_2 is the cost of a block;
- C^* is the cost of the initial line calculated as $C_1m^*+ C_2n^*$, where m^* is the number of stations in the initial line and n^* is the total number of all blocks used at all stations of the initial line.

2.2 Model Notations

The following notations are introduced in the mathematical problem presented:

Indexes:

- i, j for operations;
- q for the blocks, $q = (k\text{-}1)n_0+1$;
- k for the stations, $k = 1,\ldots,m$.
- q_0 maximal possible value of q, $q_0 = m_0n_0$;
- $S(k) = \{(k\text{-}1)n_0+1,\ldots, kn_0\}$ set of block indices for station k;
- $Q(i)$ set of block indices on which i can be processed;
- $K(i)$ set of station indices on which i can be processed;
- N_q set of operations assigned to block q in the initial line;
- N_k set of operations assigned to station k;
- N_{kl} set of operations assigned to block k of the station l;

2.3 Decision Variables

- $X_{iq} \in \{0,1\}$are binary decision variables where $X_{iq} = 1$ if operation i is assigned to block q in the new line configuration;

- $Y_q \in \{0,1\}$ is an auxiliary binary variable that indicates if block q exists (Y_q = 1) in the new line configuration;
- $Z_k \in \{0,1\}$is an auxiliary variable that indicates if station k exists (Z_k = 1) in the new line configuration.
- To calculate block processing times, auxiliary variables $F_q \in [0,\ T_0 - \tau^s]$, $q=1, 2, \ldots, q_0$ are used.
- d_g^+ and d_g^- are defined as the positive and negative deviations of goal g. The goals considered are presented in the next subsection.

2.4 Goals and Objective Function

The objective function minimizes the weighted sum of the positive and negative deviations from the given goals.

The first goal is to obtain the same weighted sum of the costs of stations and blocks as in the initial line, i.e.:

$$C_1 \sum_{k=1}^{m_0} Z_k + C_2 \sum_{q=1}^{q_0} Y_q - d_1^+ + d_1^- = C^*; \tag{1}$$

Other goals are to reuse all blocks created for the initial line. If a block is reused, then all operations assigned together to the same block in the initial line remain assigned to the same block in the new line, i.e. for each pair of i, j such that i and j were assigned to the same block in the initial line and both of them are required for the new product as well as i<j and for each $q \in Q(i) \cap Q(j)$:

$$X_{iq} - X_{jq} - d_g^+ + d_g^- = 0; \tag{2}$$

where g ranges from 2 to G where G is equal to the total sum of number of pairs of operations i, j to be assigned to the same block multiplied each time by $|Q(i) \cap Q(j)|$.

Weighted Goal Programming is used in the model presented. The weight factors $w_1$and $w_2$are assigned to the first and second objectives, respectively. These values can be fixed by the user. This makes the method subjective, but allows taking into account the user's preferences.

Therefore, the objective is to minimize the sum of deviations from the given goals, i.e.:

$$Min\left(w_1(d_1^+ + d_1^-) + w_2 \sum_{g=2}^{G} (d_g^+ + d_g^-)\right); \tag{3}$$

2.5 Model Constraints

In addition to constraints (1)-(2), the following constraints have to be taken into account.

- All operations from N must be assigned and to exactly one block

$$\sum_{q \in Q(j)} X_{jq} = 1, j \in N; \tag{4}$$

- Precedence constraints:

$$\sum_{q' \in Q(i)} q' X_{iq} \le \sum_{q \in Q(j)} q\, X_{jq}; \quad i \in Pred(j);\ j \in N; \tag{5}$$

- Station inclusion constraints:

$$\sum_{q \in Q(i) \cap B(k)} X_{iq} = \sum_{q \in Q(j) \cap B(k)} X_{jq}; \quad j \in e;\ e \in IS;\ k \in K(i); \tag{6}$$

- Block exclusion constraints:

$$\sum_{j \in e} X_{jq} \le |e| - 1;\ e \in EB;\ q \in \bigcap_{j \in e} Q(j); \tag{7}$$

- Station exclusion constraints:

$$\sum_{j \in e} \sum_{q \in B(k) \cap Q(j)} X_{jq} \le |e| - 1; \quad e \in ES;\ k \in \bigcap_{j \in e} K(j); \tag{8}$$

- The equation (7) assures that for a block q, the value of F_q cannot be smaller than any of the operation times of block q plus a constant τ^b:

$$F_q \ge (t_i + \tau^b) X_{iq}, i \in N, q \in Q(i); \tag{9}$$

- The sum of the processing times of the blocks assigned to the same station cannot exceed a given value $T_0 - \tau^s$. This is the so-called cycle time constraint:

$$\sum_{q \in S(k)} F_q \le T_0 - \tau^s, k = 1, 2, \ldots, m_0; \tag{10}$$

- A block is considered as created, if there is at least one operation assigned to it:

$$y_q \ge X_{iq}, i \in N, q \in Q(i); \tag{11}$$

- A station is considered as created, if there is at least one block assigned to it:

$$Z_k \ge Y_q, k = 1, 2, \ldots, m_0, \quad q = (k-1)n_0 + 1; \tag{12}$$

- The blocks are created sequentially within a station:

$$Y_{q-1} - Y_q \geq 0, q \in b(k) \setminus \{(k-1)n_0 + 1\}, k = 1, 2, \dots, m_0; \tag{13}$$

- The stations are created sequentially as well:

$$Z_{k-1} - Z_k \geq 0, k = 2, 3, \dots, m_0; \tag{14}$$

where $j \in N$, $i \in P(i)$, $q=1,2,\dots,m_0 n_0$, $k=1,\dots,m_0$.

3 CONCLUSIONS

In this paper, a goal programming model for the reconfiguration of transfer lines was suggested. This problem appears when an existing transfer line has to be modified due to the changes of the product being manufactured of the market demand. The new line configuration must take into account compatibility constraints between new operations and old equipment. The objective is to minimize the cost of line reconfiguration and to reuse as more as possible the existing equipment.

A goal programming formulation was used in order to deal with the multi-objective character of this optimisation problem. An experimental study is in progress in order to evaluate the performance of the proposed method on the datasets of industrial problems. The future research will concern the formulation of the same problem with the Lexicographic Goal Programming (LGP) approach and a comparison between WGP and LGP will be necessary.

REFERENCES

Abdi, M., Labib,A., 2003. A design strategy for reconfigurable manufacturing systems (RMSs) using analytical hierarchical process (AHP): a case study, *International Journal of Production Research* 41 (10), pp. 2273–2299.

Boysen, N., Fliedner, M. and Scholl, A., 2008. Assembly line balancing: which model to use when? , *International Journal of Production Economics*, 111(2), pp. 509-28.

Deckro, R. F, Rangachari, S., 1990. A goal approach to assembly line balancing, *Computers and Operations Research* 17, pp. 509-521.

Delorme, X., Dolgui, A., Essafi, M., Linx, L., Poyard, D., 2009. Machining lines automation, In: Nof S, editor. *Springer handbook of automation*, pp. 599-618.

Dolgui A, Finel B, Guschinsky N, Levin G, Vernadat F., 2006. MIP approach to balancing transfer lines with blocks of parallel operations. *IIE Transactions* 38, pp. 869–882.

Gamberini, R., Grassi, A., and Rimini, B., 2006. A new multi-objective heuristic algorithm for solving the stochastic assembly line re-balancing problem,International *Journal of Production Economics*, 102, pp. 226-43.

Gökçen, H., Erdal, E., 1997. A goal programming to mixed-model assembly line balancing problem, *International Journal of Production Economics* 48, pp. 177-185.

Gökçen, H., Agpak, K., 2006. A goal programming approach to simple U-line balancing problem, *European Journal of Operational Research.*

Guschinskaya O, Dolgui A, Guschinsky N, Levin G., 2008. A heuristic multi-start decomposition approach for optimal design of serial machining lines.European *Journal of Operations Research* 189(3), pp. 902-913.

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritchow, G., Brussel, H. V., Ulsoy, A., 1999. Reconfigurable manufacturing systems, *CIRP Annals - Manufacturing Technology* 48 (2), pp. 527–598.

Mehrabi, M., Ulsoy, A., Koren, Y., 2000. Reconfigurable manufacturing systems: Key to futur manufacturing, *Journal of Intelligent Manufacturing* 11, pp. 403–419.

Mehrabi, M., Ulsoy, A., Koren, Y., Heytler, P., 2002. Trends and perspectives in flexible and reconfigurable manufacturing systems, *Journal of Intelligent Manufacturing* 13, pp. 135–146.

Özcan, U., Toklu, B., 2009. Multiple-criteria decision-making in two-sided assembly line balancing: A goal programming and a fuzzy goal programming models, *Computers & operations Research*.

Spicer, P., Koren, Y., Sphitalni, M., Yip-Hoi, D., 2002. Design principles for machining system configurations, CIRP *Annals-Manufacturing Technology*, 51, pp. 275-80.

Urban, T. L, 1998.*Note:* Optimal balancing of U-shaped assembly lines, *Management Science,* 44 (5), pp. 738-741.

Youssef A., H. ElMaraghy, 2008. Availability consideration in the optimal selection of multiple-aspect RMS configurations, *International Journal of Production Research* 46 (21), pp. 5849–5882.