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A design of DSS for mass production machining systems

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Abstract. In this paper, we present a decision support tool (DSS) for preliminary design of transfer machines with rotary or mobile tables. In these transfer machines, the machining operations are executed on working positions equipped by standard multi-spindle heads. A part is sequentially machined on m working positions and is moved from one position to the next using a rotary or a mobile table. The operations are grouped into blocks, where the operations of the same block are simultaneously performed by one multi-spindle head. At the preliminary design stage, the goal is to select the number of working positions and to decide which spindle heads will be installed minimizing the machine cost while respecting a given production rate. The paper presents the overall approach and depicts mathematical and decision-support methods developed and implemented in a software for the optimization of preliminary design (or reconfiguration) of such machining systems.

Key words: transfer machines, preliminary design, decision support tool, optimization.

1. Introduction

The design of machining systems is a wide open area for development and application of decision making and decision support technologies. This domain is characterized by the necessity to combine the standard decision making methods, sophisticated operational research techniques and some specific rules based on expert knowledge to solve principal design problems while taking into account all existing technological constraints.

A promising trend in this area deals with the development of integrated software tools [1–3]. Their main idea consists in integrating product and manufacturing data into a common database. This enables product designers to consider the manufacturing processes constraints at an early product design stage.

We proposed a Decision Support System (DSS) of this type for preliminary design of automatic transfer machines with rotary or mobile tables. In these machines [4], a part is machined sequentially on m working positions. Each working position is equipped with one, two or three multi-spindle heads, each containing several cutting tools. The parts are moved periodically from one position to the next by means of a rotary or a mobile table. One additional position is usually used for loading and unloading the parts. These machines are used in mass production of a single type of part (or a family of similar parts). They are exceedingly expensive with the expected life cycle from 5 to 7 years of production. Therefore, the search for an effective and if possible an optimal design is an important decision issue.

The DDS includes:

1. Powerful database of standard features for part modeling;
2. Efficient mechanisms to search and parameterize the existing features;
3. Expert system to choose better process plans from database for the features selected;
4. Line balancing models based on shortest path approach for the machine logical layout design;
5. Set of problem oriented rules for the machine physical layout design;
6. User friendly software environment.

Based on these techniques and principles, software was developed for optimal process planning, line balancing, equipment selection, and physical layout design. In this paper, we present the key elements of this software tool and some mathematical models used.

2. Short literature review

The studying of design problems for mass production manufacturing systems began by considering the simple assembly line balancing problem (SALBP) [5–7]. The SALBP consists in assigning a set of operations to identical consecutive stations minimizing the number of stations required, subject to precedence constraints between operations and cycle time constraints. Many exact and heuristic approaches for SALBP were suggested in literature: Lagrange relaxation techniques [8], Branch and Bound algorithms [7, 9, 10], and heuristics and meta-heuristics [11–13]. This list is not exhaustive. A state-of-the-art can be found in [6, 14–17].

The problem where line balancing is combined with equipment selection is often called Simple Assembly Line Design Problem (SALDP) [6, 14] or Single-Product Assembly System Design Problem (SPASDP) [18]. SALDP considers

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the "high-level" logical layout design with equipment selection (one per station) from a set of alternatives. There are several equipment alternatives for each operation, and often a particular piece of equipment is efficient for some operations, but not for others [19, 20]. There is a given set of equipment types; each type is associated with a specific cost. The equipment cost is assumed to include the purchasing and operational cost. The duration of an operation depends on the equipment selected. An operation can be performed at any station, provided that the equipment selected for this station is appropriate and that precedence relations are satisfied. The total station time should not exceed the predetermined cycle time. The problem consists of selecting equipment and assigning operations to each station. The objective is to minimize the total equipment cost.

The balancing of production lines in machining environments, as it was demonstrated in [4, 21], is more complex than SALBP and SALDP. The balancing of dedicated transfer machines with rotary or mobile tables, considered in this paper, deals with grouping operations into a number of blocks (sets of operations performed by a spindle head) and assigning these blocks to working positions [4]. Each block requires a piece of equipment (a multi-spindle head), which incurs a purchase cost. Therefore, it is necessary to minimize both the number of positions and the number of blocks. To do it, all possible operations assignments to blocks and positions must be considered; otherwise the optimality of a solution cannot be guaranteed. The set of alternative blocks is not known in advance and the parameters of a block depend on the set of operations assigned to it.

3. Decision support methodology

A design methodology for manufacturing systems can be defined as a set of procedures that analyzes and segregates a complex manufacturing system design task into simpler manageable sub-tasks while still maintaining their links and interdependencies [21].

We suggested the following multi-stage iterative approach for preliminary design of mass production transfer machines with rotary or mobile tables:

Stage 1. Input of data
- Step 1.1. Part modelling with features
- Step 1.2. Input of part and machine properties
- Step 1.3. Process planning using an expert system
- Step 1.4. Constraints generation based on machining data and user experience

Stage 2. Optimization of logical layout
- Step 2.1. Finding all optimal solutions minimizing the number of spindle heads and working positions while assigning operations and defining cutting modes for spindle heads
- Step 2.2. Choice of a solution to be applied among the optimal ones

Stage 3. Definition of physical layout and machine parameters
- Step 3.1 Working plan documentation
- Step 3.2. Part positioning
- Step 3.3. Equipment selection
- Step 3.4. Preliminary 3D physical layout design
- Step 3.5. Selection of control equipment and additional devices
- Step 3.6. Cost estimation

Based on this methodology, we developed a DSS tool. The architecture of this software is presented in Fig. 1.

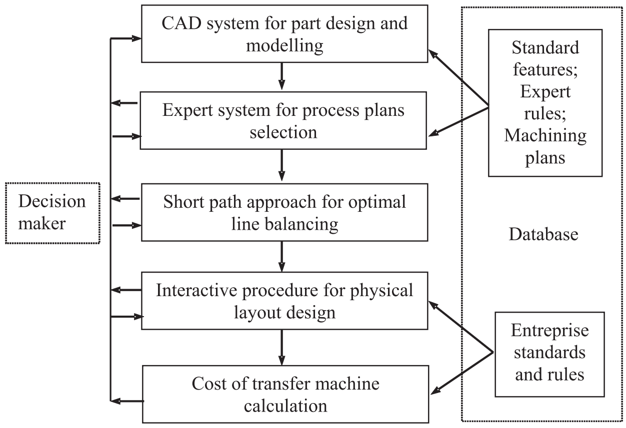


Fig. 1. Architecture of DSS

4. Product/process modelling

4.1. Part modelling. The first step deals with the modeling of a part to be machined (see for example Fig. 2). The clients provide the machine tool manufacturer with the specifications of a part already designed, which they want to produce using a transfer machine. Usually, the manufacturing process includes milling, drilling, boring, etc. a set of part elements such as planes, facets, holes of different types (cylindrical, bevel, threaded, etc). Each element must be fabricated on a certain side (or surface) of the part and is characterized by a set of technological parameters, like required tolerances and surface conditions.

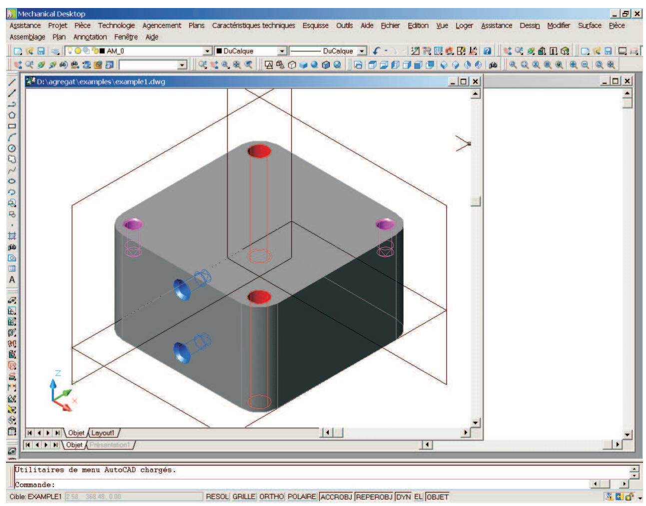


Fig. 2. An example of part to be machined

In order to use the same format for the geometric and technological data, the part is modeled with machining "features". The concept of a feature associates the technological characteristics of a machining element with its geometric parameters. Therefore, part modeling demands analyzing the part to be machined and identifying features, their geometric and topological relations.

When the part has been modeled, some additional characteristics of the part (for example, the material and its properties, the properties of the billet, etc.), and of the machine (for example, the desired productivity, the cooling method, the type of cooling liquid, etc.) must be defined as well as a desired type of machine (with rotary or mobile table) must be selected.

4.2. Process planning. At this stage, the machining operations, required tools and their parameters for each part feature are determined. The process plan of a part feature, i.e. a set of operations to be performed in order to provide the required geometric and technological characteristics is chosen using the following parameters:

1. Condition of surface before machining;
2. Diameter of machining holes;
3. Required precision for each machining element.

These parameters are stored in the data fields associated with the features. In Fig. 3, we present some examples of different types of holes from our database.

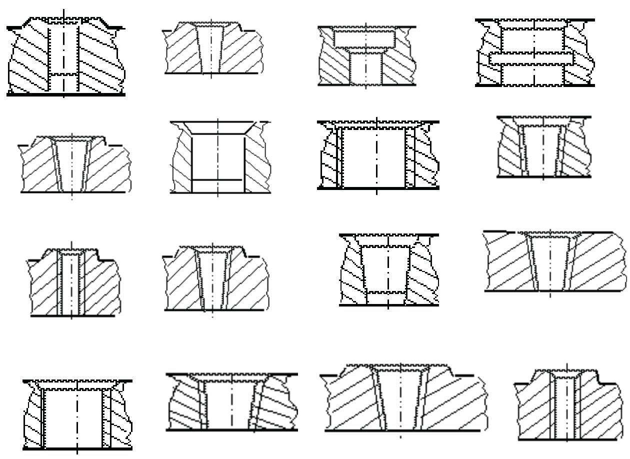


Fig. 3. Some examples of features from our database

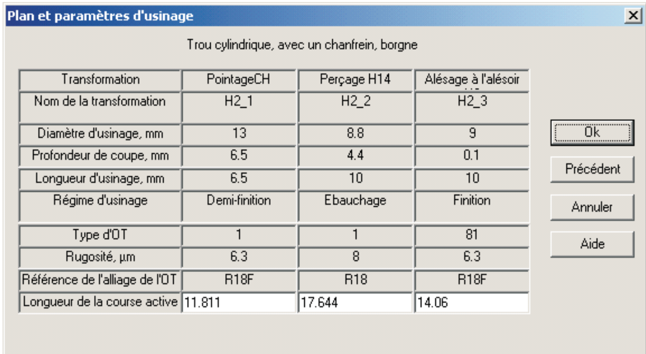
Analyzing their values and using the expert system, all possible process plans for each feature can be chosen from the process plans database. This database also contains dependences among the feature parameters and the set of all possible operations that a machine equipped by standard spindle heads can process. Then, for each feature and possible process plan the corresponding tolerances are calculated. The obtained tolerance values are compared with those required and the plan providing the values nearest to the required is chosen. For this plan, the parameters of operations (like cutting depth, machining length, type and material of cutting tool, working stroke, and cutting mode) are determined automatically.

Cutting mode is defined by minimal, maximum and recommended values of the following parameters:

1. Cutting speed;
2. Feed rate per revolution;
3. Feed rate per minute.

All machining operations are divided in two groups. When operations of the first group are performed by the same spindle head, they have the feed rate per minute that is equal to the feed rate per minute of the spindle head. Contrarily, each operations of the second group even though belonging to the same spindle head can have its own feed rate per minute different from the feed rate per minute of the spindle head. One example is thread tapping.

When DSS suggests process plans, the user analyses them and can replace or modify any aspects or create a new plan. New process plans can be stored in the database for future utilization. An example of how DSS suggests a process plan is given in Fig. 4.



Plan et paramètres d'usinage

Trou cylindrique, avec un chanfrein, borgne

Transformation	PointageCH	Perçage H14	Alésage à l'alésoir
Nom de la transformation	H2_1	H2_2	H2_3
Diamètre d'usinage, mm	13	8.8	9
Profondeur de coupe, mm	6.5	4.4	0.1
Longueur d'usinage, mm	6.5	10	10
Régime d'usinage	Demi-finition	Ebauchage	Finition
Type d'OT	1	1	81
Rugosité, µm	6.3	8	6.3
Référence de l'alliage de l'OT	R18F	R18	R18F
Longueur de la course active	11.811	17.644	14.06

Fig. 4. Choice of the process plan

In order to establish an entire process plan (for the whole part), the individual machining plans selected for the features must be completed by including the existing relations between the operations of different features. These relations are introduced by using different types of constraints.

4.3. Generation of constraints. Our decision methodology and models consider the following types of relations between machining operations:

1. Precedence constraints which define possible sequences of operations and are determined by a number of known technological factors (fixed sequences of operations for machining features, the presence of roughing, semi-finishing and finishing operations, etc.).
2. Inclusion constraints reflect the necessity to perform some operations on the same working position or even by the same spindle head. They are implied by the required precision (tolerance) of mutual disposition of machined features as well as a number of additional factors.

3. Exclusion constraints are used in the cases when it is impossible to assign some pairs of operations to the same working position (or to the same spindle head). They can be caused by a number of constructional and technological constraints: mutual influence of these operations, a forbidden tool location, etc. This type of constraint must be respected also for operations executed on the different sides of the part because they cannot be performed by the same spindle head.
4. Cutting mode constraints are defined by the common feed rate per minute for operations of the first group, performing by the same spindle head, the required production rate of the transfer machine, i.e. the maximum authorized value the machine cycle time T_0.

In Fig. 5, we present an example of precedence constraints generated automatically by the DSS tool. The operations of group 4 must be executed after the operations of group 3. Of course, the user can modify these constraints or/and create new ones. The same principle is used for inclusion and exclusion constraints.

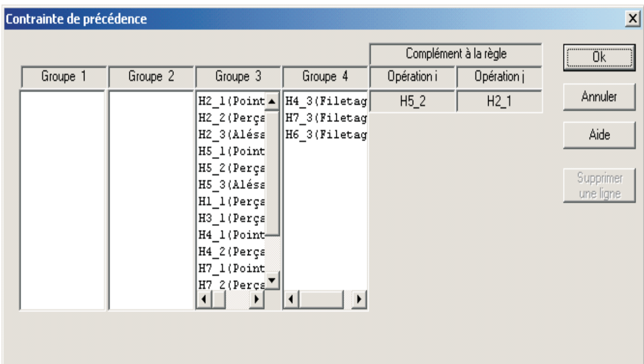


Fig. 5. Generation of precedence constraints

The overall equipment dimensions limit the total number of working positions and the number of blocks at each working position by the values of the parameters $\overline{m}$ and $\overline{n}$ respectively. The values of $\overline{m}$ and $\overline{n}$ are obtained taking into account the available machine configuration and economical constraints.

The objective production rate is obtained, if the machine cycle time T does not exceed the maximum authorized value T_0.

4.4. Logical layout optimization. The manufacturing information as well as diverse constraints related to the design of spindle heads and working positions are used as input data for the second design stage, i.e. logical layout design [22, 23]. The quantity of equipment (spindle heads, working positions) required to produce a part with the given productivity rate defines the final cost of the transfer machine. Therefore, the goal of the logical layout optimization is to find a design variant that minimizes the number of working positions and the total number of spindle heads while satisfying all given technological constraints [4, 21].

5. Optimization

5.1. Problem statement. Let $\mathbf{N}$ be the set of all operations needed to machine a part. If the machining is organized on m working positions, then at the k-th working position $k = 1, ..., m$, a subset N_k of the set $\mathbf{N}$ is performed. For these machines, each set N_k is uniquely partitioned into n_k subsets (N_{kl}, $l = 1, ..., n_k$), where the operations of each subset N_{kl} are performed by the same spindle head. Such a partition is the sole one possible due to the fact that each operation corresponds to one "side" of the part, and only the operations of the same side can be performed by one spindle head. Therefore, we have to find only the sets N_k, $k = 1, ..., m$. For each N_k, the sets N_{kl}, $l = 1, ..., n_k$ are obtained automatically. Hereafter, we will use the function $O(N_k)$ that returns the number of spindle heads N_{kl} (i.e., the value n_k) for a position k, where N_k is known.

An example of multi-spindle head is presented in Fig. 6. This spindle head executes seven operations simultaneously.

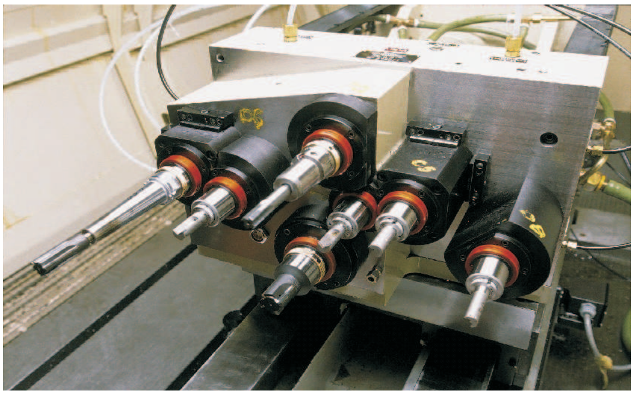


Fig. 6. An example of multi-spindle head (PCI-SCEMM, France)

Parameters of the kl-th spindle head and its execution time depend both on the set of operations N_{kl} and their cutting modes.

Let $\mathbf{N}^1$ be a set of operations of a first group from $\mathbf{N}$. As aforementioned, we assign in this group the operations which should have the same feed rate per minute as that of the spindle head. We will denote $N_{kl}^1 = N_{kl} \cap \mathbf{N}^1$ and $N_{kl}^2 = N_{kl} \backslash N_{kl}^1$.

The logical layout optimization consists in determining simultaneously:

a) Number of working positions m;
b) Partitioning the given set $\mathbf{N}$ of all operations into subsets N_k, $k = 1, ..., m$;
c) Feed per minute $\widehat{X}_{kl}$ for N_{kl}^1 and the collection $\widetilde{X}_{kl} = (x(i)|i \in N_{kl}^2)$ of feed rates per minute $x(i)$ of all operations i from N_{kl}^2 as well as the feed per revolution $s(i)$ and cutting speed $v(i)$ for each operation $i \in N_{kl}$.

All above parameters mentioned in points a), b) and c) are decision variables for this optimization problem.

Let $P =< P_1, ..., P_k, ..., P_m >$ is a design solution with $P_k = (P_{k1}, ..., P_{kl}, ..., P_{kn_k})$ and $P_{kl} = (N_{kl}, X_{kl})$, where

$X_{kl} = (\widehat{X}_{kl}, \widetilde{X}_{kl})$. Let C_1 and C_2 be the relative costs for one working position and one spindle head, respectively. Then, the aggregate objective function of the considered design problem can be formulated as follows:

$$\textit{Minimize } Q(P) = C_1 m + C_2 \sum_{k=1}^{m} n_k, \tag{1}$$

where $Q(P)$ signify the cost of solution P, remember that for each solution P the number of positions m and number of spindle heads n_k for each $k = 1, 2, \ldots, m$ are known.

5.2. Cycle time and cutting modes calculation. Let $\lambda(i)$ be the given length of the working stroke for operation $i \in \mathbf{N}$. The execution time $\tau^b(N_{kl}, X_{kl})$ of the set N_{kl} of operations performed by the *kl*-th spindle head working with the feed per minute X_{kl} is equal to:

$$\begin{aligned} &\tau^b(N_{kl}, X_{kl}) = \\ &= \max[L(N_{kl})/\widehat{X}_{kl}, \max\{\lambda(i)/x(i) | i \in N^2_{kl}\}], \end{aligned} \tag{2}$$

where $L(N) = \max\{\lambda(i) | i \in N \cap \mathbf{N}^1\}$.

The execution time for all operations of the $k-$th working position ($k = 1, \ldots, m$) is equal to:

$$\tau^p(P_k) = \max\{\tau^b(N_{kl}, X_{kl}) | l = 1, \ldots, n_k\} + \tau', \tag{3}$$

where τ' is a given constant representing an additional time for spindle head advance.

The cycle time for *machines with a rotary table* is defined by the maximum value among the execution times of the working positions:

$$T(P) = \tau'' + \max\{\tau^p(P_k) | k = 1, 2, \ldots, m\}, \tag{4}$$

where τ'' is a constant giving an additional time for the transfer of the part between positions.

The cycle time for *machines with a mobile table* is defined by the sum of the machining times on working positions:

$$T(P) = \tau'' + \sum_{k=1}^{m} \tau^p(P_k). \tag{5}$$

Let $[s_1(i), s_2(i)]$ and $[v_1(i), v_2(i)]$ be the ranges of the feasible values of feed per revolution $s(i)$ and spindle speed (cutting speeds) $v(i)$, respectively, for each operation $i \in \mathbf{N}$. Let $s_0(i)$, $v_0(i)$ be their "recommended" values.

Then the "recommended" $x_0(i)$, minimum $x_1(i)$ and maximum $x_2(i)$ feed rates per minute for each operation $i \in \mathbf{N}$ are defined as follows:

$$\begin{aligned} x_0(i) &= s_0(i) v_0(i), \\ x_1(i) &= s_1(i) v_1(i), \\ x_2(i) &= s_2(i) v_2(i). \end{aligned} \tag{6}$$

It is assumed later that $\lambda(i)/T \le x_2(i)$ for each $i \in \mathbf{N}$, where $T = T_0 - (\tau' + \tau'')$. Otherwise, the initial design problem does not have any solution satisfying the required production rate.

The interval $\mathbf{X}(N) = [\underline{X}(N), \overline{X}(N)]$ of possible values of the feed per minute $X(N)$ for the spindle head which executes the set N of operations ($N^1 = N \backslash \mathbf{N}^1 \neq \varnothing$) is calculated as follows:

$$\underline{X}(N) = \max(\max\{x_1(i) | i \in N^1\}, L(N)/T), \tag{7}$$

$$\overline{X}(N) = \min\{x_2(i) | i \in N^1\}. \tag{8}$$

If the set $\mathbf{X}(N)$ is empty, then operations of the set N cannot be executed by one spindle head.

For a fixed value $X(N) \in \mathbf{X}(N)$, the feed per revolution for operation $i \in N$ is equal to

$$s(i, X(N)) = \min[s_2(i), X(N)/v_1(i)],$$

and the cutting speed is equal to

$$v(i, X(N)) = X(N)/s(i, X(N)).$$

5.3. Optimization model. Since for this types of transfer machines, the set N_k is uniquely partitioned into subsets for spindle heads, the function $O(N_k)$ gives the number of obtained spindle heads for position k. It is assumed also that this function takes a sufficiently large value if the operations of the set N_k cannot be partitioned into subsets with regard to precedence, inclusion, exclusion and cutting mode constraints.

Then the optimization model of the considered decision making problem for logical layout design can be reformulated as follows:

$$\textit{Minimize } Q(P) = C_1 m + C_2 \sum_{k=1}^{m} O(N_k), \tag{9}$$

subject to:

$$T(P) \le T_0, \tag{10}$$

$$\bigcup_{k=1}^{m} N_k = \mathbf{N}, \tag{11}$$

$$N_{k'} \cap N_{k''} = \varnothing, \forall k', k'' = 1, \ldots, m \text{ such that } k' \neq k'', \tag{12}$$

$$O(N_k) \le \overline{n}, \text{ for all } k = 1, \ldots, m, \tag{13}$$

$$X_{kl} \in \boldsymbol{X}(N_{kl}), \text{ for all } k = 1, \ldots, m; \ \ l = 1, \ldots, n_k, \tag{14}$$

$$m = m(P) \le \overline{m}. \tag{15}$$

The objective function (9) is the estimation of the equipment cost; constraint (10) provides the required productivity rate (note: $T(P)$ is the cycle time for solution P); constraints (11–12) ensure the assignment of all the operations from $\mathbf{N}$, each operation to one and only one working position; (13) provides precedence constraints for operations, inclusion and exclusion constraints for spindle heads and working positions; (14) chooses feasible values of the feed per minute for each spindle head; (15) is the limit on the number of working positions. Remember that P is a possible solution represented as $P = < P_1, \ldots, P_k, \ldots, P_m >$ with $P_k = (P_{k1}, \ldots, P_{kl}, \ldots, P_{kn_k})$ and $P_{kl} = (N_{kl}, X_{kl})$, where $X_{kl} = (\widehat{X}_{kl}, \widetilde{X}_{kl})$.

The values $\overline{m}$ and $\overline{n}$ are defined by the type of the machine: for machines with rotary table $\overline{m} \le 15$ and $\overline{n} = 2$, for machines with mobile table $\overline{m} \le 3$ and $\overline{n} \le 3$. For machines with mobile table the expression (13) is replaced by (13*a*):

$$O(N_k) \le 2, \quad k = 1, \ldots, m-1; \quad O(N_m) \le 3. \tag{13a}$$

5.4. Optimization approach. It is easy to see that if

$$P =< ((N_{11}, X_{11}), ..., (N_{1n_1}, X_{1n_1}), ..., (N_{m1}, X_{m1}), ..., (N_{mn_m}, X_{mn_m}) >$$

is a solution of the problem (9)–(15) then

$$P' =< ((N_{11}, \overline{X}(N_{11})), ..., (N_{1n_1}, \overline{X}(N_{1n_1})), ..., (N_{m1}, \overline{X}(N_{m1})), ..., (N_{mn_m}, \overline{X}(N_{mn_m})) >$$

satisfies (9)–(15). Therefore, the optimization problem (9)–(15) may be reduced to partitioning $\mathbf{N}$ into subsets N_k, $k = 1, \ldots, m$, such that:

1. $C_1 m + C_2 \sum_{k=1}^{m} O(N_k)$ is as small as possible;
2. Constraints (11)–(15) are not violated;
3. $T(P) \leq T_0$ for $\widehat{X}_{kl} = \overline{X}(N_{kl})$;
4. $x_2(i)$, $i \in \mathbf{N} \backslash \mathbf{N}^1$ as well as $\boldsymbol{X}(N_{kl}) \neq \varnothing$.

Our optimization algorithms are based on the shortest path approach [4]. They find all optimal solutions corresponding to the different machine configurations with various operations' assignment or allocations of spindle heads to working positions. In order to choose which solution to be applied, these optimal solutions can be further evaluated by the user (with other criteria and user's preferences). If the results of the optimization are not satisfactory, the user can return to previous stages and make the necessary modifications of constraints and input data.

Let $\mu(i)$ be a constant that characterizes the tool life rate.

For the obtained partition $\mathbf{N}$ into N_{kl}, $k = 1, \ldots, m$; $l = 1, \ldots, n_k$, $x(N_{kl})$ for machines with a rotary table might be chosen in the following way:

$$x^*(N_{kl}) = \min\{(L(N_{kl})/\lambda(i))^{\mu(i)} x_0(i) | i \in N_{kl}^1\}, \tag{16}$$

$$x^{**}(N_{kl}) = \max\{\underline{X}(N_{kl}), x^*\}, \tag{17}$$

$$x(N_{kl}) = \min\{x^{**}, \overline{X}(N_{kl})\}, \tag{18}$$

$$x(i) = \max[x_0(i), \lambda(i)/T], i \in \mathbf{N} \backslash \mathbf{N}^1. \tag{19}$$

In the case of machines with a mobile table, $x(N_{kl})$ might be defined as:

$$x(N_{kl}) = \max[L(N_{kl})/t(N_k), x^*(N_{kl})], \tag{20}$$

$$x(i) = \max[x_0(i), \lambda(i)/t(N_k)], i \in \mathbf{N} \backslash \mathbf{N}^1 \tag{21}$$

where $x^*(N_{kl})$ is calculated according to (16),

$$t(N_k) = t_0(N_k) - (t_0(N_k) - \underline{t}(N_k)) \left(\sum_{r=1}^{m} t_0(N_r) - T\right) / \sum_{r=1}^{m} (t_0(N_r) - \underline{t}(N_r)), \tag{22}$$

$$\underline{t}(N_k) = \max\{\max[L(N_{kl})/\overline{X}(N_{kl}), \max\{\lambda(i)/x_2(i) | i \in N_{kl}^2\}] | l = 1, \ldots, n_k\}, \tag{23}$$

$$t_0(N_k) = \max\{\max[L(N_{kl})/x^*(N_{kl}), \max\{\lambda(i)/x_0(i) | i \in N_{kl}^2\}] | l = 1, \ldots, n_k\}. \tag{24}$$

5.5. 3D-model and cost estimation. The obtained logical layout defines the general configuration of a transfer machine and enables designers to complete this logical architecture by selecting the corresponding modular equipment from the library of standard units of the proposed DSS. Initially, designers specify the overall dimensions of the movable table and decide position of the part on the table. The part position defines the angles and positions of the spindle heads.

Then, designers define the dimensions and the specifications of the required equipment that will be designed using the graphical library of standard units. Finally, designers can obtain a preliminary 3D-model of the physical machine layout. An example is given in Fig. 7.

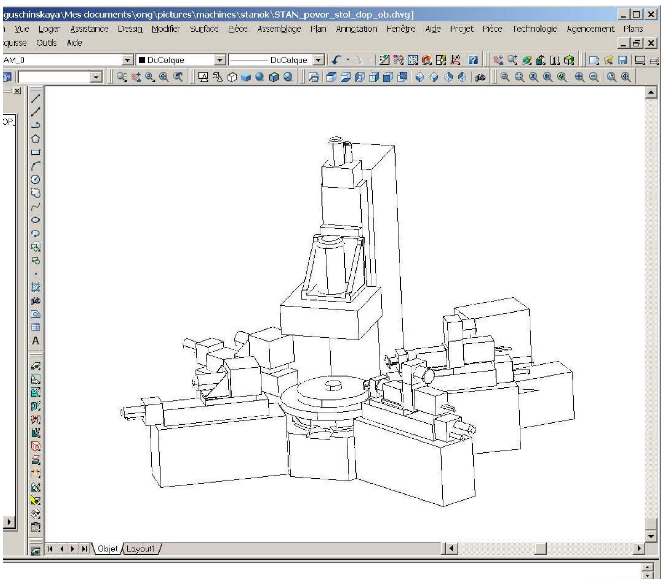


Fig. 7. Layout of a machine with rotary table

In order to estimate the total machine cost, additional devices are to be selected, like control, tool storage, loading-unloading systems. Their choice is guided by some automatically generated suggestions and accompanied by the verification of compatibility with all previous decisions. The costs of all selected devices are obtained from the database which contains market prices of standard units (spindle heads and other machine elements). The total cost estimation enables designers to formulate a commercial offer. Therefore, using the decision support system, machine tools manufacturers can provide their clients with technological plans and a commercial offer in really short times. If the offer is accepted, the detailed design of the machine with the chosen configuration is to be prepared in order to establish a manufacturing plan. At this stage a more detailed analysis of machine properties is needed, the manufacturability of parts can be verified using, for example, finite elements and simulation [24, 25].

6. Conclusions

A Design of Decision Support System (DSS) for mass production machining systems was considered. A novel and promising decision support tool was developed. This DSS is based on using conjointly advanced operational research methods, standard decision making approaches, decision support technologies and problem oriented specific rules. We have presented the general methodology, including the key methods, techniques and software elements of this DSS.

This integrated DSS was developed to help machine tool designers to obtain a high-quality (and if possible optimal) architecture of transfer machines with rotary or mobile tables. The system supports the different stages of the preliminary design of a transfer machine: modelling of a part to be machined, process planning, optimization of the machine logical layout (configuration), its preliminary 3D physical layout, and, finally, cost estimation. The key optimization problem of the preliminary design is to minimize the number of working positions and number of spindle heads (the machine cost) by assigning the manufacturing operations to positions and choosing adequate cutting modes for each spindle head.

The considered machines are expensive and designed to function from 5 to 7 years. Therefore, the use of an effective DSS becomes crucial.

Future perspectives of this research may lie in the improvement and extension of the suggested approaches for a larger class of manufacturing systems: linear transfer machines, transfer lines with buffers, multi-flow transfer lines, assembly lines, etc. Another promising approach is the integration of the process planning and logical layout steps in a common optimization model using heuristics and meta-heuristics.

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