

new requirements and DSS prototyping

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Abstract

The short-term planning and scheduling of discrete manufacturing systems has mostly focused in the past on the management of machines, implicitly considered as the critical resources of the workshops. Some of the present schedulers claim to also manage human resources, but perform most of the time a local allocation of operators to machines, these operators having regular working hours. However, it seems clear that the workforce has a specificity that should be better taken into account by short-term planning facilities. Moreover, the variability of the weekly working hours through the year will shortly become a rule and not anymore an exception. On the base of a questionnaire answered by 19 French companies of different sizes and industrial sectors, we have tried to identify more precisely some industrial requirements concerning the short-term management of human resources. The growing interest in annualised hours together with the lack of software tools that allow to implement it practically is one of the results of this questionnaire. We suggest in this article the specification of a decision support system for short-term manpower management under annualised hours, taking into account the competence of the operators. A software prototype has been developed according to these specifications; the results of a simple but representative example are described.

Keywords: Manpower; Human resource; Competence; Annualised hours

1. Introduction

The current industrial context is more and more characterised by an irregular demand on ever changing products. This irregularity can be related to a seasonal demand but can also be less predictable, because of the rapid changes of the customers' requirements and of the competitive context. In industrialised countries, optimising the operational work-

force used under variable demand becomes a critical issue in order to remain competitive against emergent countries.

The workforce allocation has seldom been addressed with its specificity in the research literature on manufacturing, in which it is often considered as part of the assignment or scheduling problem. Solutions to these particular problems have been suggested for a long time by operation research. Linear programming methods, like the simplex method or the Hungarian method (see, e.g. Winston [38]) can be used in order to assign resources to jobs optimising objective functions related to cycle times or costs. Nevertheless, the restrictive hypotheses re-

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quired by the modeling of a problem using operation research often set into question its applicability to real industrial cases. Many other techniques have been quite recently applied to job shop scheduling, like constraint-based analysis, shifting bottleneck procedures, taboo search, simulated annealing or genetic algorithms but the gap between researchers and practitioners in scheduling is still periodically emphasised in the literature (see Smith [33], Ramudhin and Marrier [30], Türksen [36]). On the other hand, the workforce management has often been considered with the point of view of building efficient teams in project-oriented management (e.g. in Belbin [3], Berne [4], Bursic [7]) and the scheduling of a team within a project is for instance addressed in Alfares and Bailey [2]. At the shop-floor level, the specificity of the human resource has been poorly taken into account in scheduling, except in some specific works like Burns and Carter [6], Emmons [13] or Hung [19] all on the case of a regular demand covered by cyclic shift patterns.

Addressing the problem of an irregular demand using annualised hours has become a more and more popular idea in Europe these last years, and particularly in the United Kingdom [20]. In France also, the new legislative context (35 h/week in year 2000, generally under annualised hours) has drastically increased the interest on that topic. Nevertheless, if annualised hours has aroused for several years the interest of the management sector (see for instance Clutterbuck [10], Lynch [25], Curran [11], Mazur [28], MacMeekin [26]), it is surprisingly absent from the literature on scheduling, with the exception of the recent studies of Hung on the subject [20–22]. These studies yet consider a seasonal and fully predictable demand, and the problem of operators having different competences is not addressed nor the practical constraints set by the recent legislative evolution in France.

The new constraints related to operators' working time in France and the way the human resource is managed in some typical manufacturing-oriented schedulers are shortly described in Section 2. Using a questionnaire answered by 19 French companies of different sizes and from different industrial sectors, we have tried to identify more precisely the user's requirements concerning the short-term planning of human resources (see Section 3). The comparison of

the available tools with these requirements shows that present software products are far from being adapted to the new context set by the future context of the French regulation. The most unanimous requirements expressed in the answers to the questionnaire are the bases of the specification (Section 4) and of the prototyping (Section 5) of a decision support system (DSS). This system illustrates the new functions that planning products should provide to workshop managers in the near future.

2. Human resources and scheduling in discrete manufacturing systems

2.1. Short-term management of the operators

For many years, the decision making process at the shop-floor level has been headed by the implicit idea to optimise the use of machines. Within "classical" production management methods like material requirement planning (MRP), manufacturing resource planning (MRPII) or even optimised production technology (OPT), the operational decision makings are still oriented on finding an adequacy between workload and machine capacity. The just-in-time philosophy has then put the emphasis on new ways to consider the human resource, insisting for instance on motivation, responsibility and polyvalence in order to promote a better balance between machines and manpower management. Nowadays, the increasing variability of customer demand has the consequence that the manufacturing paradigm is more and more oriented on finding a better balance between productivity and flexibility. In that context, the human resource comes back to the centre of the production system as the main condition to define a productive but also adaptable and reactive system. The increasing flexibility asked of the human resources, both on the competence and timetable points of view, has so created new degrees of freedom that become difficult to manage manually.

At the tactical level, examples of questions to answer are the following: Will people be assigned to jobs, parts, resources or teams? Will an operator be responsible for performing an operation or manufacturing a part? At the short-term level, these questions

become: How long do I need this operator next week? Next month? Should I give him the days-off he asks for? Which type of task will he perform next week? Can I better use his competence? Are there better alternatives considering other operators? The answers are important not only because they can set into question the performance of the workshop, but also because they can have an influence on the social atmosphere of the company.

In France, the new legislative context increases the difficulty to find acceptable answers to these questions. The French law that sets the weekly working time at 35 h at the end of the year 2000 emphasises the interest of the managers for annualised hours, which can help to increase the manpower flexibility. The signing of agreements between companies and unions is actually in progress in the various industrial branches. In all the already signed agreements, the following principles are present [27].

- The legal working time per week will be set to 35 h, without salary loss. Only one interruption per day will be possible, with a duration that would be less than 2 h. If the daily working time is more than 6 h, a break of at least 20 min is mandatory.

- The legal framework of the annualised working time should be the following: maximal working time of 10 h/day, minimum weekly working time of 28 h, maximum of 46 h (on 12 weeks), 44 h/week without extra hours, 48 h in 1 week or 60 h with special permission. A worker must be informed about his assignment 7 days before his work. Moreover, the average working time per year must be 20% less than the legal working time. A maximum difference of working time between two consecutive weeks should also be defined.

It is clear that this new legislative framework creates a lot of new constraints: without software support, making an optimal decision concerning the working time and affectation of each operator according to a work load will become more and more difficult. The limits of the existing tools dealing with manpower management are emphasised in the next section.

2.2. Some existing manpower management products

Most of the existing products dealing with short-term human resource management are concerned

with the so-called “staff scheduling”. Products like ESP (EMPLOYEE SCHEDULE PARTNER [14]), FLEXTIME [15] or ROSTERAID [31] are quite representative of these products, mainly oriented on the design of a weekly pattern according to competences and individual/collective constraints. Besides, studies recently made in France by consultancy firms have shown that the existing software products do not integrate all the constraints of the annualised hours [29], even in enterprise resource planning (ERP) systems. At the same time, the technical press underlines that a manual management of the working time becomes impossible, considering the complexity of the already signed agreements [8]. In the UK, where annualised hours have been earlier promoted, some products like KRONOS [24] or TIMELINK [35] explicitly integrate annualised hours. The ILOG products (SOLVER, SCHEDULER, PLANNER), based on constraint propagation, include libraries providing advanced features for manpower planning, for example, definition of competences, daily shifts or human resources weekly patterns [23]. These products have recently been used in France by startup companies like Temposoft as basic frameworks for defining manpower management systems including annualised hours features [34]. Nevertheless, these products do not yet take into account the manufacturing aspects: they cannot use manufacturing data such as routings or production plans as inputs for defining a work load and their result may be difficult to transfer to a machine-oriented scheduler.

On the other hand, industrial schedulers are mainly oriented on manufacturing aspects (machines, routings, orders and so on) but remain very poor about the human resource management aspects. Multiple-resource scheduling allows the assignment of a human operator to a machine for a given operation: in schedulers like SIPAPLUS [17] or ORTEMS (Ortems [1]), a list of operators can be associated with each machine; the first available operator on the list is assigned to the operation to be planned. These schedulers are oriented on a “local” assignment of the operators to the manufacturing operations, which does not allow for taking into account global constraints on their working time. Moreover, no means for analysing a workload in terms of requirement per competence are provided. An experimental version of the IO scheduler (CESIUM) that integrates new

functions concerning the management of the manpower in the agri-food industry is described in Franchini et al. [16]. This version allows the definition of a “human resource requirement planning”, but the operator can only be assigned to a work station within the framework of a previously built machine-oriented schedule.

Several software products provide some support for the follow-up of the human resource in manufacturing, or for its long-term management (e.g. evaluation of the human resource management policy, management of competences, remuneration policy or others) [12]. These tools do not support the short-term manpower management.

In our opinion, the short-term management of the human resource remains dramatically underestimated by the production management experts. An illustration is provided by a recent French guide for the choice of production management software that describes 108 products according to 300 functions [9]: the human resource management only appears through three items, namely distinct management of men and machines, consideration of men/machines couples and management of the multiple competences of men and machines. These items show that the planning of the human resource is considered here as a sub-problem of multiple-resource planning.

A sharp dichotomy appears here: on one side are schedulers oriented on manufacturing problems for which the operator is more or less considered as a “second level” resource. On the other side are workforce management systems, poorly consistent with manufacturing constraints or data but capable of taking into account the annualised hours context. We have decided to check, for the interest of industrial users, for products that could at the same time:

- provide a support for planning the workforce in relation to load requirements as they are expressed by an MRP system,
- be compliant with the set of legislative constraints induced by human resource management.

A questionnaire has been sent to 30 companies: the goal was not to make a representative opinion poll; nevertheless, we have tried to take a small sample of the various industrial areas. This questionnaire and its results are discussed in the next section.

3. Questionnaire for an analysis of the industrial requirements

3.1. Selection of the companies

Among the 30 questionnaires that have been sent, 19 have finally been returned. Among these companies, 11 are SMEs from which three are mostly sub-contractors, and seven belong to large industrial groups. The covered fields are:

- aircraft industry: 2
- agri-food: 2
- pharmaceuticals: 2
- electrical material: 4
- weapons: 1
- distribution: 1
- semiconductors: 2
- mechanical parts: 4
- sheet metal industry: 1

3.2. Results of the questionnaire

The schedule is performed by a module of production management software package (47%) or by a specific scheduler (40%).¹ It is interesting to notice that 40% of the companies use a manual schedule, sometimes in addition to a software package. An important percentage of the companies is not fully satisfied by the tools they use (29–50% depending on the tools). The best satisfaction (71%) is paradoxically obtained by companies using a module of a more general production management tool. Since these modules are usually rather simple, we interpret this as the fact that people who buy a specific scheduler in addition to their production management system have rather complex needs, difficult to satisfy even by specialised schedulers.

Many companies consider that they have specific needs in scheduling (68%), concerning mainly the management of particular resources (69%) or pecu-

¹ These ratios are important since, in order to consider companies with a good maturity on the subject, we have selected companies that have recently conducted projects in production management.

liarities of the manufacturing process (62%). The problems linked to the management of the manpower is in the third position with 46% of the answers.

The short-term management of the human resource seems mandatory to 42% of the companies, and useful to another 37%. Taking into account annualised hours is considered as useful (47%) or as mandatory (17%), and the integration of these constraints in present schedulers seems adequate for only 30% of the persons.

According to 60% of the answers, the operator assignment should be made after the schedule, but for 40%, the assignment of operators and machines should be performed at the same time. Unfortunately, we have not suggested in the possible answers that human resource management could be performed before the schedule. The individual competence is considered first as an assignment criterion (73%), then as the possibility to build teams (53%).

For most of the questioned people, an operator should be assigned to a group of resources, similar (67%) or not (53%). Assignments to a precise machine (13%), to a kind of operation (7%) or to lots of parts (0%!) are marginal. The competence of the setter (an operator dedicated to set-ups) does not make unanimity: it is considered as unnecessary by 40% of the answers.

In all the schedulers that we know, the processing times are constant. The questionnaire sets this point into question, since the opinion of the managers is that the skill of the assigned operator has sometimes (47%) or always (27%) an influence on the processing time. In that case, it is difficult to imagine an assignment that would be posterior to the schedule.

The objectives of the short-term management of the manpower are not those we expected. The suggested list was the following:

1. maximise the operator workload
2. manage the extra hours
3. manage sub-contracting
4. manage the assignment of the operators from one workshop to another
5. assign to a job the operator who has the best skill
6. have a better view on the global capacity in operators required to perform a planning
7. have a better view on the capacity per competence required to perform the planning

8. have a better view on individual assignments
9. manage continuous training

Within that list, people were asked to rank the objectives that they were considering as relevant. Unlike what was expected, the objectives linked to a better understanding of the potential of the workshop were ranked first: objective 6 was quoted by 87% of the answers with an average ranking of 2.15, and objective 7 was quoted by 80% of the answers (average rank: 2.83). The objectives aimed at improving the operational decision makings came after: 1 (73%, av. rank 3.91), 3 (60%, av. rank 5), 2 (53%, av. rank 6.13).

Here is the most surprising result from this questionnaire: the main need seems to concern a pre-analysis of the available capacity, whereas the schedulers focus on the assignment itself. Of course, people often consider one problem after another, and it seems probable that if tools are provided thereby allowing a better visualisation of the available capacity of the workshop, the next requirement will be to have a better support in the assignment process. Nevertheless, we have found this point very interesting.

As expected, the absence of software is considered as the first obstacle against an efficient short-term management of the human resources (40%), followed by the difficulty to clearly formalise an assignment strategy. This last point emphasises the interest of an interactive tool, but does not encourage the suggestion of a fully automated assignment.

In the last question, the managers were asked whether their company wanted to be involved in our developments. Four companies answered positively. Since companies usually prefer to buy products “on the shelves”, it shows that many users do not yet see products on the marketplace capable of fulfilling their requirements. The specification of a DSS based on the most relevant and unanimous requirements expressed in the answers to the questionnaire is described in next section.

4. Specifications of a DSS

The specifications expressed in this section take into account the above listed requirements but also

other sources like discussions with scheduling software editors, who are faced with an increasing demand from their customers concerning the management of the competences at the shop-floor level, research literature, and also the technical press or direct discussions with other companies. Nevertheless, it is clear that the idea is to focus first on the visualisation of the available competences, and then eventually to allow man–software interaction when affecting an operator to one of his competences comes from the obtained answers. Indeed, these points have appeared as very relevant when discussed with other companies. On the other hand, the following specifications also take into account the types of competences that were considered as marginal in most of the answers to the questionnaire (e.g. competence related to activities or parts): they should so address the requirements of a wider set of companies.

4.1. Positioning of the short-term human resource management

The constraints expressed in Section 2.1 can hardly be satisfied by a local assignment of people to machines or tasks. As a consequence, the human resource should in our opinion be taken into account

before scheduling the machines. This idea is confirmed by the answer to the questionnaire stating that the processing time can vary according to the operator skill. On the other hand, scheduling the machines within the framework defined by a precise schedule of the operators would not preserve the degrees of freedom needed to manage the technical constraints that are more and more mandatory in industrial scheduling problems. We have thus chosen to integrate first the constraints linked to the human resource through a rough planning for a short period, similar to a load planning in the MRPII method. The integration of the suggested approach in an MRP architecture is shown in Fig. 1. As it will be more precisely shown in Section 5 in an example, this short-term human resource management DSS acts as a competence requirement planning, by analogy to the capacity requirement planning (CRP) that mainly concerns the capacity in machines and work stations. Fig. 1 shows the MRP module that provides a list of articles launched for each period of the time horizon. On that base, the CRP splits articles in manufacturing operations, and sequences these operations through time. Assuming that additional data allowing the linking of these operations to required competences are available, the CRP level will use the degrees of freedom concerning the workforce in

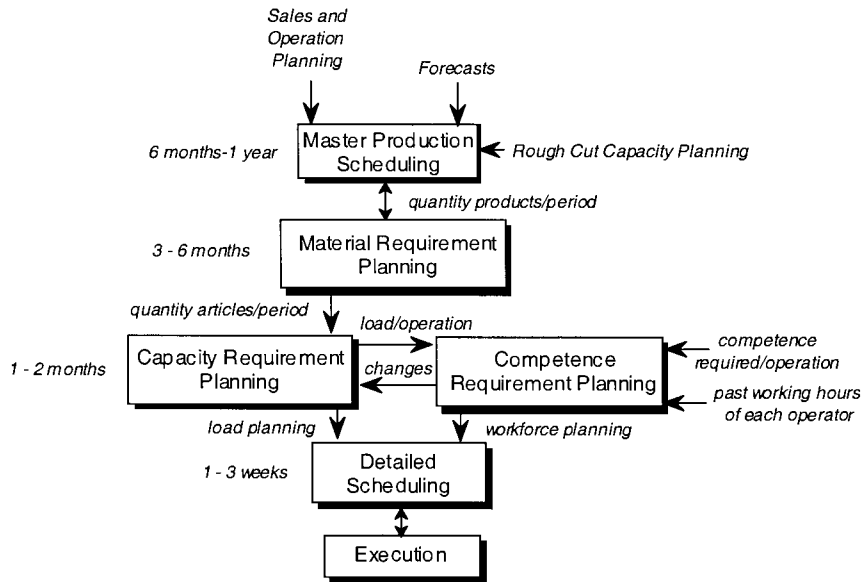


Fig. 1. Position of the competence planning.

order to make this CRP feasible. These degrees of freedom mainly concern multiple-competence, timetables and the flexibility provided by annualised hours. If no solution can be found, the load will be moved through time or sent to a sub-contractor in order to satisfy the constraints on the workforce. Once a correct ad-equation between load per competence and capacity has been found, the modified capacity planning will be transmitted to the detailed scheduling level for a precise sequencing of the operations, together with the weekly working time and the suggested competence used for each operators.

4.2. Functions of a DSS

In order to be consistent with the objectives of the users, the functions of the DSS have been defined as follows.

(1) Visualisation of the available capacity of the workshop concerning the human competences, according to different points of view (total capacity for a given competence, competences of each operator, capacity of each operator, etc.). This step is in our opinion greatly neglected in present schedulers, which focus directly on planning issues.

(2) Interpretation of a short-term production plan in terms of requirements per competence and per skill. This step requires to define the competences and skills required for an operation.

(3) Finding a general balance between load and capacity. A balance between the workload and the available capacity per competences can be obtained by two means:

- if the workload cannot be modified: calculate the capacity required to absorb it,
- if the capacity per competence is given: act on the multiple-competence to find a balance, or modify the workload using alternative resources, sub-contracting, load-smoothing, etc.

Most of the time, the two techniques should be mixed in order to find an acceptable solution.

As suggested in the previous section, we have not considered precise assignments of operators to tasks: the CRP activity aims at providing a rough ad-equation between load and capacity per competence in

order to transmit a feasible plan to the schedule level. Since a precise operation sequencing will be performed, additional constraints will be added at the scheduling level (dealing with set-ups, transport, tools and so on...). Some inconsistencies may then occur, which processing will require some adjustments in the competence planning, in the same way that a schedule may slightly set into question a load planning. Nevertheless, splitting-up competence and machine allocation allows coping with the complexity of the problem, and also gives some robustness to the obtained competence planning. Moreover, degrees of freedom are kept available for short-term reaction to unexpected events.

The data model that allows for defining a DSS according to the previous requirements is shortly described in the next section. Some of the practical problems arising are emphasized in the prototype description.

4.3. Class models of the database

The previously identified functions require data that can be organised according to the class model of Fig. 2, using the syntax of the OMT class model [32]. Since the prototype described hereafter has been implemented using the MICROSOFT ACCESS database (which is not object-oriented), entity-relationship models would be sufficient, but object-orientation allows a more synthetic description and is more consistent with the data structure of present schedulers.

An operator profile is defined by a set of competences, denoted by the "1 + " cardinality in Fig. 2. A competence is sometimes defined as a collection of knowledge and skills, skills being understood as an operational ability to use a knowledge [37]. The competence is quite often considered as involving knowledge (giving a theoretical ability), know-how (denoting a practical experience) and attitude (allowing the use of this knowledge and know-how in a social environment) [15,18]. We only consider here the know-how aspect, recognised by the company and linked to technical entities involved in the manufacturing process. A skill level is considered here as a grade in a given competence (with a scale from 1 to 5). As shown in Fig. 2, the entities on which a competence may be applied can be an activity, a

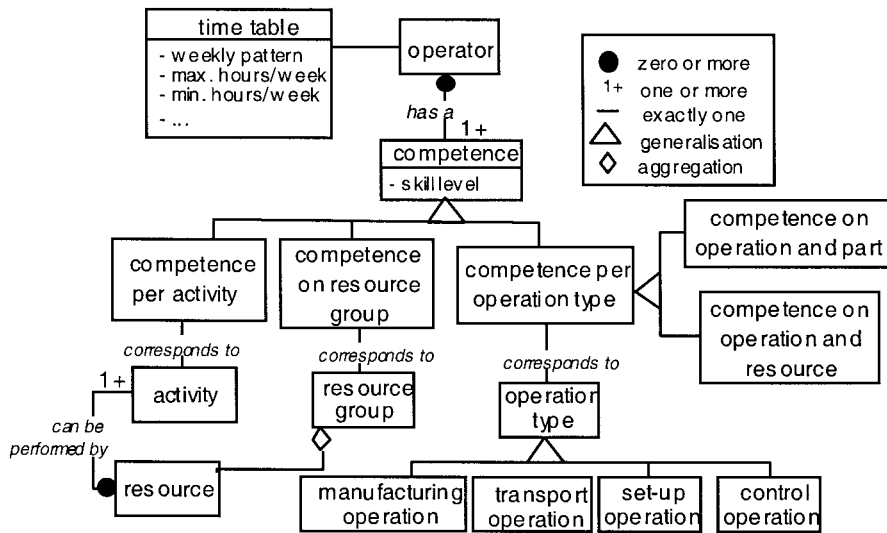


Fig. 2. Data model operators' competences.

resource group or an operation type. An activity (for instance: drilling or milling) can be performed with different machines. For instance, a milling machine or a vertical machining centre can perform a milling activity. The concept of activity can be extended to transportation, set-up and control operations when the competence of the operator does not depend on the physical resource he chooses in order to perform a task. A competence can also be related to a group

of resources, which can be reduced to one machine: this type of competence may be required when operators are only assigned to a workshop, and not to particular tasks. Finally, a competence may be linked to an operation, i.e. a precise action on a part, including manufacturing operations, transportation operations, set-up operations or control operations. In some cases, the competence of an operator concerning an operation may be restricted to a part or to

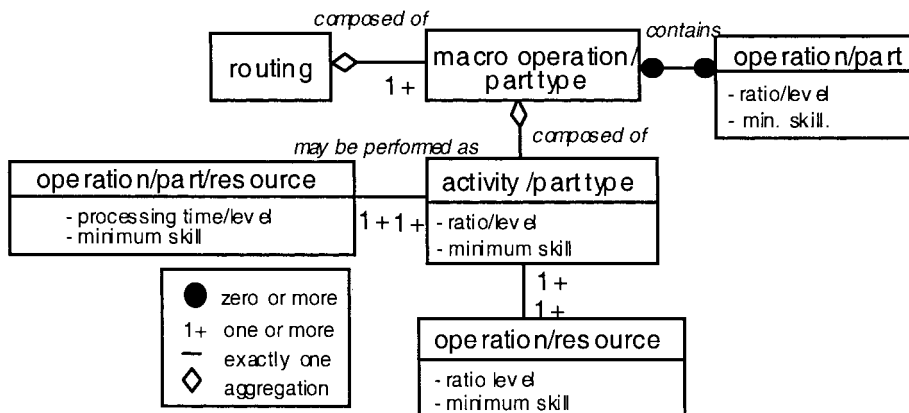


Fig. 3. Data model of a routing.

a set of parts: for example, an operator may be able to perform a control operation on a part but not on another. Such restriction may also concern a resource, for example, an operator can be able to perform a set-up only on a precise resource. These two cases are denoted by the “competence on operation and part” and “competence on operation and resource” classes on the right side of Fig. 2.

Fig. 3 shows the additions to make in order to be able to link the technical data to the competences as described above. A macro-operation is composed of elementary activities that list the auxiliary operations (set-up, transportation) and give more details on the type of manufacturing activity performed (drilling, milling, ...) (“activity/part type” class of Fig. 3). All these data concern a given routing, and are associated to a part type. A precise operation is defined by the affectation of a resource to an activity (“operation/part/resource” class). An activity may be defined independently from the part (transportation activity for instance): this case is expressed by the “operation/resource” class at the bottom of Fig. 3. If the concept of activity is not used, a macro-operation is described by a set of elementary operations related to parts (“operation/part” class at the right of Fig. 3). We have given here the possibility to associate a minimum skill level to operations and activities.

The class model of Fig. 4 allows for assigning an operator to a team, composed of operators having competences related to groups of resources or activities. A “team profile” can be defined, consisting of a number of operators having a competence on the considered resource group. We can also imagine that some constraints on the skill could be expressed (e.g. “at least three workers of skill 1 for competence x...” etc.).

A simple but representative example of the use of these concepts is given in the next section. Their implementation in a prototype is then described.

5. Example and prototyping

5.1. Description of the example

Let us consider a workshop composed of six machines (drill, grinding machine, lathe, mill, machining centre, control). Four parts A, B, C and D, will be considered: their routings are given in Table 1, including minimum skills for some operations.

Eight operators are available, whose competences and skills are given in Table 2. Considering we are in an annualisation framework, the average and last values of their previous working times per week are provided. We shall consider here a planning on 2 weeks at the beginning of September (32 weeks past, 16 weeks left).

The production plan to be performed during the 2 weeks is the following (one lot of each kind is released every day):

- five lots of part A (20, 10, 5, 4 and 4 parts)
- four lots of part B (10, 5, 3 and 3 parts),
- five lots of part C (10, 15, 20, 5 and 4 parts),
- four lots of part D (3, 5, 12 and 3 parts).

This load represents 166 h of set-up and nearly 244 h of manufacturing operations, including control. Since we have eight operators working around 28 h/week (see Section 5.2), the capacity is around 448 h for the 10 days that are considered: the problem is then highly constrained.

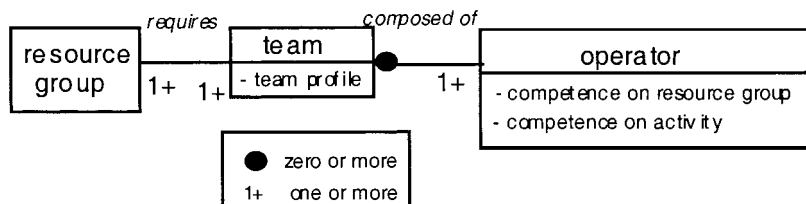


Fig. 4. Data model for assignment to a group of resources.

Table 1
Part routings (time in minutes)

	Machine	Set-up	Skill	Processing time	Skill
<i>A</i>					
10	drill	10	–	10	–
20	lathe	15	–	20	–
30	centre	10	2	10	1
40	grind	20	1	15	–
50	control	0	–	30	2
<i>B</i>					
10	mill	15	–	5	–
20	centre	20	–	15	–
30	lathe	10	–	10	1
40	drill	10	2	10	–
50	grind	20	–	15	–
60	control	0	–	25	–
<i>C</i>					
10	mill	15	–	5	–
20	centre	20	–	15	1
30	mill	15	1	50	–
40	drill	10	–	10	–
50	grind	20	–	15	–
60	control	0	–	20	1
<i>D</i>					
10	centre	15	–	5	2
20	lathe	20	–	15	–
30	mill	20	–	50	–
40	grind	10	–	10	–
50	centre	10	1	15	–
60	control	0	–	40	–

5.2. Visualisation of the capacity per operator

In case of annualised hours, the average work per week decreases down to 80% of the legal working

time. After year 2000 in France, it will then be decreased to $35 \times 0.8 = 28$ h/week. We suppose here that a maximum difference of 20% between two consecutive weeks is allowed (the exact value depends on each company). Within that framework, it is possible to suggest some intervals of the possible working time for the operators. Three strategies may be considered.

- Reach a stable working time per week that allows to obtain the target annual working time. The corresponding working time has been associated here to a “recommended capacity”.

- If the operator has competences that become critical for the following working periods, it is interesting to visualise the “maximum immediate capacity” obtained by increasing the working time as much as possible in the following periods of time. As a consequence, the working time will have to be decreased later in order to satisfy the target annual working-time constraint.

- If the operator is not a critical resource for the following periods of time, a “minimum immediate capacity” can be defined. This capacity allows for keeping as much capacity as possible at the end of the year.

These three types of capacity provide a global framework that may help the decision maker to forecast the future consequence of his short-term decision about the working time of an operator. Such a visualisation, mandatory in an annualisation context, is not yet provided by the manpower management products.

Let us consider operator Bernard as an example. The problem is to decide what will be the working

Table 2
Operator profiles (work in hours)

Operators	Control (skill)	Machines (skill)	Set-up (skill)	Past average work/week	Last week
Bernard	–	drill (1), mill (2)	drill (1), mill (1)	30	30
Daniel	(1)	centre (1)	–	30	30
Agnes	–	all machines (2)	–	40	36
Laurent	–	lathe (1), mill (1)	lathe (2)	28	26
Philippe	(2)	grind (1)	all set-ups (2)	26	28
Jose	–	grind (2), lathe (3), mill (3)	–	30	30
Xavier	(2)	lathe (1), mill (2), drill (3)	–	25	28
Thierry	–	–	all set-ups (1)	20	25

time of operator Bernard for the next weeks. Operator Bernard has had an average weekly working time of 30 h during the first 32 weeks of the year (see Table 2). In order to obtain an average working time of 28 h/week for the whole year (48 weeks), his possible average weekly work is then 24 h/week during the 16 remaining weeks. It is necessary to decrease his weekly working time. The following notation is used:

- w is the number of weeks elapsed from the beginning of the year to the date of the decision making. Here, $w = 32$ weeks.
- r is the required average working time in the remaining weeks: 24 h in the case of Bernard.
- l is the working time of the past week (i.e. the week before the decision is made). According to Table 2, $l = 30$ h.
- “max” is the maximum legal working time per week. It should be equal to 48 h/week without special permission.
- “min” is the minimum legal working time per week. We suppose here that $\text{min} = 15$ h/week.

We are in the case when $l > r$, i.e. the weekly working time should decrease in order to reach the annual average value. We shall decrease the working time by 20% each week until we arrive at a value that allows reaching the desired average annual working time (here 28 h/remaining week). Let m be the number of weeks necessary to reach a constant working time per week. The “recommended capacity” is given by the following equation:

$$\left(\sum_{i=1}^m (0.8)^i l \right) + (48 - w - m)l(0.8)^m = r(48 - w) \quad (1)$$

The first part of the left member of Eq. (1) expresses the progressive decrease of the working time, whereas the second part of the left member shows a constant working time until the end of the year, after the decreasing period. The right member of Eq. (1) expresses the remaining working time until the end of the year.

Eq. (1) is valid under the condition that $((0.8)^m l)$ (i.e. the minimum working time per week) remains

greater than the legal minimum working time per week, which is not yet known but supposed to be equal to 15 h/week here.

Since we have here $l = 30$, $w = 32$ and $r = 24$, Eq. (1) becomes:

$$\sum_{i=1}^m (0.8)^i + (16 - m)(0.8)^m = \frac{4}{5}16 \quad (2)$$

An exact solution can empirically be found for $m = 1$: the working time of week 33 and the following is set to 24 h.

In spite of the fact that Bernard has worked more than the average working time during the beginning of the year, his competences may still be required during the following weeks. The “maximum immediate capacity” can be defined by an increasing work level during some weeks, then a saturation at the maximum level of weekly work, then a decreasing working time in order to reach the target average working time per week in the period.

We shall then increase the last weekly working time by 20% until max is reached. The saturation occurs when: $(1.2)^i l > \text{max} \Rightarrow i > \ln(\text{max}/l)/\ln 1.2 = 2.5$, so after 3 weeks ($i = 3$) in the case of Bernard. As a consequence, we can only increase Bernard working time by 20%/week during 2 weeks until week 34.

The new average working time on the 34 first weeks becomes: $((32 \times 30) + (1.2 \times 30) + (1.2^2 \times 30))/34 = 30.56$ h/week.

The problem is now to find how long the maximum working time can be kept before decreasing the capacity in order to reach the new required average capacity on the 14 remaining weeks, which is $r = 21.78$ h/week. The saturation and the decreasing area are described by the following equation, m' being the number of weeks during which the maximum working time is kept:

$$m' \text{max} + \sum_{i=1}^{14-m} (0.8)^i \text{max} = 14r \quad (3)$$

Since $\text{min} = 15$ h/week, saturation at 48 h/week can only be kept during $m' = 2$ weeks, and the minimum working time is reached at week 42.

Let us consider now that we want to keep Bernard working time to a minimum value during the follow-

ing weeks. The “minimum immediate capacity” is obtained by decreasing the working time by 20% each week, then increasing it in order to reach the target average value.

The saturation at the minimum value \min occurs after $i = \ln(\min/l) / \ln 0.8 = 3.1$ since $\min = 15$ h/week.

The weekly capacity can decrease down to 15 h/week in three periods, then may remain constant for six periods, then must increase to saturate at 46 h for the last week, allowing to obtain the required average weekly working time for the year.

The possible dynamic capacity of operator Bernard, according to the previous hypothesis, is shown in Fig. 5; of course, other types of strategies could be defined. In any case, adapting the working time of an operator to an expected load at medium term requires software support in order to check that all the legal constraints are satisfied.

5.3. Visualisation of the capacity per competence

As stated above, the comparison of the load and the available capacity for each competence can be compared to the performance of a load planning in the MRP method. In the two cases, the aim is to visualise an available capacity and a corresponding expected load, then to act on the load or capacity in order to find an acceptable balance.

In the case of human operators, the main problem of visualising the capacity per competence concerns multiple competences, which may lead to consider

several times the capacity of an operator. Several solutions can be considered, none of them fully satisfactory. The two most simple are the following:

- the participation of each operator to a competence can be visualised: it is very possible to see the operators appearing several times,
- the capacity of an operator may be equally shared between his different competences. The global capacity is then exact, but the sharing does not make any sense.

In Fig. 6, the available capacities are shown for two competences (on the machining centre and the drill) per day, but other periods (like the week or the month) can be visualised. This visualisation can be a first support for the workshop manager, with the two conditions that all the graphics can be visualised at the same time (in order to see the operators having multiple competences) and that the graphics are dynamic, i.e. when an operator is assigned to one of his competences for a period of time, his capacity is removed from all the other competences for that period of time. Nevertheless, other visualisations of multiple competences could certainly be more powerful. The skills of the operators can also be mentioned in the graphs of Fig. 6. These data should allow the easy identification of the critical workers (they have few competences or a high skill in a critical competence) or the critical competences (they concern few operators).

The capacity visualisation is only interesting if it can be interactively modified by the workshop manager: days-off or extra hours should be directly introduced on the graphics by mouse or menu for instance.

5.4. Load visualisation

The second step in order to find a capacity/load balance is to interpret the short-term production plan in terms of load per competence, then per skill. In that purpose, it is necessary to know in which period of time a given competence is required. This load planning should be provided by the MRP environment; nevertheless, we can easily build it here by defining the lead time of each manufacturing opera-

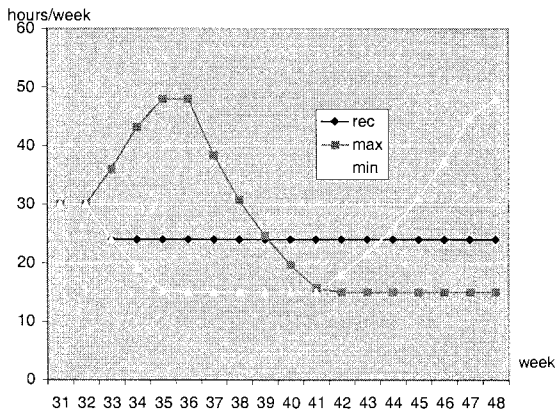


Fig. 5. Limits of capacity of the operator Bernard.

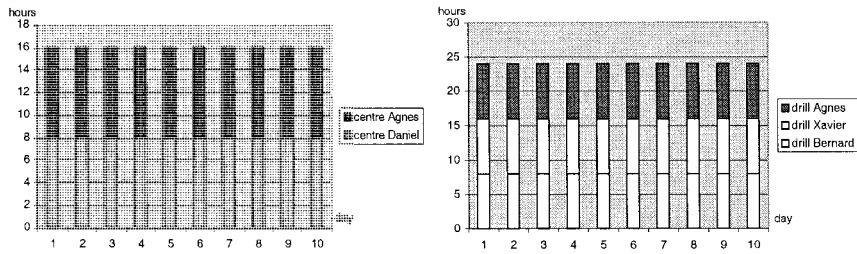


Fig. 6. Global capacity on the centre and drill.

tion: one operation per day is, for example, often considered in real workshops. The load of Fig. 7 for the “lathe” competence is built on that principle. Another possible technique, which does not require the choice of a cadence, is to smooth the working time between the releasing date and the due date of an order. For example, if an order requires 1 h on machine A, then 2 h on machine B, and finally 1 h on machine C, the smoothed load is 25% of machine A, 50% of machine B and 25% of machine C during the 4 h of the cycle time. When an important number of orders is considered, the obtained result gives an idea of the time required on the resources of the workshop, without planning the operations. We have used this approach hereafter, with a load smoothed on the two considered weeks. The choice of the period of time is important since an efficient management of the human resource requires a visibility on at least 1 week, more if possible. On the other hand, the approximation of the load smoothing or cadences is more important when the period increases, leading to possible inconsistencies with the precise assignment. Similarly, a schedule can be inconsistent with a load planning since it is not built according to the same hypothesis.

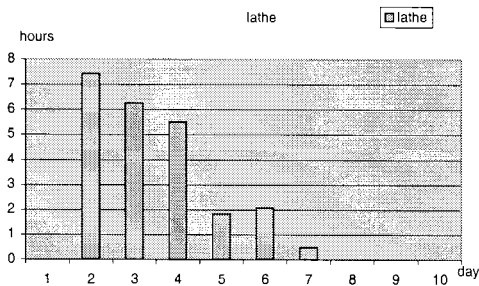


Fig. 7. Load on the “lathe” competence.

5.5. Finding a general balance between load and capacity

The problem is to compare the obtained load with the available capacity of the human resources, taking into account the multiple competences of the operators. A way to roughly assess the available capacity per competence with regards to the corresponding load on a set of periods is to share the capacity of each operator among his different competences. Let us consider that an operator has four competences. We can as a first step consider that his work will be equally shared between these competences. In that case, a capacity of 0.25 operator will be available for his four competences. Under this hypothesis, the example leads to the load/capacity comparison of Fig. 8 on the two considered weeks, with load and capacities expressed in number of operators required.

It can be seen on Fig. 8 that the “drill” competence needs 0.4 operators during the 2 weeks and has an average capacity of 0.7. On the other hand, the

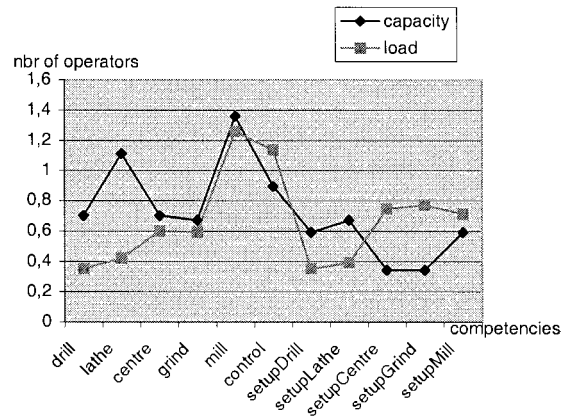


Fig. 8. Load/capacity comparison.

set-up of the machining centre and of the grind requires approximately 0.8 operators, whereas they only have 0.3. Because of the multiple competence of the operators, it is now required to check if transfers of capacities are possible between overloaded and the underloaded competences.

Let us consider Table 3 that summarises the example. This problem can directly be solved by a simplex algorithm: the sum of the possible capacities regarding a competence have to be at least equal to the required load, and the sum of the loads of an operator on his various competences must be equal to one.

Example: From column 1 of Table 3, we get:

$$\begin{aligned} & \text{DrillBer} + \text{MillBer} + \text{SetupDrillBer} \\ & + \text{SetupMillBer} = 1 \end{aligned} \quad (4)$$

and from line 1 of Table 3, we get:

$$\text{DrillBer} + \text{DrillAgn} + \text{DrillXav} \geq 0.35 \quad (5)$$

If we consider an optimisation function consisting in minimising the sum of working hours of the operators, we obtain the solution described in Table 4. We can see that only one competence (control) has too much capacity.

The annualised hours framework can also be taken into account by replacing equations of type (1) by inequations expressing that the working time of an operator must be more than $0.8 \times l$ and less than $1.2 \times l$, l being his previous weekly working time.

In order to keep a better control on the final solution, we have also tested a more empirical method

allowing the progressive building of a solution, starting from the global sharing suggested in Table 3. This method is described hereafter.

We can rank the competences according to their overloading and transfer capacity from the less loaded to the most overloaded competences. For instance, the first step will be to consider ‘‘set-up grind’’ that has the most important overload. The less loaded competence that has common operators with the ‘‘set-up grind’’ competence is the ‘‘set-up lathe’’. It is possible to transfer the 0.142 of Philippe’s capacity from the ‘‘set-up lathe’’ competence to the ‘‘set-up grind’’ one, and so on. The skill level can also be taken into account in this transfer. Table 4 shows a possible result after transferring capacity to the overloaded competences. Transfers can sometimes require transitive operations: the capacity of Bernard on the drill has, for instance, been transferred on the set-up of the drill that was already underloaded in order to allow the transfer of Philippe’s capacity on the overloaded competences. It is anyway rather easy to define an ad hoc algorithm that allows the automatic management of such transfers, eventually taking into account the skills of the operators.

This ‘‘two-step’’ technique gives in our opinion a good control on the result to the workshop manager: for that reason, it can be preferred over a fully automated way of solving the problem.

As a result of the capacity transfers, it can be seen in Table 5 that the given load can be absorbed by the available operators. Moreover, the ‘‘set-up grind’’, ‘‘centre’’ and ‘‘lathe’’ competences have an excess

Table 3
Load/capacity comparison with smoothed capacity

	Load	Ber.	Dan.	Agn.	Laur.	Phil.	Jos.	Xav.	Thi.	Capacity	Difference
Drill	0.35	0.25		0.2				0.25		0.7	0.35
Lathe	0.42			0.2	0.33		0.33	0.25		1.11	0.69
Centre	0.60		0.5	0.2						0.7	0.10
Grind	0.60			0.2		0.142	0.33			0.672	0.08
Mill	1.26	0.25		0.2	0.33		0.33	0.25		1.36	0.10
Control	1.14		0.5			0.142		0.25		0.892	-0.24
Setup drill	0.35	0.25				0.142			0.2	0.592	0.24
Setup lathe	0.39				0.33	0.142			0.2	0.672	0.28
Setup centre	0.75					0.142			0.2	0.342	-0.40
Setup grind	0.77					0.142			0.2	0.342	-0.43
Setup mill	0.71	0.25				0.142			0.2	0.592	-0.12

Table 4
Solution obtained with a simplex

	Load	Ber.	Dan.	Agn.	Laur.	Phil.	Jos.	Xav.	Thi.	Capacity
Drill	0.35	0.29		0.06				0		0.35
Lathe	0.42			0.25	0		0	0.17		0.42
Centre	0.60		0.03	0.57						0.6
Grind	0.60			0		0.13	0.47			0.6
Mill	1.26	0		0.12	0.61		0.53	0		1.26
Control	1.14		0.97			0		0.83		1.8
Setup drill	0.35	0				0			0.35	0.35
Setup lathe	0.39				0.39	0			0	0.39
Setup centre	0.75					0.1			0.65	0.75
Setup grind	0.77					0.77			0	0.77
Setup mill	0.71	0.71				0			0	0.71

capacity. In case of either excess or lack of capacity on a given competence, the result of this capacity/load analysis may help:

- to organise operator transfers between different workshops,
- to negotiate the working time of the following weeks with the operators in case of annualised hours, either by increasing or decreasing the working time of their last planned week, in consistence with the constraints described in Section 5.2. Using the graph of Fig. 5, it is in that case immediately possible to check that this increase remains compatible with the target working time for the year.

5.6. Description of the prototype

The aim of this prototype was to implement the main concepts mentioned above in order to visualise

what could be a DSS for the short-term management of human resources in the context of discrete manufacturing. MICROSOFT ACCESS has been chosen as a test tool in order to assess whether a simple and common tool can allow the development of an acceptable system.

The data used by the prototype have been structured according to the models described in Section 4.3. The prototype has the following functions:

- description of operators, with their competences and skills, and storage of their past weekly working time. Only competences related to operations have been used in the prototype.
- visualisation of the recommended, maximum and minimum working times of each operator, according to the constraints developed in Section 5.2.

Table 5
Result of capacity transfers

	Load	Ber.	Dan.	Agn.	Laur.	Phil.	Jos.	Xav.	Thi.	Capacity	Difference
Drill	0.35	0.00		0.10				0.25		0.35	0.00
Lathe	0.42			0.00	0.27		0.33	0.00		0.60	0.18
Centre	0.60		0.36	0.54						0.90	0.30
Grind	0.60			0.26		0.00	0.34			0.60	0.00
Mill	1.26	0.25		0.09	0.34		0.33	0.25		1.26	0.00
Control	1.14		0.64			0.00		0.50		1.14	0.00
Setup drill	0.35	0.35				0.00			0.00	0.35	0.00
Setup lathe	0.39				0.39	0.00			0.00	0.39	0.00
Setup centre	0.75					0.54			0.20	0.74	-0.01
Setup grind	0.77					0.34			0.60	0.94	0.17
Setup mill	0.71	0.39				0.12			0.20	0.71	0.00

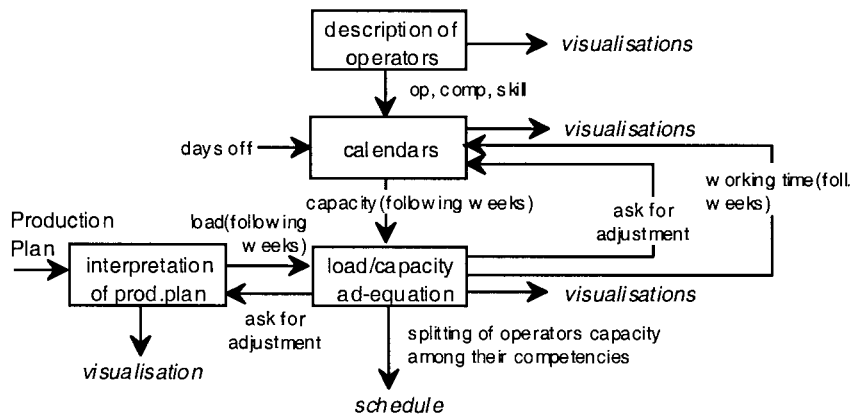


Fig. 9. Architecture of the DSS.

- management of the operators' calendars, i.e. calculation, visualisation and storage of their daily and weekly working time taking into account

their vacations. The output of this module provides the potential capacity of each operator per week.

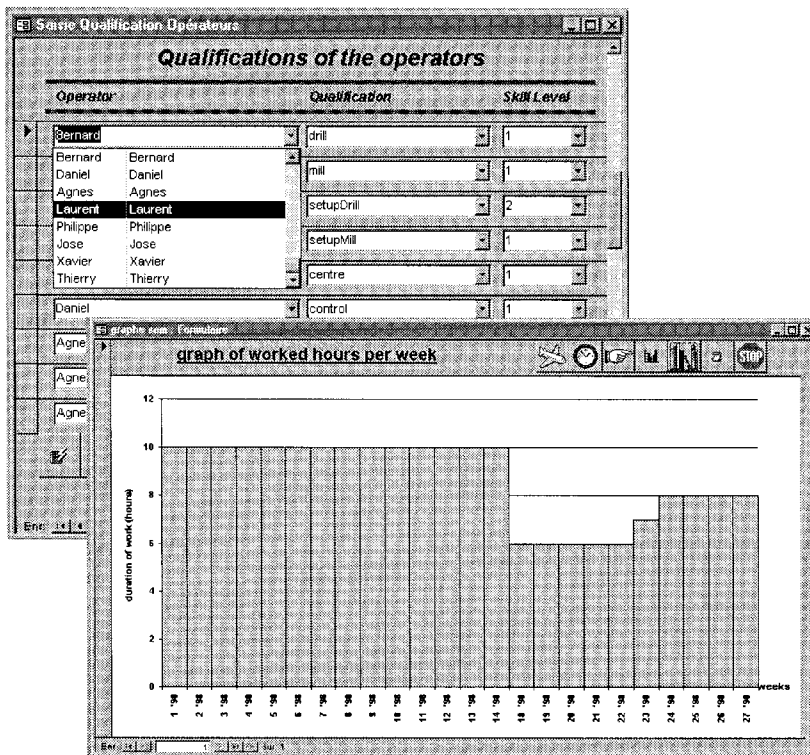


Fig. 10. Examples of screens.

- calculation of the load per competence according to the production plan of the following weeks,
- search for a balance between load and capacity per competence, using multiple competences.

Fig. 9 shows the principle of using of the DSS together with the exchanged data and the visualisations provided. Fig. 10 shows two screens of the system. The back screen allows the entry of the competences and skills of each operator. The list of the available operators is given in a pop-up field. The buttons at the bottom of the screen allow us, respectively, to visualise the list of operators per competence, to visualise the list of competences per operator, to visualise an exhaustive list, to create a new competence and to make a new association between competence and operator.

On the front window is shown the screen that visualises the weekly working time of an operator, taking into account his days-off. These working times are the input of the following visualisations. The worked hours for each competence can also be visualised. The buttons at the top of the window allow the entry of new days-off, new working times and the visualisation of the working hours per day.

Fig. 11 shows the graph of the possible working hours of an operator during the following weeks (see

Fig. 5). The reference and name of the operator appear in the fields at the top of the window, so does the average working time per week done. On Fig. 11, the expected working time on the immediately following period has already been chosen, and the three typical working times are visualised (maximum, minimum, recommended). On that version, the minimum and maximum working times on the two following periods are only shown. The buttons at the top of the screen allow us to visualise the working time per day and per week, to enter new working times and new days off, to visualise the annualisation graph per day and to create a new operator.

When the working time of the weeks to plan has been chosen for each operator, it is possible to look for a balance between load and capacity per competence with the technique described in Section 5.5. If capacity lacks or excesses are noticed, it is possible to increase or decrease manually the working hours of operators (in the limits depicted by the graph of Fig. 11) in order to try to find an acceptable solution.

6. Conclusion and perspectives

The interest in the short-term workforce management grows up in manufacturing systems with the

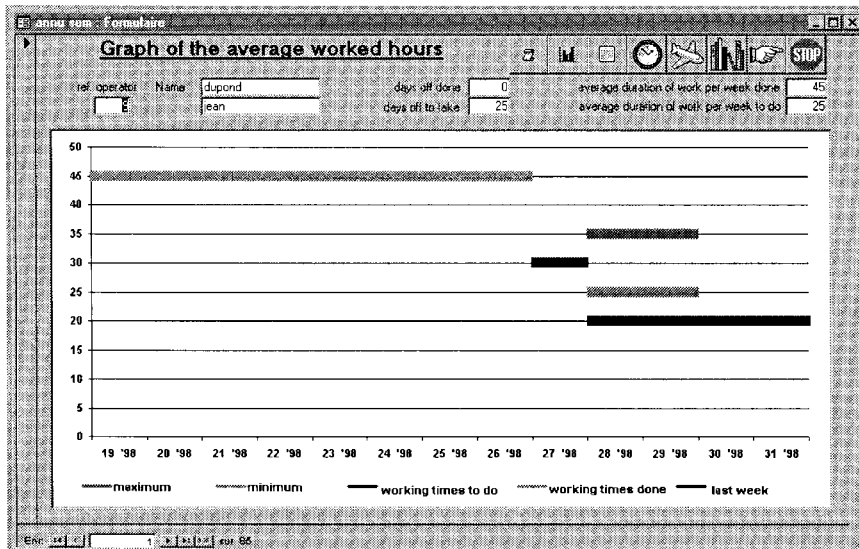


Fig. 11. Possible working hours of the following weeks.

necessity of being more and more flexible, and the possibility of the use of annualised hours. Nevertheless, the existing products are far from giving a satisfactory answer to the new problems that are set by this evolution: the answers that have been given to our questionnaire show that the visualisation of the available capacity in a workshop (global capacity or capacity per competence) is considered as a more important support by the users than the automatic assignment of operators to tasks. In that context, we have oriented our study on decision support, the suggested system being in charge of visualising the degrees of freedom and performing interactively a load/capacity balance while checking that the technical and legislative constraints are satisfied.

The specifications and prototype that we suggest have been shown to several industrial partners, leading to the following remarks.

- The suggested approach seems interesting. The main interest that is seen is that a lot of ways to correlate and visualise existing but hidden information are provided: information on competences, skills and working hours is, for example, not easily available yet and is often roughly considered.

- The prototype is far from an industrial product, but it has helped the companies to materialise their ideas. In order to improve it, three main points have been mentioned concerning the interface as well as the functions of the system.

(1) In order to be able to correlate different types of information, it is mandatory to be able to visualise several windows at the same time, and to dynamically link the information provided on the windows. For example, when the load and capacity are set in balance, the consequence in terms of efficient working time for the operator should be immediately actualised and visualised on the window similar to Fig. 11.

(2) Interactive graphics would allow us to hierarchise information; for example, it would be interesting to visualise how the working hours of an operator have been shared between his competences during the last weeks by clicking on a period of the graph of Fig. 10.

Concerning these two points, tools other than MICROSOFT ACCESS must be chosen, since it does not allow for multi-windowing, neither for interactive graphics.

(3) The management of manpower can be modeled by a network of constraints between orders and human resources that define the problem to solve and the decision variables. In that context, the value taken by a variable can be considered either as a cause or as a consequence of the values taken by the others: for example, the working time of a week can be defined as a pre-requisite, or as a consequence of the load/capacity adjustment. Defining a purely algorithmic way of solving the problem of management of competences does not easily provide this flexibility.

Concerning this last point, constraint propagation is in our opinion an interesting solver: the problem can be easily modeled by constraints, and the adequacy of a solution to industrial requirements can be increased by adding or removing constraints without setting into question the resolution method. We have, for example, made experiments in order to perform load/capacity adjustments using ILOG solver®.

A precise assignment of the operators to tasks has not seemed mandatory to our industrial partners. This encourages us in this approach, which is more oriented on checking the feasibility of a production plan in terms of available capacities, and on identifying the competences that are lacking or in excess in order to allow a better organisation of the workforce at the shop-floor level.

Acknowledgements

The authors thank Lionel Franchini (EMAC, France) for his valuable comments on the draft version of this paper.

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