Coordination in planning and scheduling
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5. Coordination modes and task interdependence

This chapter discusses the influence of organizational and behavioral variables on coordination between planners during plan adaptation. Fast communication and mutual alignment are necessary to maintain schedule feasibility in a situation with several schedulers. Therefore, coordination modes are required that facilitate communication and joint problem solving. Moreover, building upon interdependence theory, we hypothesize that the schedulers’ perceptions of task interdependence have an influence on rescheduling performance. Experimental results indicate that a group decision-making coordination mode enforcing cooperation outperforms a distributed decision-making coordination mode involving emergent alignment. The level of perceived task interdependence provides an explanation for this better performance. Therefore, perceptions of task interdependence are put forward as an important behavioral factor influencing rescheduling performance, having several important implications for theory and practice.9

5.1 Introduction

Over the past decades, the organizational design of coordination as an instrument to manage interdependencies between decision makers has been studied extensively (Thompson 1967; Van de Ven et al. 1976; Crowston 1997; Olson et al. 2001; Albino et al. 2002; Molleman and Slomp 2006). However, the traditional approach of developing coordination structures based upon an analysis of predictable and stable interdependencies appears to have limited applicability within organizations operating in a high-velocity environment (Crossan et al. 2005; Faraj and Xiao 2006; McPherson and White 2006). The variety and unpredictability of the many events within this environment cause a high variety in type and criticality of interdependencies. Conditions of high uncertainty and fast decision making challenge the assumption in much interdependence and coordination theories “that the environment is predictable enough to characterize existing interdependencies and that predefined mechanisms can be designed for various contingencies” (Faraj and Xiao 2006: 1156).

This type of high-velocity environment characterizes many rescheduling situations (Vieira et al. 2003; Pinedo 2008). Rescheduling has been defined as “the process of updating an existing schedule in response to unexpected disruptions” (Herrmann 2006: 137). Disruptions like machine failures, material shortages, order changes, and operator absence can cause

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9 This chapter is based on: De Snoo and Van Wezel (2011a). Coordination and task interdependence during schedule adaptation. Submitted for publication. Earlier versions have been presented during the POMS-2008 conference in La Jolla, USA and the HOPS-2008 conference in Lausanne, Switzerland (De Snoo and Van Wezel 2008a; De Snoo and Van Wezel 2008b).
schedule infeasibilities that often need a quick response. Moreover, these events frequently require adaptation of not only a single schedule, but rescheduling of several interrelated schedules, because, due to the interdependencies between schedules, a change in one schedule can easily affect other schedules (Koh et al. 2002; Aytug et al. 2005). When multiple schedulers develop these schedules, efficient coordination is crucial to enable rescheduling on time. Coordination modes determine the possibilities for coordination between interdependent decision makers (Van de Ven et al. 1976). Regarding rescheduling, the coordination mode should comply with the coordination needs of the schedulers. It should allow the schedulers to manage the variety of interdependencies to keep all schedules feasible and optimal.

High rescheduling performance can only be realized if the adapted schedules are mutually aligned. Interdependence theory states that people’s commitment to mutual alignment activities varies according to their perceptions of task interdependence (Wageman 1995; Van der Vegt and Janssen 2003; Bachrach et al. 2006b). In rescheduling, this means that the schedulers’ perceptions of their dependence on each other will influence their coordination behavior. Consequently, both coordination mode and perceptions of interdependence will influence rescheduling performance.

The possibilities and contingencies regarding the organizational design of coordination between schedulers are hardly discussed in literature. In a review of scheduling studies, Kouvelis et al. (2005) concluded that much scheduling research is focused on models that “overlook the complexity, uncertainty and involvement of intelligent agents as well as other realistic attributes of the environments that industrial schedulers and production managers routinely face” (p. 462). McKay et al. (2002) remarked that “there is much more to be done to understand the issues and the impact of task design on schedule quality” (p. 256). This study contributes to this call by investigating the relation between coordination modes, human perceptions of interdependence, and rescheduling performance. Drawing on coordination and interdependence theories, we generated hypotheses about the linkages between these variables; hypotheses were tested by means of a controlled experiment simulating a typical rescheduling environment involving multiple interdependent schedulers.

The chapter continues with a further elaboration on the need for coordination in rescheduling in the next section. We discuss interdependence theory and state our hypotheses. We describe the experimental method used and the experimental results, followed by a discussion on the main findings. The chapter ends with discussing several theoretical and managerial implications, and suggesting opportunities for future research.
5.2 Theory development and hypotheses

5.2.1 The need for coordination in rescheduling

Scheduling situations are often too complex to be dealt with by just one scheduler. The overall scheduling task is then broken down into several smaller scheduling tasks that are executed by different schedulers (Kreipl and Pinedo 2004; McPherson and White 2006). Departments, time buckets, and product families are often used as decomposition criteria (Vollmann et al. 2005; Pinedo 2008). For example, the scheduling of production orders may be done per production department: each department has a scheduler who is responsible for the scheduling activities for that department only. Clearly, the various production schedules are related: orders will be worked on in several departments and appear on multiple schedules. Thus, the decomposition results in interdependencies between human schedulers (McKay and Wiers 2006). Empirical studies describing the practice of scheduling show that the scheduling process encompasses a variety of activities to handle these interdependencies, like communication, negotiation, and lateral coordination (MacCarthy and Wilson 2001; Jackson et al. 2004; Berglund and Karltn 2007).

During scheduling, that is during the initial construction of the schedule, interdependencies can be managed by means of simple rules and agreements; the different schedulers for instance develop their schedules sequentially. In case of problems, there is sufficient time available for schedule adaptation, feedback, communication, and coordination. The organizational design of coordination modes can be based upon an analysis of predictable and stable interdependencies.

During rescheduling, the situation is quite different. Schedules are released to the operators and are being executed. Events disrupt schedule feasibility and often need a quick response. Generally, it is uncertain when an event will happen and what its impact will be on one or multiple scheduled operations and resources. Complete rescheduling is usually impossible because of time constraints or undesirable because it results in nervousness on the shop floor. Therefore, schedules are normally adapted partially (Vieira et al. 2003; Aytug et al. 2005; Subramaniam et al. 2005). Nevertheless, changing one schedule could easily require a modification to another schedule. For instance, alternative sequencing of operations in one department could be a prerequisite to solve a material shortage problem within someone else’s schedule. To find solutions quickly, communication and deliberation between the schedulers are needed (Van Wezel et al. 2006b). Consequently, the organizational design of coordination structures for rescheduling will differ from the coordination design for scheduling, due to the
different situation characteristics. Because in rescheduling, the schedules are already released and being executed, and solutions have to be found quickly, appropriate task division and coordination structures for scheduling could be inappropriate for rescheduling. In sum, rescheduling poses specific requirements on the task design of the schedulers, especially regarding the design of coordination modes to manage task interdependencies.

5.2.2 Task interdependence and performance

Interdependence theory deals with the relationships between work units, describing the extent that one’s actions are dependent on actions of others and/or influence actions of others (Thompson 1967; Van de Ven et al. 1976; Molleman and Slomp 2006). Dependencies are dictated by technological, environmental, organizational, and interpersonal aspects and are specified by the division and assignment of tasks (Victor and Blackburn 1983). Humans are “task interdependent when they must share materials, information, or expertise in order to achieve a desired output or performance” (Van der Vegt and Van de Vliert 2002: 51). A common categorization of types of interdependencies is the distinction between pooled, sequential, and reciprocal interdependencies (Thompson 1967). The task complexity, the distribution of resources, and the instructions about how to carry out the work all influence the type and level of task interdependence (Kiggundu 1981; Wageman 2001; Van der Vegt and Van de Vliert 2002). In rescheduling, task interdependencies are caused by events that require actions by multiple individuals. The impact of an event on the task performance of the schedulers, and its impact on the type and level of the task interdependencies between them depend on many factors, like the event characteristics, the time available to respond, and the possibilities for rescheduling. Determining the type and level of all these task interdependencies in such high-velocity environments is almost impossible, and the traditional way of designing coordination modes based upon an analysis of these interdependencies does not fit (Faraj and Xiao 2006). However, we suggest an alternative way to approach the coordination problem for such situations. Several studies have shown that perceptions of task interdependence influence human performance in decision alignment (Bishop and Scott 2000; Wageman 2001; Van der Vegt and Janssen 2003; Bendoly et al. 2008). Perceived task interdependence (PTI) is “the extent to which employees perceive that their tasks depend on interaction with others and on others’ tasks being completed” (Bishop and Scott 2000: 440). For instance, social interdependence theory argues that group members are motivated to cooperate with each other when they perceive such interdependence
(Johnson and Johnson 2003). Therefore, PTI could be an important variable to be taken into account during task and coordination design.

From these theories, it can be expected that the level of PTI experienced by schedulers influences their willingness to coordinate with each other. A higher level of PTI will result in more efforts in coordination to enable efficient rescheduling. The result of this coordination becomes visible in the quality of the adapted schedules, because they show the level of optimal alignment between all (re)scheduling decisions. Consequently, a possible explanation for performance differences is related to the level of task interdependence as perceived by the interdependent schedulers.

5.2.3 Research model and hypotheses

Because of the necessity for efficient coordination between schedulers during rescheduling, a better understanding of the role of coordination modes in rescheduling is needed. Further, the difficulty to design generally appropriate coordination modes in rescheduling, due to the many variable task interdependencies between the schedulers, calls for a better understanding of perceived task interdependencies to investigate their probable role in explaining the relation between coordination modes and rescheduling performance. Therefore, we aim to provide insights into the usability of coordination modes in rescheduling and into the explanatory role of PTI in determining rescheduling performance.

Decision-making theories roughly propose two alternative modes of coordination between interdependent decision makers: distributed decision-making (DDM) and group decision-making (GDM) (Kleindorfer et al. 1993; Schmidt et al. 2001; Schneeweiss 2003; Brodbeck et al. 2007). Whereas in GDM the problem is to achieve consensus among members of a group who are all capable of understanding the problem as a whole, in DDM the problem is to coordinate the efforts of humans that have limited models of the overall problem, and who may never achieve a global understanding of it (Brehmer 1991). In GDM, all decisions are taken jointly: group consensus is a prerequisite for all decision making, whereas in DDM such consensus is not necessary, decisions are be taken by individuals or (sub-) groups. Finally, in DDM, group members are dealing with only a sub-set of all problems, whereas in GDM, all group members are treating the full set of problems.

The distinction between DDM and GDM provides a structure to design two alternative coordination modes in rescheduling. The DDM coordination mode reflects the situation most common in firms: the overall scheduling problem is split into sub-problems, and each
scheduler is responsible for a part of the overall problem. The schedulers may communicate
with each other to discuss alternative rescheduling solutions. This coordination is not always
necessary; some events can be handled individually. However, although a minor event can
probably be solved individually, this event could also provide room for total schedule
improvement that is only realized via coordination with other schedulers. The schedulers
themselves decide when they communicate with each other and what information they share.

In the GDM coordination mode, schedulers are jointly solving all rescheduling problems.
All information is available, but each scheduler is also expected to process all this
information. Further, joint problem solving requires the efforts of the schedulers to be fully
aligned to reach group consensus about all schedule adaptations. Therefore, the schedulers are
obliged to share all information and to jointly agree upon rescheduling decisions. Figure 5.1
shows the main variables of interest.

Because of the many task interdependencies to be handled in a short time during
rescheduling, we expect GDM to lead to better performance compared to DDM. Therefore,
we hypothesize:

\textit{H1. In rescheduling, a GDM coordination mode leads to better performance than a DDM
coordination mode.}

As discussed before, interdependence theory states that the level of PTI influences humans’
coordination behavior. Therefore, we expect that a higher level of PTI stimulates schedulers
to get all schedules aligned perfectly, resulting into high rescheduling performance.
Consequently, we can hypothesize:

\textit{H2. In rescheduling, performance will be better if schedulers perceive more task
interdependence with each other.}

Third, we expect the level of PTI within a group of interdependent schedulers to be related to
the coordination mode of the group. In the GDM mode, the schedulers are forced to
coordinate their decisions, and therefore, they will perceive higher levels of PTI. Because of

![Diagram showing variables: Coordination Mode, Perceived Task Interdependence, and Rescheduling Performance]
Coordination modes and task interdependence

this, PTI could provide, at least partially, an explanation for the differences in performance between groups of schedulers working in a DDM or a GDM coordination mode. We hypothesize:

\[ H3. \text{In rescheduling, a GDM coordination mode results into a higher PTI than a DDM coordination mode.} \]

5.3 Design of experiment

To investigate the relation between coordination mode, PTI, and rescheduling performance, a controlled experiment has been set up. The main reason for adopting a laboratory experiment is that the setting and environment could be controlled much better than in a field study (Bendoly et al. 2006a). In the scheduling domain, experiments have mainly been used to investigate the tasks and behavior of an individual scheduler (Nakamura and Salvendy 1988; Cegarra and Hoc 2008): coordination between schedulers has not been experimentally studied. Recently, controlled experiments have again been used and promoted for examining the complex interactions between behavioral and organizational variables and operations management questions (Speier et al. 1999; Schmidt et al. 2001; Speier et al. 2003; Croson and Donohue 2006; Bendoly et al. 2006a; Bendoly and Swink 2007; Gino and Pisano 2008; Bearden et al. 2008; Bendoly and Cotteleer 2008; Bendoly et al. 2008; Cantor and Macdonald 2009). In this section, we successively discuss the scheduling assignment that subjects had to perform in the experiment, the operationalization of the variables studied, and the experimental setting.

5.3.1 Scheduling assignment

Within each experimental scenario, a team consisting of three schedulers was jointly responsible for three mutually related job shop schedules. A group size of three is often used in experimental group studies because it provides a sensible compromise between feasibility, complexity, and realism (Olson et al. 2001; West et al. 2003). The scheduling situation could be characterized as a flexible job shop (Pinedo 2008). Each workcenter \((w)\) had a number \((m)\) of identical machines. There were \(n\) jobs and each job passed through a number \((l)\) of workcenters following a predetermined route \((r)\). The participants did not create the schedules but instead received consciously developed suboptimal schedules in the form of Gantt charts (Appendix 5A). The schedules were strongly interconnected: each order consisted of two production sub-orders that had to be produced using one of three possible routings. Processing
times differed per sub-order. Each production department had three identical machines suited to its particular task. Using the formal notation, the experimental scheduling situation could be characterized as follows: \( w = \{\text{sawing, cutting, milling}\}, m = 3, n = 12, l = 2, r = \{\text{sawing-cutting, cutting-milling, or milling-sawing}\}\). Transport times, set-up times, and inventory were not taken into account. Note that the interdependencies within and between the initial schedules were the same for each pair of schedules. Each schedule contained the same number of orders with equal variance in processing times, sequence dependencies between operations related to a single order were equally distributed, and each schedule contained the same amount of slack and redundancy.

Participants were confronted with event information at different points in time (Appendix 5B) and were asked to adapt the schedules based on this event information. Due to the routings of the orders, adaptation of one schedule quickly resulted in infeasibility in another. Subjects had a range of possibilities in changing a plan: schedule an order earlier or later on the same machine, move an order to another machine, and add or remove an order. The schedulers were jointly responsible for the timely delivery of orders and the efficient utilization of machines.

### 5.3.2 Coordination modes

Figure 5.2 shows the two investigated forms of coordination: DDM and GDM. In the DDM coordination mode, the schedulers are physically separated from each other, in our experiment by placing them in different corners of a room facing the wall (Fig. 5.3). They could only view their own schedule but could communicate changes to it to the other schedulers. In the GDM coordination mode, the three schedules were combined and the schedulers were physically located around the same table (Fig 5.4). They were instructed to handle all events jointly and to make all decisions together.

In general, communication within a DDM coordination mode can take place in many different ways, ranging from no communication to intense communication. Because communication possibilities influence the coordination behavior of humans (Olson et al. 2001; West et al. 2003), we decided to prescribe the possibilities and rules for communication strictly. Moreover, we decided to investigate two alternative DDM coordination modes to study the potential influence of this variable: individual distributed decision-making (I-DDM) and cooperative distributed decision-making (C-DDM).
In the I-DDM coordination mode, the schedulers could communicate changes to their schedules by calling aloud another scheduler’s name and the change details. Deliberations with other schedulers about alternative rescheduling decisions were not allowed. In the C-DDM coordination mode, the schedulers were allowed to communicate and deliberate with each other through physical meetings. Cooperation clearly had some costs: the schedulers had to leave their working places and, after deliberations, had to apply the agreed actions to their individual schedules (with a risk of error due to poor recall). The main reason for the distinction between I-DDM and C-DDM was that if differences in performance and PTI-levels between the DDM modes are negligible, we could filter out the effect of communication possibilities within the DDM mode. As a result, our comparison of DDM with GDM would not be hindered by this variable.
5.3.3 Perceived Task Interdependence

As indicated, PTI is the extent to which an individual scheduler believes that he or she depends on fellow-schedulers for being able to carry out his or her task (Bishop and Scott 2000; Wageman 2001; Van der Vegt and Janssen 2003). Within each experimental group, three schedulers were jointly responsible for adapting related job shop schedules. PTI was measured using the construct also used by De Jong et al. (2007). In a post-experiment questionnaire, we asked each subject “How dependent were you on X in order to carry out your task adequately” (answers on a Likert seven-point scale ranging from ‘not dependent’ to ‘fully dependent’). This question was asked twice, with X being replaced by the role of each partner scheduler in turn (e.g., by ‘sawing scheduler’ and ‘milling scheduler’ for the ‘cutting scheduler’). Next, we measured the scheduler’s perception of the level of dependence of these partners on him or her by asking: “How dependent was X on you in order to carry out his or her task adequately.” Again, this question was repeated, with X being replaced by the functions of the two partner schedulers.

5.3.4 Rescheduling performance

The dependent variable rescheduling performance indicates the extent of optimization in the final schedules. It was calculated by summing the costs associated with delivery delays and machine underutilization. For each hour a product was delivered after the due time, a cost of €100 was imposed. Each hour a machine was unnecessarily idle was charged at €75.

5.3.5 Experimental setting

One-hundred forty-four undergraduate business students participated in the experiment for course credit as part of an Operations Management course. Subjects participated in just one experimental scenario to avoid learning effects. Therefore, we collected data from 48 groups each consisting of three subjects. No significant differences across scenarios were found with respect to the average age, prior scheduling experience, and group composition (e.g., with respect to gender or prior collaboration between the group members). Because groups participated one at a time, the researchers were able to observe the coordination activities of the subjects and to control the experiment precisely; for instance, communication behavior that was not allowed could be corrected immediately.

The experiment started with a reading of the detailed assignment text outlining the specific characteristics of the scheduling situation and the rules about communication and
coordination. Subsequently, the participants had to solve a practice rescheduling issue. In this way, their understanding of the scheduling situation and the coordination rules were tested and clarified if necessary. Next, the participants were provided with the start schedules (Appendix 5A) and an order book containing the delivery time targets and processing times per sub-order. The schedules were displayed on a LEGO board with bricks representing the scheduled orders (Fig. 5.5). By moving the bricks, the subjects could adapt the schedules. At fixed points in time, the groups were confronted with written information concerning an event (Appendix 5B). Subjects had twelve minutes to update and improve their schedules. These twelve minutes represented a four-hour period (8 a.m. until 12 noon); a special clock showed the progress of time (Fig. 5.6). In this way, the high-velocity environment of rescheduling situations in reality was simulated. After the experiment, the subjects completed a questionnaire with which we collected some demographic data and measured PTI.

The experimental design was piloted several times with faculty staff and students, resulting in minor adaptations in the assignment and event texts. A final pilot took place with a group from the target sample to check the fit of all material and settings with these subjects.

Figure 5.5 (left) Three schedules for three departments with each a cancelled job
Figure 5.6 (right) Clock time represented with an accelerated railway station clock
5.4 Analysis and results

Of the 144 participants, 62% were male and the average age was 20.4 years. Eighty-five percent of the participants had no experience with this type of rescheduling in practice. Results from six teams were not included in the analysis due to participants ending up with completely infeasible schedules. In most of these groups, one of the three schedulers lost sight of the overall objective and acted illogically (e.g., changing the route of an order, or neglecting event information). Cantor and Macdonald (2009) report a similar percentage of observations that were excluded due to incorrect behavior, misunderstandings, or past experience. In our study, ten other groups ended up with schedules comprising one (small) error, like two processing activities on a single order that were scheduled to be taking place at the same time in different departments. In some of these instances, the cause was a miscommunication between the schedulers; in other cases, a form of scheduling complacency was observed: schedulers thought they had a feasible optimized overall schedule whereas in reality there was still an error in it. The other 32 groups adapted the schedules in such a way that a feasible overall schedule was delivered for their scenario. Total performance in costs of due date violations and machine underutilization ranged from € 0 to € 375. Performance results were classified into three categories: high, moderate, and low performance. A high performance was realized if total costs were below € 100: the final schedules contained at most one hour of machine waiting time. Moderate performance was related to schedules have a total costs of at most € 200 due to machine waiting times and/or due date violations. Low performance was realized if the costs exceeded € 200 or if the final schedules contained one error, execution of these schedules would result in high costs because of their infeasibility.

To investigate statistical differences, the Mann-Whitney University (MWU) test was chosen. This non-parametric test has been applied by several researchers to conduct pair wise comparisons in this type of experiments (Wu and Katok 2006; Croson and Donohue 2006; Cantor and Macdonald 2009). First, differences between the two alternative forms of DDM were considered to investigate the influence of communication possibilities in this coordination mode. The MWU-test shows no significant differences between I-DDM and C-DDM regarding performance ($n_I$ = 14, $n_C$ = 14, $z = -1.29$, $p = .20$) and average PTI per team ($n_I = 14$, $n_C$ = 14, $z = -2.30$, $p = .82$). Therefore, combining the results from I-DDM and C-DDM seemed to be appropriate to investigate the differences between DDM and GDM coordination modes in rescheduling.
5.4.1 Coordination mode

The selection of coordination modes was motivated by decision theories as explained above. Whereas in the GDM mode the subjects were forced to coordinate all decisions, in the DDM mode the subjects were free to allocate the available time to individual activities or coordination with others. To ensure that our manipulations provided appropriate contrasts between both coordination modes, we asked the subjects to indicate how they allocated the available time during the experiment. In the post-experiment questionnaire, the time allocation to the two main activities within rescheduling: problem solving and coordination had to be indicated on a five-point scale (to avoid confusion, we phrased coordination as ‘communication and deliberation’).

Figure 5.7 shows the percentage of participants for each approximate time breakdown between problem solving and communication/deliberation per coordination mode.

![Bar chart showing time allocation per coordination mode](image)

**Figure 5.7** Time allocation per coordination mode (N = 124 individuals from 42 teams)

No subjects spent all of their time on coordination activities, and only one subject indicated to have worked without coordination (this, indeed, resulted in poor performance). Clearly, schedulers working within a group decision-making mode spent more time on communication and deliberation in comparison with schedulers within the distributed decision-making mode. The MWU-test confirms this difference in time allocation between the coordination modes.
statistically \( (n_{DDM} = 82, n_{GDM} = 42, U = 710.0, z = -5.853, p < .001) \). Indeed, DDM and GDM appear to lead to different coordination behavior of schedulers.

### 5.4.2 Coordination mode and performance

A visual inspection of Figure 5.8 provides a visible clue for the main hypothesis that coordination mode does influence performance. This figure shows the portion of groups within a performance category per coordination mode. The Mann-Whitney test confirms that the group decision-making coordination mode outperforms the distributed decision-making coordination mode \( (n_{DDM} = 28, n_{GDM} = 14, z = -1.904, p < .05) \). Therefore, we find support for Hypothesis 1.

![Figure 5.8 Performance per coordination mode (N = 42 groups)](image)

### 5.4.3 Perceived Task Interdependence

Within each team of three schedulers, twelve values relating to PTI were collected: all the three individuals rated their dependence on their two colleagues and that of their colleagues on them. From our 42 groups, we had a total of 42 * 6 = 252 dependency relationships (or ‘dyads’), each assessed by both parties in the relationship. We first examined the consensus between these two perceivers regarding their level of PTI using ANOVA and a correlational approach (cf. De Jong et al., 2007). The one-way analysis of variance with dyad number as predictor and PTI as criterion variable produced a significant outcome \( (F(251,250) = 2.202, p < .001) \), that is, the variability in perceptions between dyads is larger than the variability within dyads. The zero-order correlation between X’s interdependence on partner Y and Y’s perception of X’s PTI on Y was also significant \( (n = 250, r = .376, p < .001) \). These results imply that people have shared perceptions of the task interdependence in a particular
situation. The correlations reveal sufficient similarity to justify the calculation of average PTI levels per group to compare them among the different experimental scenarios. Therefore, a second test considered the similarities in PTI on the group level. First, a group average of the twelve dyad-related PTI-values was calculated. Then, an ANOVA test, using group number as predictor and average PTI as criterion variable, produced a significant result \( F(41,460) = 3.345, p < .001 \). That is, the variability in perceptions of task interdependence between groups is larger than the variability within groups. Table 5.1 shows the mean group PTI-values, standard deviations, and the lowest respectively highest PTI-values for each scenario.

<table>
<thead>
<tr>
<th>Coordination Mode</th>
<th>N</th>
<th>M\textsuperscript{a,b}</th>
<th>SD\textsuperscript{b,c}</th>
<th>Min\textsubscript{gr}\textsuperscript{d}</th>
<th>Max\textsubscript{gr}\textsuperscript{d}</th>
<th>Min\textsubscript{ind}\textsuperscript{d}</th>
<th>Max\textsubscript{ind}\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: DDM</td>
<td>28</td>
<td>4.06</td>
<td>.44</td>
<td>3.25</td>
<td>4.95</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>B: GDM</td>
<td>14</td>
<td>5.22</td>
<td>.73</td>
<td>4.00</td>
<td>6.00</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>All</td>
<td>42</td>
<td>4.45</td>
<td>.77</td>
<td>3.25</td>
<td>6.00</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

\textsuperscript{a} M = average PTI.
\textsuperscript{b} Means and standard deviations are calculated on the group level (the group value being the average of the twelve dyad-related values).
\textsuperscript{c} SD = standard deviation.
\textsuperscript{d} Min\textsubscript{gr} (Max\textsubscript{gr}) shows the lowest (highest) average PTI-value from all groups of three individuals.
Min\textsubscript{ind} (Max\textsubscript{ind}) shows the lowest (highest) PTI-value from all individuals.

5.4.4 PTI and performance

Bivariate correlations between PTI and performance are calculated using Spearman’s \( \rho \) because of the non-normal performance distribution. This test shows that the correlation between PTI and performance is significant \( (\rho = -.268, p < .05) \) indicating that a higher average PTI per team results in lower costs, thus, better performance. Therefore, we also find support for Hypothesis 2.

5.4.5 Coordination mode and PTI

The Mann-Whitney test shows that the average PTI per team of groups working in the GDM coordination mode is higher than the average PTI per team of groups working in the DDM coordination modes \( (n_{DDM} = 28, n_{GDM} = 14, U = 39.0, z = -4.196, p < .001) \). Therefore, we find support for Hypothesis 3. Another remarkable finding relates to the variety in perceptions
of task interdependence between the coordination modes (see Table 5.1). All participants in the GDM coordination mode indicated at least a moderate level of interdependence (a score of at least 3 out of 7). Thus, PTI appears to be higher in group decision-making situations than in those employing distributed decision-making.

5.5 Discussion

The research reported in this chapter has investigated the linkages between organizational and behavioral aspects of coordination design and rescheduling performance. Rescheduling situations are characterized by a high-velocity environment: many diverse events require a quick response. Moreover, rescheduling often requires the adaptation of interrelated decisions in several schedules. Because these adaptations have to be realized quickly, efficient coordination between the schedulers is crucial. Our findings demonstrate the influence of organizational and behavioral variables on coordination performance in several ways.

First, the results indicate that enforced coordination, represented here as a group decision-making structure, facilitates this coordination in a better way than voluntary coordination, represented as a distributed decision-making structure, confirming Hypothesis 1. While scheduling problems are decomposed to deal with complexity, resulting in the allocation of distributed scheduling tasks to several schedulers (Vollmann et al. 2005; McPherson and White 2006), our findings suggest that rescheduling problems can better be solved by grouping the schedulers and by enforced group decision-making. Thus, rescheduling demands for a different organizational design than that is proposed in literature for scheduling.

Second, our results do support the hypothesis that PTI positively influences rescheduling performance: higher levels of PTI result into better performance. This finding is in line with interdependence theory stating that group members are motivated to cooperate when they perceive interdependence (Johnson and Johnson 2003); this theory seems to be valid within rescheduling. Thus, within a high-velocity environment such as rescheduling, performance appears to be dependent on this behavioral variable: perceptions of task interdependence influence a scheduler’s coordination behavior resulting in a higher level of mutual alignment between the rescheduling decisions. Consequently, PTI is a necessary behavioral variable to take into account in the organizational design of rescheduling processes.

Third, our study shows that the level of PTI in a group is dependent on the coordination mode, providing one approach to manipulate the level of PTI in a group of interdependent decision makers. Within GDM, the average PTI is significantly higher than within DDM,
confirming our third hypothesis. A possible explanation relates to the level of consensus that needs to be reached in the two types of decision-making. Within DDM, a lower level of consensus is sufficient, because only agreement on a limited number of decisions is needed, whereas, within GDM, a full consensus has to be reached regarding all rescheduling decisions. This finding is in line with Wageman’s study showing that groups with both individual and group tasks experience lower levels of interdependence than groups with only collective group tasks (Wageman 1995). More important, the perception variable ‘PTI’ appears to be influenced by the organizational design variable ‘coordination mode’. Because of the close link between coordination mode and PTI, and the significant positive relation between PTI and performance, PTI provides an explanation for the performance differences realized within the DDM and GDM coordination mode. High levels of PTI are caused by enforced coordination, but result in better coordination behavior leading to better rescheduling performance. Whereas the current research provides initial evidence for the link between coordination mode, PTI, and performance, further research is encouraged to investigate other determinants of PTI and their effects on rescheduling performance.

5.5.1 Contribution and implications

The study adds to planning and scheduling theory by providing an organizational view on the determinants of rescheduling performance and by discussing alternative coordination structures between schedulers. In this way, the study responds to the call for research that investigates the impact of task design on schedule quality (McKay et al., 2002). Further, the chapter demonstrates the relevance of a behavioral view on task interdependencies between schedulers. In this way, the findings contribute to several recent calls to investigate behavioral variables in decision-making and operations management settings by using multidisciplinary approaches (Bendoly et al. 2006a; Cegarra and Hoc 2008; Gino and Pisano 2008). By showing how perceptions of task interdependence enhance collaborative decision-making, our findings also complement behavioral and organizational literature examining the impact of task interdependence and of perceptions on (group) performance.

For practitioners, the study has several managerial implications. First, during the design of tasks for schedulers, firms should carefully consider the needs and possibilities for coordination between schedulers. Coordination needs differ between the scheduling and rescheduling phase: during rescheduling, coordination modes are necessary that enable quick coordination between schedulers. Our experimental results indicate that enforced group
decision-making is a better alternative compared with voluntary, emergent coordination between the distributed decision makers. Consequently, firms should think about the extent to which coordination behavior of schedulers has to be prescribed, and how this behavior should be facilitated. Finally, our study shows that perceptions of task interdependence play a role in the coordination behavior of schedulers. These perceptions are partly determined by the way the schedulers can coordinate their decisions with each other. Firms should therefore consider mechanisms that influence employee’s perceptions of task interdependence to improve coordination performance.

5.5.2 Limitations and future research

To the best of our knowledge, this is the first experimental study concerning coordination between schedulers. The experimental approach turned out to be a valuable research methodology for investigating both organizational and behavioral factors in a specific, controlled setting. The experimental setting used in this study certainly has an impact on the findings, limiting their generalizability. First, we only investigated a few coordination modes, and we instructed the participants to behave according to specific rules for each coordination mode. Clearly, there are many ways in which coordination between schedulers can take place, and further research is needed to understand the consequences of other coordination modes. Second, the relationship between PTI, coordination behavior, and performance within a rescheduling context needs a better understanding. Our results show that high levels of PTI result in a higher performance. Future research is necessary to confirm this causal relation in a variety of rescheduling contexts in practice. Moreover, alternative mechanisms that influence perceived task interdependence to improve coordination efficiency and performance are to be examined. Finally, in a high-velocity environment, often some tasks are executed individually, but other tasks require intense coordination. As a result, flexible modes of coordination are necessary to enhance both individual and collaborative decision-making. We look forward to future research investigating combinations of coordination modes, both in experimental and field studies.
**APPENDIX 5A:** Start schedules for all participants

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APPENDIX 5B: Events provided to the participants

1. **8:30 a.m.** The sales department has received a request from a potential client to deliver a trial product. If the delivery of this product is achieved on time, the client will likely place important orders in the near future. The management has therefore decided to fulfill this request. Order 13 has to be delivered at the latest at 17:00; the product first requires sawing (processing time 3 hours), and then has to be cut (processing time 3 hours).

2. **8:50 a.m.** The distribution department reports product damage during onward delivery. The product has to be re-milled. Milling is the only processing activity required for this ‘rush order’ (processing time is 2 hours). Order 14 has to be ready by 15:00.

3. **9:40 a.m.** The raw materials for Order 12 do not meet the quality requirements. Therefore, these materials have to be resupplied. Order 12 is therefore postponed; it can be removed from the milling and sawing schedules.

4. **10:10 a.m.** The shop floor notifies that the cutting department does not have the highly specialized skills required for Order 4. The management decides to outsource the cutting activities on Order 4. Order 4 only needs input from the sawing department.

5. **10:40 a.m.** The production manager reports that Sawing Machine 1 requires attention. Maintenance activities will take place between 14:00 and 15:00. No orders can be scheduled on the machine during this hour.

6. **11:20 a.m.** A rush order (Order 15) is received that has to be delivered by 16:00. The product first requires cutting (processing times 2 hours), and then milling (processing time 2 hours).