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The making of robust schedules: Strategies to dealing with uncertainties

Laetitia FLAMARD^{1,2}, Adelaide NASCIMENTO¹, Pierre FALZON¹ and Ghislaine TIRILLY²

¹ CRTD, Cnam, Equipe d'ergonomie, 41 rue Gay Lussac, 75005 Paris, France

² SNCF, Agence d'Accompagnement des Managers, SNCF, 2 place aux Etoiles, 93633 La Plaine St Denis, France

Abstract. The abstract should summarize the contents of the paper in short terms, i.e. 150-250 words.

Keywords: Scheduling, Robustness, Management of constraints.

1 Introduction

Scheduling means assigning resources to tasks so as to meet objectives in dynamic unstable environments [1]. It is regarded as a key function in production management [2,3]. Companies use it for leverage to adapt to business competition and to the requirements of their ever more demanding customers [2].

Empirical research has characterised scheduling activities as a continuous management of constraints [4,5]. These constraints arise at both strategic levels, which define objectives, and operational levels, which reflect the current state of production [6]. Iterative reschedulings are needed in order to cope with the dynamic context of production [4].

In particular, we are interested in staff scheduling, i.e. the assignment of human resources to tasks during given periods of work [7,8]. Staff scheduling is particularly important when the need for human resources varies over a working day in order to satisfy the demand for production of goods or services [7, 9]. Its output is the work schedules of the employees and determines part of their working conditions. Many studies underline the importance of taking into account social criteria such as the characteristics and preferences of operators [7, 10]. However, this work remains most often underpinned by a managerial vision of work according to which resources must be made profitable [11].

Given the complexity of scheduling situations, this function is often distributed among several schedulers according to the time horizon and the service they are in charge of [5, 12].

The multiplicity of actors involved in scheduling, together with complex production objectives, can in some cases lead constraints to conflict [4, 13]. To deal with such

situations, schedulers endeavour to make sure their scheduling is robust. Drawing from Billaut, Moukrim and Sanlaville [14], we will use the term robustness for describing the complete process by which scheduling is constructed in the presence of uncertainties. Robustness is understood as the ability of a system to resist to uncertainties [15].

The term can take on several different meanings according to how the scheduling activity is modelled [16]. Taking a static approach, robustness equates to stability, i.e. scheduling is considered robust if it stays constant despite changes in the production environment [16]. In this approach, rescheduling is considered as degrading robustness. Conversely, in a dynamic approach, rescheduling is necessary to pursue the design of production plans in acceptable conditions. Here the term robustness is often associated with flexibility, i.e. schedulers have some freedom to adapt production plans, while maintaining a level of performance near or equivalent to that of the initial scheduling [17]. In this case the solutions adopted by the schedulers are robust if they successfully deal with uncertainty and perturbations while ensuring set objectives are met [15, 16].

Nevertheless, the taking into account of a single criterion of robustness seems to be reductive in view of the dynamic environment in which the scheduling process is designed. Currently, we know of no work suggesting that in a context of dynamic scheduling, the criteria of robustness change as the scheduling advances. Thus, concerns relating to robustness are often limited to production issues and the analysis of scheduling activities does not highlight the specificities relating to human resources management.

A research was conducted in the French public rail transport service and more particularly in the scheduling unit responsible for workers allocation in sales units. The aim of this communication presents schedulers' strategies to ensure robustness of staff scheduling in order to avoid vacancies in order to propose the conditions to support schedulers' activity whose objective is to design robust schedules.

2 Method

2.1 Context

This research was conducted, in the French public rail transport service (Groupe Public Ferroviaire, GPF), France's sole passenger rail transport operator until 2019. Specifically, it took place in a production sales unit responsible for service provision to customers at 17 different high-street counters staffed by a pool of 130 commercial agents.

A request to address this problem was made by the manager of the in order to analyse the organization of planning, i.e the staff scheduling, with regard to the recurrent occurrence of "unstaffed positions", i.e. sales positions that were not open to customers, because no commercial agent could be assigned to them. This was adversely affecting both the performance of the unit (loss of turnover, customer dissatisfaction) and the health of the agents and their managers (e.g. high absenteeism).

2.2 The scheduling process

The scheduling process concerns the assignment of commercial agents to work shifts at sales points to ensure planned service production. Inside this unit, three levels of management could be considered as schedulers insofar as they assigned resources to positions at different times and with different scope:

- Strategic level. The three senior managers made decisions based on yearly trends in human and physical resources and needs;
- Tactical level. The two controllers oversaw the organisation of the resources to meet the production objectives set for each sales counter;
- Operational level. The operational managers were in charge of managing the assignment of resources over smaller geographical areas on the actual day the service was offered.

Figure 1 shows the scheduling support by the different scheduler levels

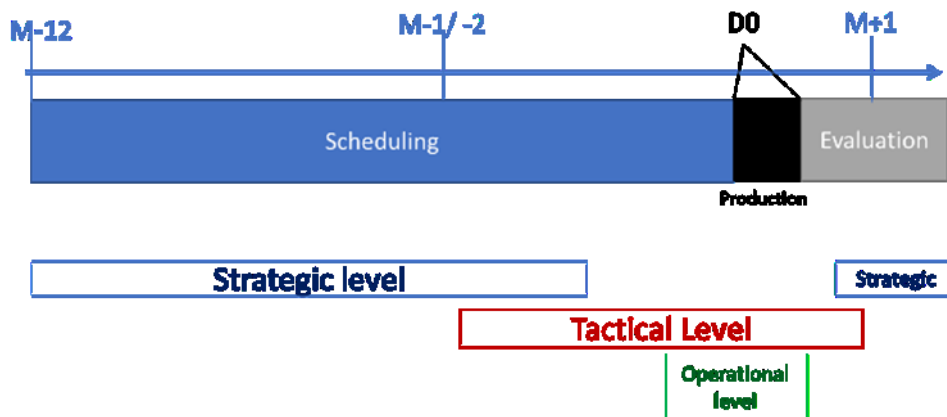


Fig.1. Course of scheduling activity by management level involved

In this article, we are interested in the schedulers at the tactical level, who are in charge of reducing the number of unstaffed positions on a daily basis by rescheduling production plans, in particular to respond to the specific context of labour relations. This management level comprised two schedulers:

- *Agent I* had worked as a scheduler for 10 years, and in this unit for 5 years. He had previously been a commercial agent.
- *Agent P* had been employed for 1 month at the time the observations were made. He had no other prior experience as a scheduler but had worked in the company as a human resources records manager.

2.3 Data collection and analysis

The method we used was ergonomic on-site analysis, with observation of the activity deployed by the schedulers at the tactical level.

First, open observation sessions totalling 8 h were performed between July and September 2015 on two schedulers in order to understand their role and their positioning with respect to the actors at other levels who were involved in scheduling. These observations also served to build a systematic observation grid for which we drew on the framework proposed by MacCarthy et al. (2001). The production environment was taken into account by recording the characteristics of the human and physical resources. The distribution of tasks among schedulers and how they saw their work were also integrated into our analysis.

Second, six periods of systematic on-site observation were performed between October and December 2015. These enabled us to cover all the variability of the scheduling process, and to take into account time constraints in the analysis. The verbal protocol method was used (Hoc & Leplat, 1983). This consisted in asking the schedulers to describe their activity out loud while performing it. If actions were not explicitly described, the researcher asked the scheduler for more details.

The data were processed from notes taken on the collection grid. We defined a ‘scheduling problem’ as a situation when scheduling has to be modified to integrate a new constraint. All the scheduling problems were transcribed into an Excel spreadsheet for analysis using a set method devised by the researcher.

Each scheduling problem was characterised by the following:

- How much time the schedulers had to deal with the scheduling problem. This time was calculated as the interval between the day the production plan concerned by the scheduling plan was to be executed, and the day of observation;
- The management time needed to deal with the scheduling problem;
- Characteristics of the new constraint introduced, according to two criteria (with subcriteria) drawn from Crawford & Wiers (2011) and Chevalier & Cegarra (2008): the origin of the new constraint (i.e. how it came to enter the design planning process) and the nature of the new constraint which refers to the dimensions of production;
 - The results of the action taken to deal with the scheduling problem.

3 Results

In the first part of the results, we will identify the diversity of constraints faced by tactical-level schedulers and then analyse the strategies they put in place to deal with them.

3.1 A permanent management of constraints

In all, 150 scheduling problems were identified (99 for Agent I and 51 for Agent P). The table 1 presents the characteristics of the constraints that generated the 150 scheduling problems, according to their origin and nature.

Origin \ Nature	Nature		Total
	Human	Operational	
Prescribed	38	29	67
Unforeseen	38	1	39
Constructed	5	8	13
Deduced	12	19	31
Total	93	57	150

Table 1. Characteristics of constraints generating scheduling problems by nature and origin.

Concerning the nature of the constraint, two thirds of the introduced constraints were related to human dimensions and one third to operational dimensions. Constraints of different natures had to be met throughout the design process. By contrast, on the day the production plans were executed, only constraints of a human nature were integrated. Figure 2 presents the proportion of constraints introduced in the scheduling according to their nature and time of occurrence.

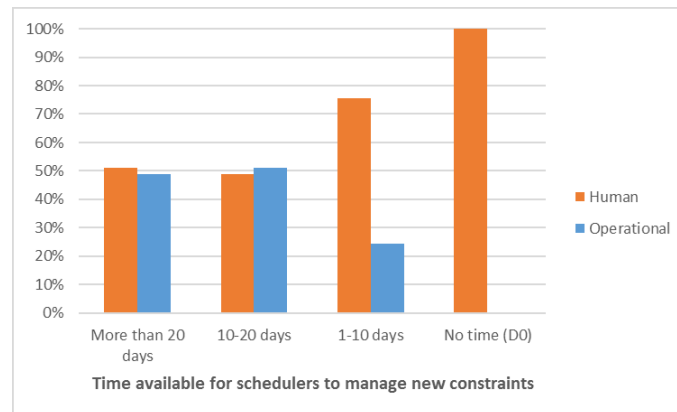


Fig.2. Nature of the constraints introduced according to the advancement of scheduling

Throughout the design process, schedulers have to articulate the different dimensions of production.

Concerning the origin of the constraint, the new constraints, i.e. those causing the scheduling problem, were introduced in different ways during the design stage. They broke down as follows: 13 constructed, 31 deduced, 39 unforeseen, and 67 prescribed. Figure 2 shows the proportion of constraints managed by schedulers according to their origin and time of occurrence.

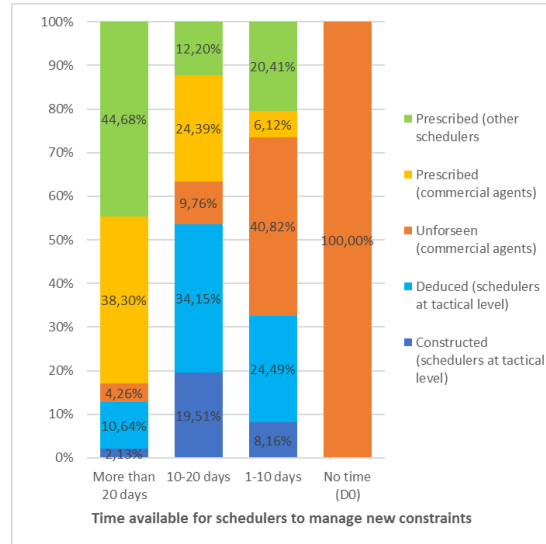


Fig. 2. Origin of the constraints introduced according to the advancement of scheduling

The prescribed constraints are formulated as often by the strategic schedulers as by the commercial agents and they are introduced at the beginning of design. As design progresses, it can be seen that schedulers themselves introduce a large number of constraints, qualified as deduced or constructed, on the basis of their knowledge of the scheduling process and commercial agents, or on the basis of the partial evaluations they carry out during the design phase. At the end of the design, disturbances occur and lead to the introduction of unforeseen constraints, which underlines the particularly unstable nature of production at this design stage. In total, 1/3 of the constraints managed by the schedulers were qualified as unforeseen.

3.2 Dynamic management of constraints to build scheduling robustness

The way in which the problems of scheduling are managed evolved with design progress and the type of constraints that schedulers must manage. The implementation of these different strategies leads to the dynamic construction of robustness which takes different forms and concerns several temporalities.

At the start of the design process by tactical schedulers

In meeting the prescribed constraints of an operational nature that were formulated, the schedulers took into account the human dimension by endeavouring to allow for the life-work balance of the commercial agents. In addition, the schedulers accepted some adaptations requested by commercial agents, i.e. constraints of a human nature. These decisions might oblige schedulers to arbitrate preventively between these constraints and those of an operational nature. The following example shows how Agent P opted to assign a mobile agent who had no position on Monday afternoon after a rest period : *“There, as I’ve got the choice, I’m going to let him start on Monday at 1:30 pm. That*

way he'll have a week-end of two and a half days" (Agent P). This strategy enables the schedulers to reduce the uncertainty in the availability of the commercial agents. In the present context of labour unrest, if the commercial agents were satisfied with their assignments, there would be less risk of them being absent from work. Schedulers seek to build so-called "immediate robustness" through stable decisions that they will not reschedule.

Despite such adjustments, schedulers did not meet all the human constraints that were formulated. They also implement strategies of less compromise, i.e. they arbitrated preventively in favour of constraints of an operational nature. Five constraints of a human nature were not met, and the schedulers postponed the treatment of two others. In the following example, the scheduler chooses to postpone the management of this constraint when he will have more information on the progress of the design: *"In theory I can grant him his two weekends. For now I have some slack, but you never know, if it gets complicated I might need it. I'll put that aside, we'll see how it goes"* (Agent P). Indeed, if he makes the decision immediately he may not be able to manage future constraints. With this type of strategy, schedulers seek to maintain flexibility and maintain robustness until the implementation of schedules, in other words to build a "delayed robustness".

Using forward planning to maintain scheduling robustness

As the design of production advanced, the schedulers also looked ahead, i.e. they foresaw that changes would occur in the data they had to design the scheduling. Schedulers perform a diagnostic-prognostic activity. This forward planning resulted in the schedulers formulating 26 deduced constraints and 12 constructed constraints between 1 and 20 days before execution of the production plans. Integrating the resulting constraints compelled the schedulers to partially reschedule the production plans. To deal with these scheduling problems, they had to create extra leeway. In the following example, the scheduler rescheduled to anticipate the possible unavailability of one of the commercial agents: *"So why am I bringing in Myriam as an extra? I know very well that Catherine [a commercial agent] is going to want a day off for union work, so when I can, I put her on as an extra and look for someone else."* (Agent I).

When the decisions arising from their forward planning were 'efficient', it was when they had the necessary leeway to make them. The management of this type of constraint thus resulted in the new constraint being met without generating any unstaffed positions. Following the anticipation made by the scheduler in the previous example, he avoided the occurrence of an unstaffed position: *"Catherine's just got time off for union work. Since I planned for it, all I have to do now is validate what I planned to allow for her change."* (Agent I).

Overall, the management of 15 out of the 39 unforeseen constraints generated no unstaffed positions because the schedulers had anticipated the evolution of the production environment. This type of strategy allows schedulers to stabilize their decision and maintain robustness for the end of the design, i.e. build a "deferred robustness".

At the same time, schedulers implement mutually beneficial strategies, i.e. schedulers make the choice to satisfy additional requests from sales agents (e.g. a change of schedule or the agent for a day off) in exchange for additional opportunities, which they used to manage situations in which unstaffed positions might be generated. In the example below, after the scheduler had agreed to modify a commercial agent's assignment to meet a family commitment, he wanted to modify another of his assignments to prevent a position becoming unstaffed: *"As the other day I agreed to change him so he could start later, now I'm going to call him to see if he'll agree to do this shift. That way I can be sure to open the counter on Friday."* (Agent I). At the same time, this type of decision allows schedulers to gain flexibility in designing future schedules, which we have identified as building "sustainable robustness".

Making considered sacrifices to limit the degradation of scheduling robustness

A few days before the implementation of production plans, the schedulers managed unforeseen constraints that had not been anticipated. However, given the narrow leeway the schedulers had, and the large number of unforeseen events that could arise, they could not always avoid unstaffed positions. To limit the ensuing adverse effects, they had to consider which commercial and economic activity they wanted to maintain, and which they were ready to sacrifice. This meant arbitrating between constraints of an operational nature.

To make this choice, several criteria were taken into account by the controllers, such as hours and 'sales potential' estimated as a function of turnover and expected customer flows. Each of these criteria was weighed according to the situation to be managed. In the following example, the scheduler took into account both the 'sales potential' of the counter and the shift times of the unstaffed positions : *"So I've unstaffed a position, that is I've taken off a commercial agent who was an extra at the station – on a Saturday it's like unstaffed a position – so as to let the agent have the weekend and put him on a shift Monday. I use him on the opening shift at the station. I had to cover him. But they'll be one agent short on the closing shift though, because I had to staff the position at B5."* (Agent I).

Although some of the decisions made by the schedulers generated unstaffed positions, arbitration let them choose which position would be unstaffed, i.e. where. The aim was both to limit the adverse impact on the health of the commercial agents and ensure that positions were staffed at specific counters.

At the end of the design process, schedulers may not have enough leeway to arbitrate responsively. In all, 17 scheduling problems led to this type of situation. They were characterised by the advent of unforeseen constraints of a human nature some days before or on the day when production plans were to be executed. Thus about half of all the unforeseen constraints could not be managed by the schedulers.

4 Discussion- Conclusion

Results confirm that schedulers have to manage a multitude of dynamic constraints [4,5] that correspond to the needs of the company, the operators and the schedulers.

Schedulers adapt their strategies according to the diversity of the constraints they have to manage, in particular time-related ones, and to the production's context. The strategies employed by the schedulers make it possible to integrate the human and social dimension into scheduling choices. Schedulers take operators' preferences into account, negotiate with them, and foresee what may happen. They attempt to anticipate disturbances that may arise in this uncertain context. The implementation of these strategies leads the schedulers to carry out numerous rescheduling, which confirms previous findings [4,5].

Our results allow us to provide elements to define robustness in the field of personnel scheduling. Unlike other works [14,15,16,17], our results show that the robustness is multidimensional. The analysis of the strategies implemented by schedulers shows that the robust contract of scheduling takes different forms, depending on each other. Schedulers seek both to build stable solutions that they won't go back on, while making some flexible decisions to be able to re-order until the day the schedules are implemented.

In addition, robustness concerns relate to several temporalities. Schedulers seek both to build:

- An "immediate robustness" linked to progress at time t of scheduling
- A "deferred robustness", i.e. the schedulers are already building up resources so that scheduling remains robust until they are implemented.
- A "durable robustness", i.e. the schedulers build up potential resources for the design of future schedules.

Despite these strategies, some vacancies remain due to a failure to maintain robustness at the end of the scheduling's process. These results lead us to focus on the conditions, especially collective conditions of the robustness' construction to dealing with uncertainties. From shared knowledge of the production management process, and discussion of the various underlying rationales, the unit's actors would be better able to adjust their organisational practice to reduce dysfunction due to unstaffed positions.

Moreover, given the number of constraints formulated by the executors of the plans, especially at the end of their design, their involvement in the scheduling process should not be overlooked. Indeed, both schedules have consequences on the way operators perceive the quality of their working conditions, and the constraints formulated by the operators have effects on the quality of the schedules designed.

In order to reduce uncovered positions, the organization should therefore also recognize operators as the designer of their own schedules. Meeting schedulers and operators would contribute to "organizational work" [18] aimed at re-engineering scheduling rules to satisfy all stakeholders.

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