Impact of Flexibility and Employees' Preferences on Shift Scheduling: a Simulation Approach

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***Abstract*-This article presents a simulation approach for staffs scheduling and rescheduling into a dynamic environment of a paced multi-product assembly center based on multi-agent algorithm. Our purpose is to investigate the impact of modelling flexibility and employee preferences, on the quality and- cost of the shift-scheduling solutions. The proposed simulation takes into consideration the individual competencies, mobility and preferences of each employee, as well as the personnel and competency requirements associated with each assembly activity given both the current master assembly schedule and the line balancing for each product. Experimental results show that flexibility may lead to a reduction of the staff's cost allocation and improve employee satisfaction.**

Keywords- Personnel Shift Scheduling; Multi-Agent Systems; Employee' Preferences; Cross-Training; Flexible Work Schedule

I. INTRODUCTION

Personnel scheduling problems are particular cases of resource allocation problems [1]. They aim to build a working timetable for each employee by defining start time periods, duration of work, break intervals, as well as the tasks to be fulfilled. The objective of the timetable is to optimize one or several criteria's while respecting a set of constraints such as labor requirements, individual preferences, or specific competencies [2-3]. Typical classifications of personnel scheduling problems tend to separate problems into three categories: shift, days-off and tour scheduling problems which combines the first two categories [3].

In this article, the simulation focuses on shift-scheduling problems in a large assembly line environment, where the pace setting takt time between individual product units is preset, equal to at least few minutes. We consider an assembly line with multiple workstations in charge of assembling different product-models sequentially. For each product, there is a predetermined line balancing which specifies the assembly tasks to be realized at each station when this product is assembled. Each assembly task requires one or several employees with a specific competency profile. In addition, in regards to the manpower pool, we take into account individual competencies, mobility and preferences. Especially the following ones:

- Each worker has a specific degree of cross-training, enabling him to carry one or several types of assembly activities during a work shift.
- Workers are allowed to move between workstations in order to fulfill specific assembly activities according to the product assembly schedule.
- Workers can be assigned to secondary activities, which can be either productive, administrative or learning, while not assigned to an assembly workstation.
- Each worker has a set of individual preferences related to (a) the shift duration, (b) the assignable activities and (c) the number of transfers between activities.

Due to product changeovers and the specific manpower competency requirements associated with each product at each station, there are often large waves of personnel moves among stations. This causes significant disruptions to the operations, deterring the overall productivity of the line and generating dissatisfactions among the personnel.

In previous articles, (Sabar et al. 2008) [4] proposed a formal description and mathematical modeling of this multi-objective decision problem. The experimental results demonstrate, on one hand, that for smaller cases, it is possible to reach the optimal solution by using a commercial solver; and in the other hand, that optimal resolution time is bound to be huge for larger size classes. Moreover, results have shown that even for smaller cases, commercial solvers cannot be reliably used in a fast interactive and uncertain environment requiring the generation of solutions in short times, pointing toward the need to develop heuristic optimization approaches. A multi-agent-based approach for personnel scheduling problems has been proposed [5]. Experimental results show that this approach can produce high-quality and efficient scheduling solutions in a short computational time.

Also, Sabar et al. (2012) [6] consider that if a disturbance related to operators' absenteeism occurs at a given time period, the variables representing the personnel' scheduling up to this period are fixed to the matching values from the original plan and, the disturbance' parameters are reflected on the remaining time periods. Then, a new rescheduling has to be performed on the global level through complete regeneration of personnel schedule. Regarding the operators' absence, we distinguish full

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absenteeism (operator absence from work during the entire shift) from partial absenteeism (operator arriving late to work or leaving work during working hours due to sickness or personal matters). In both cases, the rescheduling aims to generate a new allocation plan which replaces absent operators by transferring activities to the available and on-call workers.

In this context, Sabar et al. (2012) [6] present a multi-agent based approach (MAS) that aims to tackle the complexity of the targeted personnel scheduling / rescheduling problem through distributed problem-solving. The proposed approach is based on cooperation among several rational agents which encapsulate individual competencies and preferences of employees. In this approach, the agents negotiate to form coalitions which allow them to improve their individual schedules, and consequently to iteratively improve the global solution of personnel scheduling problem. To benchmark the performance of the multi-agent approach, solutions obtained through a simulated annealing approach have been used. The performed experiments have demonstrated that the multi-agent approach can produce high quality and efficient solutions compared to simulated annealing approach. Fig. 1 illustrates the global anytime algorithm for scheduling and rescheduling problems.

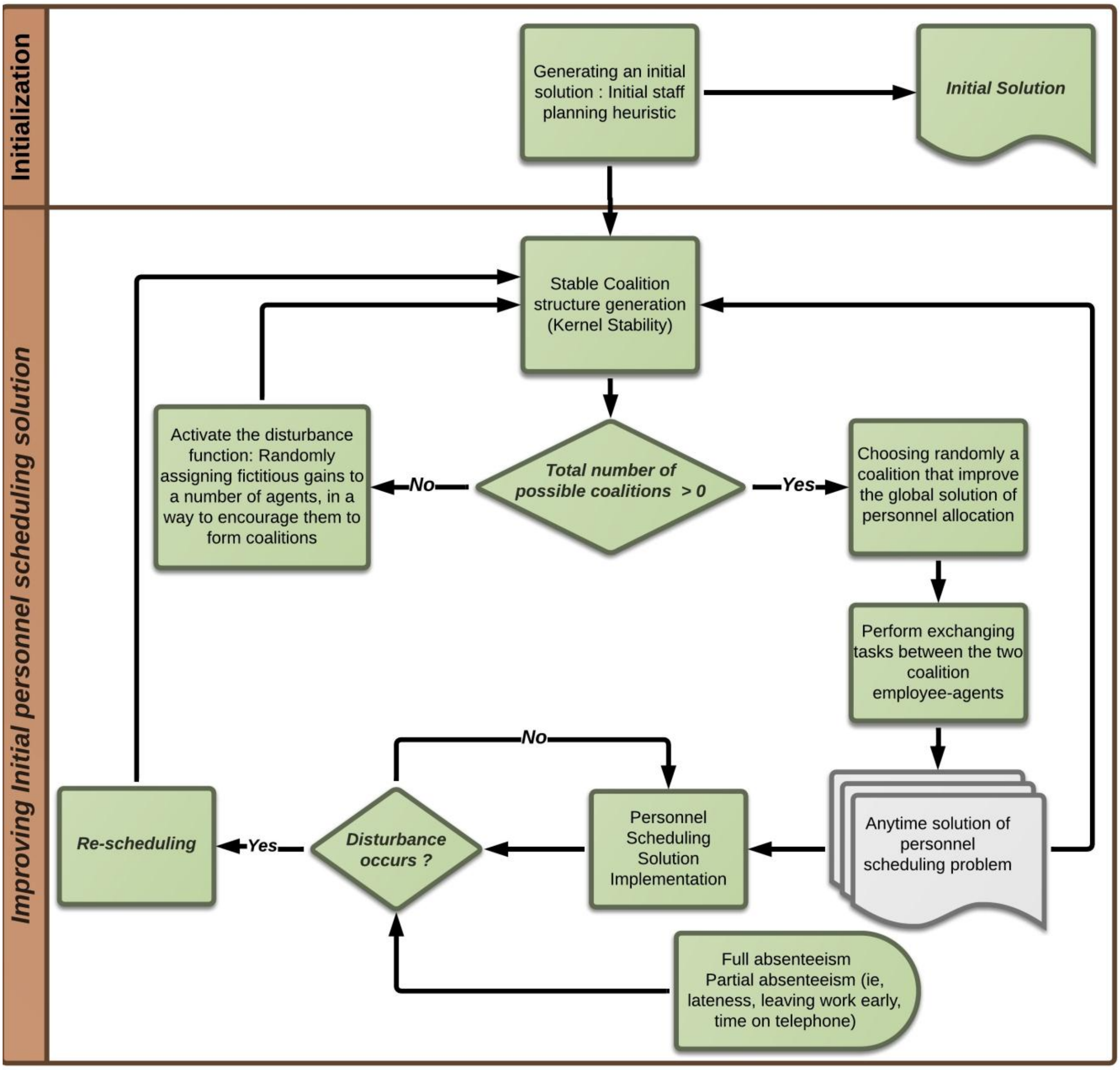

Fig. 1 Multi-agent algorithm for personnel scheduling and rescheduling problems

In this article, for studying two aspects of strategic human resources management, we exploit the algorithms based agents and simulated annealing, which have been previously developed and experimented by Sabar et al. (2012) [6]. These aspects are: the flexibility of the elaboration of work schedules, and the impact of preferences' consideration in the staff scheduling process.

In the personnel scheduling process, the dimension related to the working time flexibility appears today as a key element for the improvement of human resources management. Many studies have demonstrated the benefits of flexibility [7-10]. From these researches, it emerges that a high flexibility makes the development of schedules works' easier, and it also allows an

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improvement of the employee's productivity. Indeed, according to Bailey and Field (1985) [7], flexibility has a positive impact on the working environment: the employees are motivated, thusthe rate of absenteeism and lateness decreases. The basic idea of the working time flexibility consists in diversifying the work schedules models in terms of work periods' times and locations, or in minimizing the temporal limits of these models, in order to cope with fluctuations and variations of production, and to accommodate the preferences and personal constraints of the employees.

The flexibility in personnel scheduling can take many forms. The most common examples are:

1. Adoption of several types of shifts which have distinct durations and hourly range (Shift-length flexibility) [2, 9, 8, 11];
2. Flexibility on shifts' start time per day and per week (Start-time flexibility) [2-11];
3. Flexibility on the location and duration of the weekly rest days (Days-off flexibility) [14-16];
4. Flexibility related to the locations of daily break periods (Break-placement flexibility) [2, 8, 11-14].

The remainder of the paper is organized as follows. Section 2 introduces the personnel scheduling problem we focus on, and describes the settings and approach of simulations. Section 3 presents analysis of the impact of flexibility on employee scheduling. Section 4 describes the simulations results regarding the impact of preferences. Finally, section 5 presents conclusive remarks.

II. DESCRIPTION OF SIMULATIONS

In this article, we are interested in the work flexibility related on one hand to the dimension of the shifts' duration and, in the other hand to the dimension of the shift start time. Our goal is to compare the potential gains linked to a flexible management of working time strategy, against the traditional model (typical shift) generally characterized by a 9-hour period and a single period of the labor start, generally 8am (called in the following: *model #1*). For each of the two flexibility dimensions selected, there are two distinct levels, which respectively reflect an average and a high level of flexibility:

- For the dimension of shift duration, in the first flexibilities' level we consider four possible working times per a specific employee for each shift. The chosen durations are respectively 4, 5, 7 and 9 hours. In the second level of flexibility, there is no pre-established period of presence. The only constraint at this level focuses on the minimum duration of an employee's presence. This time is considered to be equal to 4 consecutive hours per shift.
- For the dimension of shift startup, we consider at the first level that a work shift can begin every 2 hours starting from a reference hour (8 am, for example). In the second level, the start frequency is higher. In this case, a work shift can start every hour.

The combination of these two dimensions gives rise to four possible models for the working time management as shown in Fig. 2.

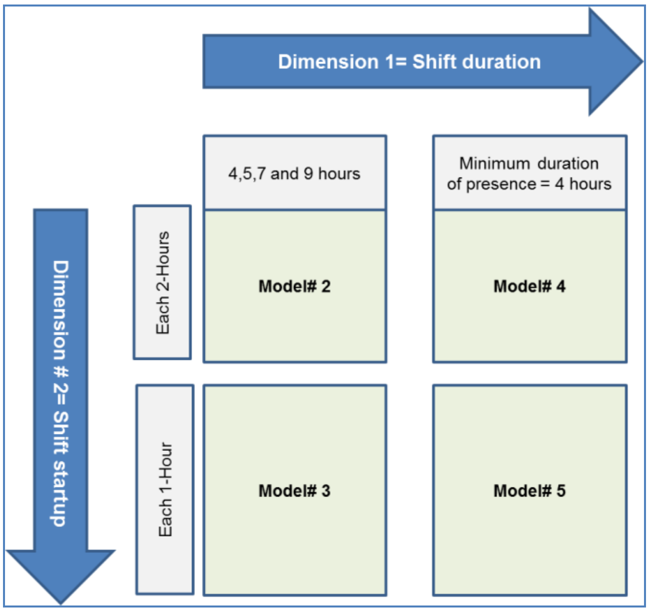

Fig. 2 Flexible management of working time models

To evaluate the impact of the five chosen flexibility' models, we tried to solve a personnel scheduling problem for a production plan spread over sixty shifts. Particular care has been given to the development of this production plan in order to have many types of work load, which varies from a low to a high load in terms of number of required employees. In addition, at each shift, we simulate a number of disturbances related to the total or partial employee absence.

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For scheduling and rescheduling problems, we build five large-scale problems with long time horizon (60-shifts). Experiments have been performed on an assembly line consisting of 40-workstations. Regarding the staff, we consider that the offer and the demand per shift for employees vary between 150 and 200 employees including 5% as team leaders. The daily absenteeism rate varies according to the shift number, from a minimum of 1% to a maximum of 5% of total employees. In case of surplus employees, the employees who will not be affected in activities during the shift will be considered as on-call workers.

To implement these different models, we use two approaches to solve staff scheduling problems: the approach based on agents, as well as the second variant of the simulated annealing algorithm (permutation block activities) [6]. It allows comparing the performance of these two approaches on a sizable horizon. Regarding the calculation time used for each shift, we have set ourselves a time equal to 10 minutes to process scheduling and a duration of 100 seconds for rescheduling in case of total or partial employee absence.

III. ANALYSIS OF THE IMPACT OF FLEXIBILITY ON EMPLOYEE SCHEDULING

We will now discuss the experimental results from the resolution of a five models series, through the simultaneous use of the agent-based approach and simulated annealing. In the first instance, we focus on analyzing the impact of flexibility, by comparing the costs of different working time models management. In the second step, we are reviewing the performance of both approaches resolution; thanks to the sizeable duration of simulations (60 shifts / model), we will be able to have a more representative idea of the performance linked to the based agents approach towards the simulated annealing algorithm.

Table 1 presents the cumulative results of the objective function for different types of flexibility and for both methods scheduling-rescheduling.

TABLE 1 CUMULATIVE RESULTS OF SCHEDULING SOLUTIONS/RESCHEDULING

	Model#1 (normal working shift of eight hours)	Model#2	Model# 3	Model# 4	Model# 5
Multi-agent Approach	**1 502 191 $**	**1 489 087 $**	**1 479 411 $**	**1 469 174 $**	**1 462 620 $**
Simulated annealing	1 514 589 $	1 499 607 $	1 491 662 $	1 487 892 $	1 485 603 $

Tables 2 and 3 compare the differences between gap models of flexibility. For both methods of resolution, the gap between two distinct models is calculated using the formula:

$$\frac{(\text{Solution of the model in column} - \text{Solution of the model in line})}{\text{Solution of the model in line}}.$$

TABLE 2 COMPARISON OF COST MODELS FLEXIBILITY FOR MAS APPROACH

	Model# 1	Model# 2	Model# 3	Model# 4	Model# 5
Model# 1	_	- 0,9 %	- 1,5 %	- 2,2 %	- 2,6 %
Model# 2		_	- 0,6 %	- 1,3 %	-1,8 %
Model# 3			_	- 0,7 %	- 1,1 %
Model# 4				_	- 0,4 %
Model# 5					_

TABLE 3 COMPARISON OF COST MODELS FOR FLEXIBLE SIMULATED ANNEALING

	Model# 1	Model# 2	Model# 3	Model# 4	Model# 5
Model# 1	_	- 1 %	- 1,5 %	- 1,8 %	- 1,9 %
Model# 2		_	- 0,5 %	- 0,8 %	- 0,9 %
Model# 3			_	- 0,3 %	- 0,4 %
Model# 4				_	- 0,2 %
Model# 5					_

We note that in terms of the gap between the first three models, the two resolution approaches lead to similar results. Conversely, for the most flexible models 4 and 5, the gaps obtained by the MAS approach are almost twice bigger than those of simulated annealing.

Regarding the flexibility's impact on the staff scheduling and rescheduling cost, these two resolution approaches have interesting results. They demonstrated that the adoption of the concept of flexibility can generate significant gains. Indeed, the

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main result is that the cost reduction is at least equal to -0.9% between the use of the conventional work shift of 9 hours of work, without any flexibility on starting the shift (model#1) and of any of the flexibility models proposed. Comparing the Model#1 to Model 5, this cost reduction can reach -1.9% in case of using simulated annealing and -2.6% in the case of MAS approach.

Otherwise, by comparing model 2 respectively, with the models 3 and 4, the results suggest that flexibility on the shift duration may be more interesting than flexibility on shift 'periods start up'. Indeed, going from model 2 to 3 (startup of work shift every 2 hours vs. all hours), cost reduction is about -0.5% to - 0.6%, while going from model 2 to 4 (duration shift set at 4, 5, 7 and 9h vs only a limit of minimal presence of employees equal to 4h), cost reduces from about -0.8% to - 1.3%.

From a human resources management stand point, these results confirm the relevance and interest of the notion of flexibility in the personnel scheduling processes. However, it is essential that any strategy of flexibility should take into consideration the specificities related to the nature of the company's activity and also to the situations, availability and preferences of employees. Adopting much flexibility by the employer can cause adverse effects, for example, scheduling frequently irregular hours for employees, or bringing some employees to work less than others. Those effects increase the risk that the working lives of employees encroach on their family time. In practice, the implementation of a flexibility strategy in certain activity sectors can be a difficult task, that requires the adaptation of the business organization to this new situation, and sometimes requires new investments related for example to employees transport when working at late hours of the day.

Fig. 3 illustrates the evolution of the difference between the cumulative costs obtained by the two approaches for each flexibility model. At each work shift(s) the gap between the two approaches is calculated through the cumulated deviation CDs, between the best solutions founded by these two approaches for a computerized time equal to 10 minutes for scheduling and 3 minutes if rescheduling is required.

$$\text{CDs} = \frac{\text{MAS cumulated cost at (s)} - \text{SA cumulated cost at (s)}}{\text{SA cumulated cost at (s)}}.$$

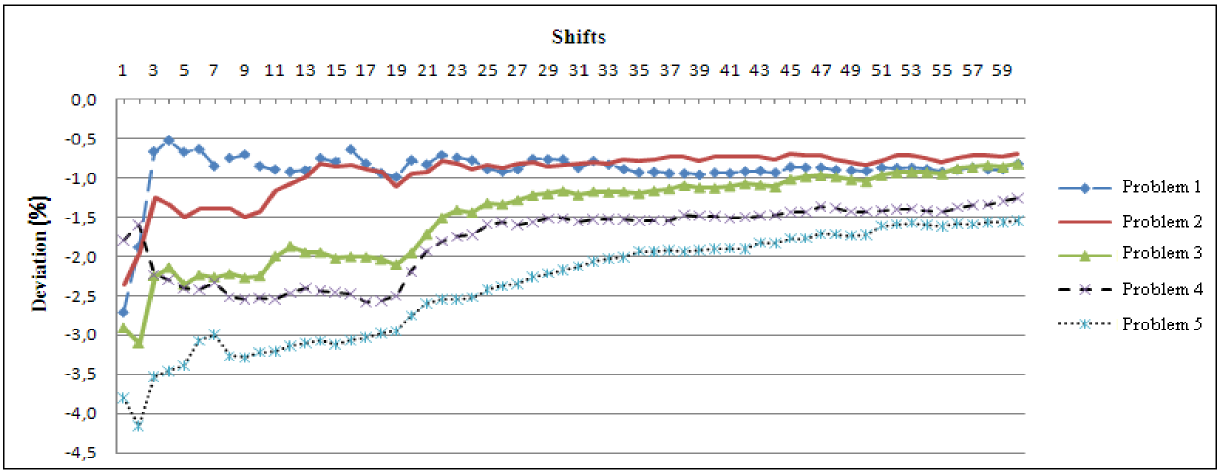

Fig. 3 Deviation between MAS and SA results

We easily observe that the results confirm the good performance of the approach based agents in comparison with the simulated annealing approach. The best performance is obtained in more flexible schedules model (model 5). In this case, the results indicate a difference of -1.6%. The lower difference is recorded in model 2. This difference is equal to -0.7%.

On the basis of these results, it is pertinent to note that even if the values of differences between the two approaches to solving or appear insignificant in relative percentage terms, their absolute values may be significant. For example, for an average company with 200 employees, weekly payroll staff can reach \$ 180,000 = (200 employees) × (5 days / employee) × (9 hours / day) × (\$ 20 / hour) .In this case, an average savings of 1% through the use of the MAS approach represents \$ 1,800 per week which means a savings of \$ 93,600 per year. If we add to this amount an average saving of 2% due to the introduction of a flexible policy management of working hours, we get a total of about \$280,800 per year. In our view, this represents a substantial savings that can be allocated to different uses, notably, training employees and improving their work environment. In this perspective, one way is to pay special attention to the consideration of the preferences of employees in the scheduling process. In order to assess the impact of such an approach, we analyze the influence of the inclusion of employee preferences on the total cost of staff scheduling in the following section.

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IV. ANALYSIS OF THE IMPACT OF PREFERENCES

In this section, we will focus on evaluating the impact of taking into account employees' preferences on the cost of the scheduling and rescheduling staff solution. Several studies have emphasized the importance and positive impact of employees' satisfaction and measures that improve their productivities' quality at work) [17-20]. In addition, several studies have incorporated dimensions related to employees' preferences in the process of solving the problem of personnel scheduling) [21-26].The most frequent aspects in the scheduling preferences are related to the shift duration, the number of weekly working hours, the number of consecutive working days, the model of rotation among employees, and resting days. To the best of our knowledge, most related to personnel scheduling studies were limited to the modeling of the problem taking into account aspects of preferences and the search for a better approach to resolution. Any exploitation of the results has been made in the sense of exploring the impact of preferences on the cost of scheduling.

In this article, we incorporated in our simulation modeling three dimensions that express the preferences of employees. Dimensions are included in our model (Sabar et al. 2012) [6]:

1. Employees' preferences regarding to the shift duration. This preference is expressed in terms of desired working hours and organizing their work schedule;
2. Employees' preferences about favorite activities. Each employee expresses a choice whether activity is desired, unwanted or indifferent;
3. Employees' preferences regarding the number of inter-station transfers.

These preferences are modeled in our objective function through penalties and gains at reflect the amplitude of the deviation from the desired values for each employee [6].

To assess the impact of these preferences on the scheduling result, we perform a series of six simulations. In each simulation, we vary the relative weight given to penalties and gains related to the objective function preferences. This approach allows identifying variations of the impact of preferences on the result of scheduling.

For each employee, we consider that the nominal value *p* penalties and gains related to preferences are selected in conjunction with the corresponding cost to its presence at work during a time unit. Table 4 illustrates the different coefficients of correlation chosen for each simulation. Thus, for each of the six simulations, we consider a correlation coefficient C, nominal p-value is calculated through the formula: $p = C \times$ unit cost of attendance. With a coefficient of 0%, the simulation # 1 reflects the consideration of non-scheduling preferences.

TABLE 4 CORRELATION COEFFICIENT VALUES OF PENALTIES AND GAINS RELATED PREFERENCES / COSTS OF ATTENDANCE OF EMPLOYEES

	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6
Correlation coefficient *C*	0%	6,5%	20%	50%	80%	100%

The distribution of the nominal value p between the three preferences is done according to the following scheme:

- Preference activities: a penalty of p / 3 if the employee is assigned to unwanted activities; 0 if it is indifferent; and a gain of - p / 3 if assigned to favorite activities.

- Preference for the work shift duration e: a penalty of p / 3 for each planning period more or less respecting the desired duration by the employee.

- Preference for inter-station transfer: a penalty of p / 3 for each transfer more or less compared to the desired number by the employee.

For the simulations' implementation, we have chosen the same production parameters to those used in the previous section with model #5 as a strategy of flexibility. In addition, we used the approach based on agents as a method of solving the problem of personnel scheduling.

While comparing the simulation results, we focus on two measures of performance:

- The net cost of the solution: means the total cost of employee attendance. It does not include penalties or gains related to preferences.
- Employee preferences: since that simulations have separate ratings for penalties and gains related to preferences, we present the results of three-dimensional preferences reduced to unit cost basis (applied to the solution of each simulation a penalty of $ 1 and a gain of $ -1 for calculating the preferences), and to simplify the interpretation and comparison of results on a common basis for all simulations.

For each of these two measures, we are interested in the relative deviation of the value obtained in the case of the simulation # 1, whose results are considered as the comparative basis for the other five simulations which take into account the employees' preferences. Table 5 presents a synthesis of simulation results.

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TABLE 5 SIMULATIONS RESULTS OF THE PREFERENCES IMPACT ON THE RESULTS OF SCHEDULING

	Correlation coefficient	Objective function ($)	Net-cost ($)	Deviation net-cost	Average Penalty & gain / employee / preference / shift					
					Favorites Activities		Shift Duration		Inter-station transfers	
					PG	Var. %	PG	Var. %	PG	Var. %
Sim1	0%	1 502 845	1 502 845	-	-4,4 $	-	5,48 $	-	2 $	-
Sim 2	6,5%	1 462 620	1 505 016	0,14 %	-24 $	448%	5,43 $	-1%	2 $	0%
Sim 3	20%	1 370 415	1 506 308	0,23 %	-24,5 $	461%	5,43 $	-1%	2 $	0%
Sim 4	50%	1 166 042	1 509 816	0,46 %	-25 $	470%	5,20 $	-5%	2 $	0%
Sim 5	80%	945 510	1 511 413	0,57 %	-25 $	470%	5,07 $	-8%	2 $	0%
Sim 6	100%	812 243	1 517 295	0,96 %	-25 $	470%	4,95 $	-10%	2 $	0%

Note. Sim=Simulation; Var=Variation, PG= Penalty & gain.

We observe that the increase in the relative weight of preferences affects to a lesser extent the net cost of the solution compared with its impact on measures of employee preferences.

Indeed, comparing simulations 1 to 6, we observe a 100% increase in the weight of preferences in the objective function increases of approximately 0.96% the net cost of the scheduling solution, and also improves the allocation of activities and times shift preferred by employees whose value is respectively equal to 470% and 10%.

Furthermore, taking into account the fact that an employee is assigned to a maximum of 32-periods of shift work (Shift-9 hours = 32-periods of work about 15 minutes + 4-periods of 15 min breaks) an average gain of 25 $ / shift due to favorite activities is equivalent to an average allocation of 83% for an employee = 25/32 of his working time to activities they prefer the most. We also note, that a slight increase of 6.5% in weight of preferences allows exponentially increasing employee satisfaction regarding to the activities allocated to them (approximately 448% improvement). Beyond a weight equal to 20%, the rate of improvement for this preference is insignificant.

Moreover, on average penalty related to the number of inter-station employee transfer, we do not observe any change in function of weight change for this preference in the objective function. One possible explanation for this phenomenon is due to the rigid nature of the constraint used into modeling the employees' transfer state. Indeed, the transfer of an employee between two workstations occurs only if the production plan requires such a measure. Constraints related to this aspect do not allow creating an artificial employees' transfer state only to meet their preferences.

V. CONCLUSION

In this article, by using a simulation approach, we investigate the impact of modeling flexibility and employee preferences on the quality of the scheduling solutions obtained. The simulation results have shown that flexibility may lead to a reduction in the staffs' cost allocation. By following the strategy adopted, the reduction ranges from -0.9 to -2.6% compared with a conventional model work shift.

We also sought to determine the impact of taking into account the preferences on the net cost of scheduling. The analysis of simulation results shows that improved employee satisfaction 448% of the activities allocated and 1% of the duration of the shift (simulation 2)increases the cost of scheduling approximately 0.14%.While an improvement of 470% and 10% for the same preferences increases the cost of approximately 0.96%.

From this set of results, we find that the gains from the implementation of the flexibility strategy would compensate the costs piecing consideration the preferences of the employees in the scheduling process. Thus, the combination of these two dimensions of personnel management can best meet the interests of the employer and the employee. Indeed, in one hand, thanks to the flexibility, the company wins in terms of responsiveness and dynamic to adapt and cope with the vagaries of production and market fluctuations, and in the other hand, employees will be more satisfied with their working conditions

Our future research will focus on the impact of dynamic random events, such as product quality issues on the line, and probabilistic operation times potentially depending on the operator's skill level.

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