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Assigning product manufacturing according to workers skills and quality constraints

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Abstract: This paper deals with the allocation of product references to workers according to their abilities.. Workers skills are characterized by the ability to make a good final product and to work as quickly as possible. Our mid-term aim is to propose a dynamical model that precisely takes into account workers skills. Two ways are investigated to assigns non-quality products: results show that the first method which assigns bad products on the same period is more effective than the second one which assigns them on the next period. These data are based on an industrial partnership with a small business.

Keywords: Planning, Skill, Multi-periods, Non-quality integration.

1. INTRODUCTION

This paper deals with the difficulty to assign work orders to the staff according to its abilities. Our aim is to propose a model that can help managers to solve capacity utilization problems according to workers skills, order book and quality requirements. The model we propose is based on a classical linear programming method that makes assignment of product manufacturing according to workers skills and availability. In this model we will express the quality constraint on two ways. These ways depend on the shop floor control of the company. First way assumes that a wrong product will be repaired during the same period the manufacturing order has been launched. On the other hand, the second way assumes that the wrong product will be repaired during the next period. In this paper we will present the tests run for those two methods.

Our study is led in the context of an industrial partnership with a small business that counts 90 employees. Its high quality products are made by hand and main high value-added operations are done thanks to know-how. Those tasks are done by workers of the assembly workshop who uses small manual or electrical equipment rather than machines. Obtaining this know-how takes a lot of time (it requires a few years of experience) since no specific training exists. Moreover, all the products are different and require a suited know-how. Consequently, the main difficulty that face planning and scheduling managers is to establish a balanced capacity utilization by taking into account the skills of each employee. Facing recruitment and job learning difficulties, the company has the will to train and to develop both its raw and experienced workers.

After a short explanation on the notion of skill supported by the reading of different authors, we will present in the Second

Section the significant work dealing with the integration of competences' features in planning and scheduling. Section 3 deals with the presentation of the model we propose. The main results will be treated in Section 4. Finally, in the Fifth Section we will draw up a general conclusion on this study with its actual limits and we will suggest improvements.

2. INTEGRATION OF COMPETENCE

Several studies in planning and scheduling have been led to optimize productivity of companies and their workshops. Recently, thanks to their competences, human resources became a complementary and essential source of performance to take into account (Boucher X., Bonjour E., Grabot B, 2007).

2.1 The notion of competence

Various authors tried to define the notion of competence with accuracy. We have actually noticed a convergence of the definitions between main approaches: a sociological way with Zarifian (1999 and 2004) and an engineering way with Le Boterf (2010 and 2011). Thus, we synthesize this concept in the following way. The competence is the capacity of an individual placed in a professional and sometimes changing environment to make use of its acquired resources, alone or in a workers network, so as to reach a result that satisfy a specific issue. The professional environment includes a set framework, material resources (machine tools, materials...) and the individual has non-material resources (knowledge, know-how and inter-personal skills).

In scientific literature, some other authors tried to structure and to formalize the features of competence. Pépiot et al. (2004) propose a splitting up structure of workers skills. The model integrates both the skills dependency to the context, and it distinguishes the acquired skills by workers from those

required by the operations. Others authors as Belkadi et al. (2006) have featured the influence of the context (which is working context) on characterization of competence; each competence includes different interactions in a given specific working context. The qualitative knowledge of a situation helps to determine the linked competence. This competence is then defined by the mobilization and the dynamic organisation of multiple mixed cognitive resources. Those resources lead to the production of an admitted productivity in relation with a given situation in a delineated context of activities. From an operational point of view, skills can be assessed through various tools (Le Boterf, 2011): assessment of non-material resources (knowledge, capacities...), assessment of know-how in ordered operations or through instructions, assessment of practical experience characterized by knowing how to behave (taking initiatives, managing complex situations...), and assessment of results that are often called performances and measured with indicators. Although the concept of competence is more precise thanks to those definitions, the review written by Boucher X. et al. (2007) clearly points out that skills integration into production planning models has been and is still sometimes restricted to the temporal productivity of workers yield and is usually far to represent in depth the whole concept. However, since our approach aims to help decision-makers in management of load and capacity, we will propose a point of view centered on the results of worker's skills. Those results will be presented in the following model and characterized by two indicators: yield and quality rate.

2.2 Integration of competence in planning and scheduling

In planning, two quoted studies show the interest of taking into account competence in the success on planning and scheduling. The first one, Grabot B., Letouzey A. (2000), proposes a decision support system including workers' competence so as to manage short-term manpower under annualised hour's constraint. Competence is linked to technical resources of the manufacturing process, and to operations (like the set up or the use of machines ...). It is then estimated on a scale that varies from one to five. The proposed system calculates the remaining time or competence for each worker in the above context mentioned above. This is based on a general MRP reasoning. Constraint propagation is used to assign multi-work station to workers. Thus the aim is similar to our as it helps to realize capacity utilization, but the assessment of skills' approach is different, and the general context that is taken into account is different (35h and the MRP approach varies). The second one, Franchini L. et al. (2001), proposes a model that allows to obtain competence's load and to deduce the required quantity of workers needed. After a classical machine scheduling, workers are assigned to machine tools. Here, skills are linked to a specific operation (transport, set up, manufacturing, quality control ...). Also, the assessment of skills is not based on the result of the use of competences, and the consideration of skills takes place in a second part, after a scheduling of machines is developed.

In scheduling, several studies on integration of competence have also been led. Most of them deal with MSRCPS problem (Multi-Skilled Resource Constrained Project

Scheduling Problem) by taking into account various constraints that are linked to a particular project or to resources. A dynamical model is proposed in Attia E.A. et al. (2011), it allows a flexible assignment of workers according to their skills (multi-skilled workers) in order to optimize costs. This model takes into account human resource flexibility, working time adaptability, and the dynamical evolution of competence. A genetics algorithm allows to find a solution in an acceptable time but the yield (spent time/standard hours) is the only criteria used to measure skills. In the same RCPSP problematic and by considering disjunctive resources (as in scheduling field), Benour et al. (2011) try to minimize required human resources for a given activity. It is based on skills profiles which are acceptable for an assignment. Operational skills are assessed with levels. Several versions are proposed and vary whether priority is given to size of the team, to inferred costs, or to unavailability rate of workers. Lastly, in her Ph.D., Gruat La Forme- Chretien F.A. (2007) assesses the impact of management of skills on productivity. She proposes a scheduling model which is based on heuristic rules. The model takes into account quality of final product, productivity and rarity of know-how and proposes performance indicators. Finally, on a wider point of view, we can quote Lovén et al. (1997)'s article in which a study was done to show the influence of the diversity in demanded tasks, on improvement of skills. They also developed the influence of feed-back to workers concerning the quality of their works, this way they improve their skills. The aim of our proposal is to integrate worker's skills in tasks assignment. This assignment is done by scheduling and planning managers. However, our approach is made during several periods. Indeed, the model allows to change the number of periods taken into account in the research of the solution. The approach is also multi-products, with variable complexities that vary according to available skills, but we will speak of one kind of working station since every worker realizes the same kind of operations. Our will is also to propose a dynamical model that takes into account improvements in workers skills. Here, we will discuss the competence in term of temporal productivity and of quality of the final product, for each product manufactured by each worker.

3. PROPOSED MODEL

With this model we will test different objectives that a company can choose when assigning works orders. The proposed method is based on linear programming. It proposes multiple periods, various products, and a unique work station since we consider that all the workers realize alone the assembly tasks of the assigned lot. Otherwise, we wish to introduce in this model a dynamic that will take into account the development of workers skills.

3.1 Indexes

i : index of the product to manufacture ; $i \in [1..N_{ref}]$ with N_{ref} the quantity of product references that can be manufactured.

j : index of the shop worker ; $j \in [1..N_{op}]$ with N_{op} the number of shop workers.

k : index of the period, on a daily, weekly or monthly basis; $k \in [0..N_{periods}]$ with $N_{periods}$ the length of the planning horizon.

As we tested our model on MS Excel 2010 software, we limited the dimensions of those indexes to five. So we set N_{ref} , N_{op} , and $N_{periods}$ to five.

3.2 Data

Ta_i : Standard hours for each product i . They are set by an expert.

Q_j^p : Minimal number of products which belongs to a family Fp of products that a worker has to manufacture. This helps to develop and keep workers skills.

η_{ij} : Mean yield of a worker j to manufacture a product i . It is a productivity rate that represents proportion of running time on net time. It is updated at each period k and can be based on statistics.

q_{ij} : Worker's efficiency in terms of quality: proportion of good products i achieved in the past by operator j . It is updated at each period k and can be based on statistics.

$\tau_{ij} = 1 - q_{ij}$: Proportion of wrong products i achieved in terms of quality by operator j .

h_k : Working hours demanded by the company for most workers during a period k .

PP_k^j : Proportion of attendance of each worker j during each period k that schedulers can forecast with little imprecision (correspond to vacation, known absences ...).

v_{ik} : Quantity of customer orders of products i for the period k .

Fp : Family of products created by experts. Products are sorted by level of complexity or similarity of operations.

CR_{ik} : Costs of shortage in product i during period k .

T_{ik} : Turnover generated by the sale of a product i during period k .

E_{ik} : Expenses due to the production of product i during period k .

3.3 Variables

v_{ik}^j : Quantity of product i assigned to worker j during the period k .

S_{ik} : On-hand product i at the beginning of k period; it is always positive.

R_{ik} : Shortage of product i at the beginning of k period; it is always positive.

L_{ik} : Losses due to non-quality products that cannot be fixed. If the product is repaired several times, it can be more economical to throw and make a new one rather than repairing it. If we consider that the wrong product is repaired during the same period, the number of time it is repaired is set, so L_{ik} is always positive. Whereas if we consider the second case where product is repaired during the next period, our model repairs products towards infinity, and so L_{ik} value is always zero.

$h_k^j = h_k \times PP_k^j$: Forecasted working hours of worker j during period k .

3.4 Constraints

3.4.1 Quality and inventory balance constraints:

As noted above, we will present here the two ways for expressing the quality constraint. The first way where wrong products are repaired during the same period (k) will be called M1, and the second one, where wrong products are repaired during the next period ($k+1$) will be called M2.

3.4.1.1 First way

Time a worker needs to do the assigned work must be less important than forecasted working hours of the worker.

$$\forall j \in [1..N_{op}], \forall k \in [1..N_{periods}],$$

$$\sum_{i=1}^{N_{ref}} \left(\frac{v_{ik}^j}{\eta_{ij}} \times Ta_i \times \left(\frac{1-\tau_{ij}^{n+1}}{1-\tau_{ij}} \right) \right) \leq h_k^j \quad (1)$$

n is the number of repairing of a product in shop floor. It is assumed that, during a period, a same worker will have to work again on a given product until it is of good quality. This rework results in an increase of the worker load. For the experiment we set n at one. The coefficient $\frac{1-\tau_{ij}^{n+1}}{1-\tau_{ij}}$ represents the proportion of time the worker will theoretically take for working or reworking n times a product. Initially, the worker j has to make v_{ik}^j products and he misses $\tau_{ij} \times v_{ik}^j$ products. If during the same k period he repairs a first time the $\tau_{ij} \times v_{ik}^j$ quantity, he will theoretically miss $\tau_{ij}^2 \times v_{ik}^j$ products. Consequently the load during the k period will be equal to $v_{ik}^j \times \sum_{r=0}^{n} \tau_{ij}^r$ (with $r \in \mathbb{N}^+$), and $\sum_{r=0}^{n} \tau_{ij}^r = \frac{1-\tau_{ij}^{n+1}}{1-\tau_{ij}}$.

The more n is important, the less is losses due to non-quality. This coefficient can also be false when q_{ij} is equal to zero. It matches with the case the worker j has never done the

product i . To avoid this situation and help the solver we propose to replace zero by a smaller enough value, 10^{-4} for example. The solver will consider this value similar to zero and won't take it into account as it is very small compared to other values.

A second constraint is that the quantities assigned to workers must match with the demand and with on-hand balance and delays.

$$\forall k \in [1..Nperiods], \forall i \in [1..Nref],$$

$$\sum_{j=1}^{Nop} (v_{ik}^j) + S_{ik-1} + R_{ik} = v_{ik} + R_{ik-1} + S_{ik} \quad (2)$$

3.4.1.2 Second way

Time a worker needs to do the assigned work must be less than forecasted working hours of the worker. Here, quality come backs from the former period $k-1$, over volume of product due to non-quality is assigned to each worker.

$$\forall j \in [1..Nop], \forall k \in [1..Nperiods],$$

$$\sum_i \left(\frac{v_{ik}^j}{\eta_{ij}} \times Ta_i \right) \leq h_k^j \quad (3)$$

The quantities assigned to workers must match with the demand and with on-hand balance and delays.

$$\forall i \in [1..Nref], \forall k \in [1..Nperiods],$$

$$\sum_j (q_{ij} \times v_{ik}^j) + S_{ik-1} + R_{ik} = v_{ik} + R_{ik-1} + S_{ik} \quad (4)$$

Consequently, the quantity of products assigned must take into account the wrong products of the previous period so that time will be spent in repairing products.

$$\forall i \in [1..Nref], \forall k \in [1..Nperiods],$$

$$\sum_j (v_{ik}^j) \geq \sum_j ((1 - q_{ij}) \times v_{ik-1}^j) \quad (5)$$

3.4.2 Upgrading abilities constraint:

This constraint depends on the industrial strategy. According to Loven et al. (1997) study, people with multi tasks skills have a better development of their knowledge. Some industrial managers can be interested by this constraint that will contribute to make multi-skilled workers. We propose to create families of products Fp (where the products are sorted into levels of difficulty for example). The manager has to order to each worker a minimum of products of the same family. This prevents the model from systematically assigning the most difficult products to the best workers, and raw workers can improve their skills.

$$\forall Fp \in [1..Np], \forall j \in [1..Nop], \sum_{k,i \in Fp} v_{ik}^j \geq Q_j^p \quad (6)$$

3.5 Targets

Different targets can be tested and depend on each company's strategy. As our objective for planning is to forecast for which product we may risk a shortage, we propose that the target for this assignment model is to satisfy the demand by avoiding shortages (and so delays):

$$\text{Min} \left(\sum_{k=1}^{Nperiods} \sum_{i=1}^{Nref} (1000 \times R_{ik} + L_{ik}) \right) \quad (7)$$

The proposed coefficient 1000 is added to help the solver to distinguish shortages due to planning and human resources availability from those due non-quality products that cannot be repaired (losses). If we do not add this coefficient, the solver prefers to launch orders of products that are not ordered or not in the same quantities.

4. RESULTS

4.1 Data

To test our model, we chose typical workers that well represent the diversity of competence in a company. The first worker (j1) works slowly but makes high quality level products; the second one (j2) works quickly and makes high quality products; the third one (j3) works quickly but quality level of his products is quite bad, the fourth one (j4) works well on easy products and his speed is normal for more difficult products; the last one (j5) is a raw one: works slowly and has not learned to do all references yet. On the same way we chose typical products that are representative of the sales. Product i1 is very easy to make, i2 is easy to make, i3 is rather difficult to make and products i4 and i5 are very difficult to realize and require long years of experience. The dynamic of the model is represented by the possibility to make evolve workers skills along the different periods. We present in tables 1 and 2 the values for q_{ij} and for η_{ij} rates with their evolution along the five periods used in this experiment.

Table 1. Evolution of quality rate along the k periods

q_{ij}	Product	j1	j2	j3	j4	j5
k=1	i1	1.00	1.00	0.90	0.90	0.80
	i2	1.00	0.90	0.90	0.80	0.50
	i3	1.00	1.00	0.90	0.85	0.50
	i4	1.00	0.90	0.50	0.50	0.00
	i5	1.00	0.00	0.00	0.00	0.00
k=2	i1	1.00	1.00	0.90	0.90	0.80
	i2	1.00	0.90	0.90	0.85	0.60
	i3	1.00	1.00	0.90	0.85	0.70
	i4	1.00	0.90	0.60	0.55	0.00

	i5	1.00	0.00	0.00	0.00	0.00
k=3	i1	1.00	1.00	0.90	0.90	0.80
	i2	1.00	0.90	0.92	0.85	0.60
	i3	1.00	1.00	0.90	0.85	0.70
	i4	1.00	0.90	0.60	0.55	0.00
	i5	1.00	0.20	0.00	0.00	0.00
k=4	i1	1.00	1.00	0.95	0.90	0.80
	i2	1.00	0.90	0.92	0.85	0.65
	i3	1.00	1.00	0.90	0.85	0.70
	i4	1.00	0.90	0.60	0.60	0.00
	i5	1.00	0.50	0.00	0.00	0.00
k=5	i1	1.00	1.00	0.95	0.90	0.80
	i2	1.00	0.90	0.92	0.85	0.65
	i3	1.00	1.00	0.90	0.85	0.70
	i4	1.00	0.90	0.65	0.63	0.00
	i5	1.00	0.50	0.00	0.00	0.00

Table 2. Evolution of productivity rate along the k periods

η_{ij}	product	j1	j2	j3	j4	j5
k=1	i1	0.50	1.20	0.80	0.80	0.70
	i2	0.50	1.00	0.80	0.60	0.20
	i3	0.50	1.30	0.90	0.80	0.50
	i4	0.60	0.70	0.80	0.20	0.00
	i5	0.60	0.00	0.00	0.00	0.00
k=2	i1	0.50	1.20	0.80	0.80	0.70
	i2	0.50	1.00	0.80	0.65	0.40
	i3	0.50	1.30	0.90	0.80	0.55
	i4	0.60	0.70	0.80	0.30	0.00
	i5	0.60	0.00	0.00	0.00	0.00
k=3	i1	0.52	1.20	0.82	0.80	0.70
	i2	0.52	1.00	0.80	0.65	0.40
	i3	0.50	1.30	0.92	0.80	0.55
	i4	0.60	0.70	0.85	0.30	0.00
	i5	0.60	0.15	0.00	0.00	0.00
k=4	i1	0.52	1.20	0.85	0.80	0.70
	i2	0.52	1.00	0.80	0.65	0.40
	i3	0.56	1.30	0.92	0.80	0.70
	i4	0.60	0.70	0.85	0.45	0.00
	i5	0.60	0.30	0.00	0.00	0.00
k=5	i1	0.52	1.20	0.85	0.80	0.70
	i2	0.52	1.00	0.83	0.65	0.50
	i3	0.56	1.30	0.95	0.80	0.75
	i4	0.60	0.75	0.85	0.50	0.00
	i5	0.60	0.40	0.00	0.00	0.00

We have decided to run those tests on MS Excel 2010 software as our objective is to check if the proposed model gives logical result, so as to go further in a second time. This software limit us in the number of variable modeled (the limit is 200). That is why we chose to limit our study to 5 workers, 5 products and 5 periods. In this case there are 150 variables. Values of q_{ij} and η_{ij} are based on first measurements and observations that come from the worker's support provided by managers.

To understand the main differences between the two methods M1 and M2 about management of wrong products, we set most parameters: orders and qualifications of workers do not vary along the k periods, Fp is constant too (we do not impose a minimum for family $F1$ but we set minima in family $F2$: 5 for j2, 10 for j3 and j4. We chose some quantity of orders a little more important than the available human resources, so that a solution can theoretically be found and shortages are noticeable. For each period k we propose to set orders to those values in Table 3. They are based on main annual percentage of sales and the total load is feasible (in the virtual case where all workers work perfectly).

Table 3. List of orders for each product i and each period k

i1	i2	i3	i4	i5
70	42	70	42	12

4.2 Results

We first checked that the two models works when changing quantity of ordered products or Fp minimum of products for improvement. As the quantity of ordered product increases, both models reduce quantity of assigned products that have the longest standard hours. This is in phase with assignment method of the model that consists in taking shortest standard hours products first. Changing the Fp parameter has not any impact on the assignment method of solver. If the solver find a better solution by giving work to a more experienced worker, it will just give the minimum imposed by Fp parameter to the less experienced worker decider wants to upgrade.

We analysed then the behavior of both proposed ways of taking into account wrong products, M1 and M2. We present in Table 4 our results of target value in different contexts. We first tested the model when skills of workers are constant and equals to the values of the first period. In lines 4 and 5 of Table 4 we make evolve skills of workers along the five periods. Finally we tested the impact of the removing of worker of the model.

Table 4. Values of target cells in different situations; values are expressed in number of products.

Method	Scenario	$\sum_{ik} R_{ik}$	$\sum_{ik} L_{ik}$
M1	Skills are constant	62.1	54.1
M2	Skills are constant	90.6	0

M1	Skills evolve	28.9	46.1
M2	Skills evolve	69.2	0
M1	Skills evolve without j1	297.8	46.2
M2	Skills evolve without j1	378.4	0
M1	Skills evolve without j2	447.7	27.0
M2	Skills evolve without j2	502.1	0
M1	Skills evolve without j3	184.5	129.1
M2	Skills evolve without j3	306.6	0
M1	Skills evolve without j4	173.7	29.4
M2	Skills evolve without j4	212.3	0
M1	Skills evolve without j5	143.9	22.0
M2	Skills evolve without j5	167.6	0

We can say with table 4 that for both models, as the skills evolve, quantity of shortages is significantly reduced. The assignment evolves as workers skills increased and tasks can be given to different workers. That means our model

really takes into account their improvements. However it allows work only if the worker is enough qualified. That is where the number Fp can be useful for managers. To use practically one of the two models, values of productivity and quality will evolve along the time. If we could forecast them as precisely as possible, planning system will be more precise than if we just consider skills of the last period. The two methods seem to react to changes on a similar way but they differ by the assignments and results. On Table 4 we can see that results of method M2 are always worse than those of method M1. This must be due to method for managing non-quality products. As the model rework products toward infinity, its load of work is more important than those which rework only one time products. Table 4 also shows that logically, with method M1 the quantity of non-quality products decreases when skills upgrade. More over one can shows the impact of the absence of a worker on losses. The absence of well skilled workers slows down the system (and increase), whereas the absence of raw workers makes the system lighter.

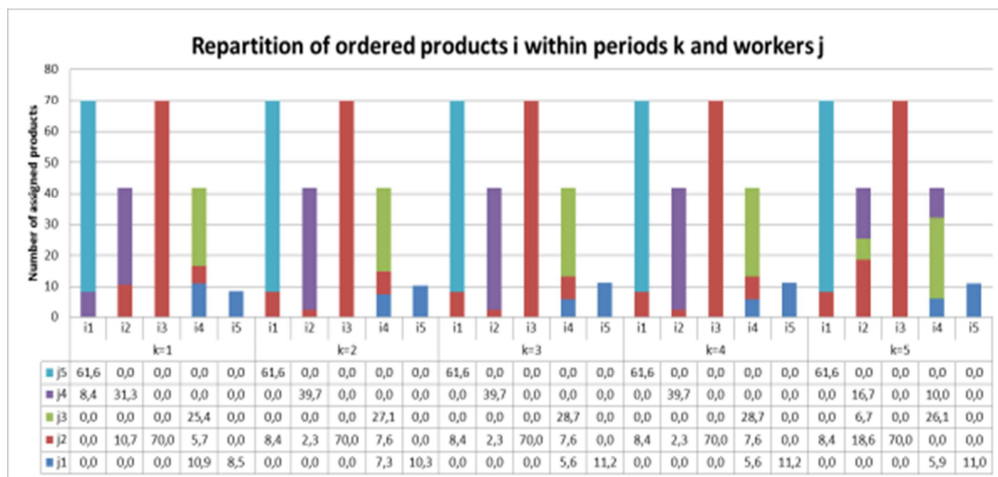


Figure 1 : Assignments in case M1, workers skills upgrade

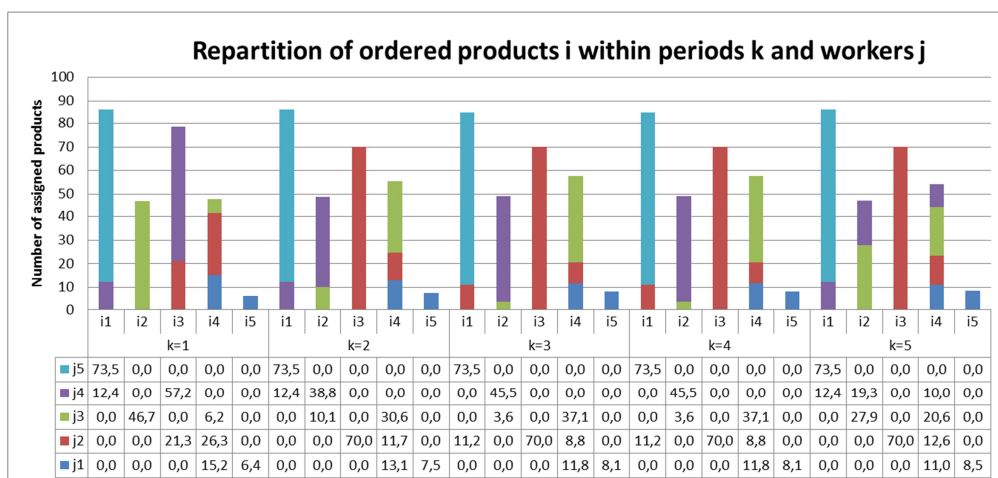


Figure 2 : Assignments in case M2 workers skills upgrade

With figures such as figures 1 and 2 we first observed that the two methods first assign easiest products with shortest standard hours. Indeed, the most complex product i5 is

always in shortage, and if we increase the total load, the second complex product will be in shortage too. This is the same method applied by managers when they do not pay

attention to products similar to product i5. The consecutive risk is to not satisfy demand of a category of customers. Moreover, we can observe that the two methods M1 and M2 propose different assignments of the work. The only difference between the two figures is the load for each week. Indeed, in method M2, the impact of wrong products is more important.

5. CONCLUSION AND IMPROVEMENTS

The proposed model allows us see gradually the impact of different parameters. With the two proposed methods and the tests run, we can conclude that skills of each worker have an impact on scheduling that can be taken into account throw the dynamic aspect of our model (in terms of periods). However the second method could be upgraded as we cannot compare it with method 1. In M2 case, we cannot really differentiate wrong products from new launched products.

This model could become more exact. . A lot of parameters can be added so as to upgrade precision of this planning system. For example, our model considers that standard hours are identical for making products or repairing them. We know that the repairing products takes more time, and we will include this new parameter in short term. We can integer the fact that a product has fewer chance to be defective after having been repaired a first time than after its first quality control. Last, we think it is important to integrate the will of a worker to make a product. It is possible that a worker do not like (for different reasons) manufacturing some references of product, and could have more difficulty to make headways without being motivated. But the main important change to continue our research is to implement a trustable system to acquire and to manage dynamic data in the company. This should allow us to lead experiments on a larger scale. Those tests could be performed on a more high-performance solver.

This model helps us to understand its usefulness for managers. It can be used to help them in planning and scheduling decisions.. For example, on mid-term planning level, managers can know for which product they expect to suffer from a shortage of skills availability. It can also help managers to follow and upgrade skills of their workers at the shop floor level.

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