Modelling Human Aspects of Collaborative Scheduling

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ABSTRACT

When groups are working on joint tasks they need to develop schedules together. The design and deployment of new technologies and the operation of multi-stage supply chains are situations where there are many joint tasks to schedule within and between participating organisations. The scheduling function demands collaboration between groups if activities are to be coordinated efficiently and effectively. Changing events and circumstances give this scheduling collaboration a strong iterative and dynamic flavour because a party responsible for a certain domain must deal with dynamic information relating to other parties’ schedules, resources and limitations. Decision making in such an environment is characterised by dispersed, uncertain, incomplete, and conflicting contextual information which is difficult to represent and apply in computerised decision support systems. Therefore human decision-making remains central to collaborative scheduling. This paper defines a framework for understanding and modelling dynamic and collaborative scheduling processes that span parties distinguished by distinct organisational boundaries. This framework, posited within a socio-technical perspective, is intended to define the salient aspects of the human role in multi-party scheduling processes within which parties cooperate to satisfy both common and individual goals.

Keywords: Collaborative Scheduling, Cooperative Problem-Solving, Cognitive Task Analysis, Human Decision-Making.

1. Introduction

Today’s commercial and industrial environment requires organisations with a diverse range of technical capabilities to work together. Such collective work might happen in geographically distributed locations and involve firms that differ markedly in size and high-level business objectives. The planning and scheduling environment is often characterised by goals, roles, activities, and resources that are dynamically changing, unstated or uncertain. Nevertheless, for mutual benefit the participating organisations should collaborate to coordinate their activities. The key question is how to wisely use collaboration resources to a competitive
advantage (Harvey and Koubek 2000). One of the resources needed for collaborative organisations is human decision-makers whose key role in the scheduling function is to provide dynamic decision-making and apply logical induction to changing or unexpected circumstances. The purpose of this paper is the recognition and modelling of the human aspects and attributes that affect inter-organisational scheduling processes. We begin by examining the role of humans in collaborative and cooperative activities and we concentrate specifically in the inter-organisational scheduling function. From this we present a model for collaborative scheduling and study its components and attributes through a case study of the project-scheduling processes adopted by a Middle-Eastern automobile manufacturer and its technology suppliers. The use of the model as a tool for analysing, evaluating and designing the structure and processes of collaborative systems is then discussed in the context of future research in this field.

2. Humans in Scheduling, Collaboration, and Cooperation

Scheduling is a process that allocates physical resources to activities over time. From a mathematical standpoint, activity scheduling problems of industrial or sub-industrial scales are usually NP-hard (e.g. see Lawler, Lenstra, Rinnooy Kan and Smoys 1993) and thus optimum solutions to these problems are generally elusive. Indeed, in inter-organisational scheduling even the determination of feasible and mutually-acceptable schedules can be a major challenge (e.g. see Kowalczyk, Phiong, Dunstall and Owens 2004). Furthermore, automated scheduling methods, whether heuristic or rule-based, might not produce realistic schedules in environments where contextual information is inadequately represented. Where goals are complex and unstated, and situations are dynamic and uncertain, domain experts can address these issues (McKay, Safayeni and Buzacott, 1988; Higgins and Wirth, 1995; Higgins 1999; Wiers 1997; Sanderson 1989). Under these circumstances, human schedulers bring to the scheduling process their inductive and pattern recognition abilities.

Collaborative scheduling occurs where different organisational units coordinate individual activities for joint benefit. Participants in this process deal with multi-attribute, multi-party, and multi-criteria decision-making and negotiation; in general this environment is characterised by distributed, uncertain, and conflicting contextual information. Typically this complexity can neither be adequately modelled mathematically nor sufficiently captured in information databases. Hence, human schedulers are crucial in collaborative scheduling.

Collaboration is about autonomous stakeholders sharing information, resources, ideas and/or costs and risks for a common purpose. Collaboration is an interactive process that shares rules, norms, and structure, to act or decide on issues of mutual interest (Wood and Gray, 1991). The success of a group formed to coordinate the collaboration process depends upon its members communicating through an understanding each other’s terms and perspectives (Harvey and Koubek, 1998). Coordinating groups generally consist of heterogeneous, cross-functional individuals from a variety of expertises that come together for a common purpose (Chandler 2001). While the members belong to separate entities that have their own tasks, resources and goals, they also participate in a more holistic process as a group, with joint tasks, resources, plans and goals. By cooperating within the group, members aim to improve performance in their own domain. Therefore, key aspects of a collaborative process are communication and common purpose.

Collaborative scheduling is a process of cooperation within a specified organisational structure. The individual activities of persons cooperating are not independent. Hoc (2001) defines cooperation as the management of the interference between individual activities in order to facilitate each member’s sub-tasks and the group’s joint task. According to Hoc, two persons are in a cooperative situation if “(1) each one strives towards goals and can interfere with the other on goals, resources, procedures, etc.” and “(2) Each one tries to manage the
interference to facilitate the individual activities and/or the joint task when it exists.” Hoc classifies cooperative activities into action, plan and meta levels, based on interference management and facilitation. The action level consists of operational cooperative activities that are directly related to goal during task performance. The plan level concerns cooperative activities at a higher abstraction level than the action level. Finally, at the highest level of abstraction are meta operations that include general data useful to the cooperative activities of the two lower levels. Members of the coordinating group are not only responsible for scheduling activities in their own dynamic domain, but they deal also with dynamic information from their collaborators regarding schedules, resources and limitations. They manage interferences between themselves and facilitate the meeting of their own goals, their collaborators’ goals and the coordinating team’s goals.

3. Model of Collaborative Scheduling

A model of collaborative scheduling includes human aspects of cooperation in scheduling. It is a structural representation of the goals, tasks, roles, and resources of each collaborating domain and coordinating group. It includes domain knowledge, group knowledge, group goals, each domain’s goals, group and individual tasks and group decision processes. It identifies information, functions and cooperative abilities required for each level of decision-making. It represents the sharing of contextual information among the collaborative parties and supporting strategies for developing and adjusting schedules.

Members of the coordinating group are responsible for scheduling decisions within their own domain. The heuristics they apply and the performance criteria they deem relevant and appropriate are based on their expertise. Their domain knowledge covers, inter alia, organisational goals, policies and procedures and the capabilities of physical resources. Scheduling activities may range from solely human to automated systems. However, as human decision makers are ultimate responsible for the whole process, they must be within the decision-making loop (see Sanderson, 1989; Hoc 2001).

Group knowledge is common knowledge that is shared by collaborators. Effective communication of knowledge within the group depends upon a common language — distinctive vocabulary — and common knowledge. Common knowledge enables schedulers to improve their own and the team’s performance by pooling cognitive resources. Krauss and Fussell (1990) suggest three mechanisms for common knowledge between individuals: direct knowledge, category membership, and interactional dynamics. The first type concerns personal knowledge that each member maintains about the others. Second type is concerned with the information about each member by its group membership. The last category is the mechanism of acquiring knowledge through communication in dynamic cooperation. Effective communication depends upon ‘mutual understanding’ (Dix, 1994). Whereas Salas, Prince, Baker, and Shrestha (1995) refer to ‘shared situation awareness’. Clark and Brennan (1991) see communication as a process of establishing a ‘common ground,’ which for Harvey and Koubek’s (1998) depends upon a shared ‘vocabulary schema.’ Hoc (2001) addresses the significance of shared competencies to prepare and perform action in groups. He refers to a ‘common frame of reference (COFOR)’ at the core of cooperation. According to his classification, COFOR is constructed in three levels of: action, plan, and meta-level, each comprises a different abstraction level of problem representation, from the most operational to the most abstract. Schedules, organisational information, resources, activities, goals, etc should be represented in appropriate level to be useful to the team members.

Collaborative scheduling requires participants to orient their goals toward the set of common aims that brought them together. It means that common group goals between parties are constructed when participating organisations, with different goals, seek mutual benefit through collaboration. Individual goals influence the common goal. Once group goals are
established, each collaborator has additional roles associated with the collaborative domain. These roles are defined within the context of the collaborative process for meeting the group goals. Each collaborator has a role in collaborative scheduling within the cooperative framework of the group. Two conditions for cooperation, discussed above, are managing interferences between individual activities and the facilitating each other’s goals. Hoc (2001) defines four kinds of interferences between cooperative parties: precondition, interaction, mutual control, and redundancy. To manage interferences, each scheduler has to cooperate with the other collaborators. A key requirement is that individual goals do not depend upon the group’s goal.

The task is the fundamental element that drives groups to seek collaboration in scheduling (Harvey and Koubek 2000). Group tasks are defined in such a way to ensure that group goals are achieved through collaboration. Simultaneously, collaborative schedulers undertake individual tasks for their own domain, derived from both individual and group goals, in relation with the joint group tasks. As the organisational boundaries of the collaborators must be respected, each party is responsible for its own domain. Human schedulers in participating organisations must have ownership of their decisions. Group tasks in collaborative environments can be additive, conjunctive, or disjunctive. Each participant has an assigned group role; a role that is characteristic of — and closely associated with — the group tasks that are defined within the cooperative scheduling structure/process. The relationship between the individual and group domains is shown in Figure 1. A simple example would be two companies collaborating: a manufacturer and a technology supplier. Individual goals of the collaborators affect group goals, as the arcs in Figure 1 indicate. The achievement of group goals requires the formation of a cooperative structure and processes through which specific roles for coordination and group tasks are identified. Meanwhile, group goals and roles influence individual goals and tasks, thereby ensuring that each party’s effort is toward the accomplishment of group task within the assigned role.

A collaborative model of scheduling includes three attributes for cooperation (defined in section 2): structure, level, and form. The structure of cooperative work between collaborative organisations is important to the quality of performance. Many organisational structures are proposed for different situations. Millot and Lemoine (1998) apply a two-dimensional structure, vertical and horizontal, to cooperative parties. The vertical structure refers to a hierarchical relationship of authority between parties. Although the party at the higher level has ultimate responsible for decisions, it must cooperate with the other party at the lower level.
to manage interferences and also ensure that the second party can facilitate its goal. A horizontal structure refers to a heterarchical relationship; both parties are at the same level of authority. While managing their individual tasks, each manages interferences between their joint tasks. More complicated forms of structures can be constructed by combining these generic forms (Shen, 2002). Hoc’s (2001) three levels of cooperation — action, plan and meta — were introduced in section 2. At the action level, there are four types of cooperative activity relating to local interference management and goal identification. At the plan level, activities relate to a common knowledge representation (COFOR maintenance). The Meta level handles the integration of long-term infrastructures. These categories can be used to classify scheduling tasks and decision-making functions.

Different forms of cooperative activity can occur during collaborative scheduling. Schmidt (1991) identifies three types of cooperative activity: augmentative, debative, and integrative. For the augmentative form, all parties have similar domain-knowledge expertise. They cooperate with each other to solve workload problems. The group task is shared into similar subtasks (e.g. scheduling by humans using similar contextual information at comparable levels of organisational responsibility). With the debative form, parties with similar expertise cooperate on a unique task by comparing their results to improve performance quality (e.g. human schedulers working on a common schedule but applying different domain expertise and contextual information). The integrative form occurs where participants have different domain knowledge and cooperate on different (and complementary) subtasks of a joint task (e.g. human schedulers at different levels of organisational responsibility using similar contextual information and looking at the problem from different abstraction levels).

Miller (1988) represents the group decision process in collaborative environments with an intellectual process classification. He proposes three phases of conceptualisation, visualisation, and realisation in collaborative manufacturing. The same concepts are applicable to scheduling cooperation. To produce an inter-organisational schedule collaboratively, participating organisations first conceive in common which activities are to be scheduled and the boundaries of the problem. This phase concerns functions at a high level of abstraction and macro-level processes. In the next phase the concepts in the first phase are visualised by applying documented characteristics. Sketching schedules, documenting contextual and group knowledge and communicating schedules to manufacturing personnel are examples of activities in this phase. This phase includes the transference of scheduling orders between different levels of the work organisation. The last phase concerns the formation of physical products. Finalising schedules, allocating resources, and timing are made at this phase. Cooperative activities are mainly at the same level of work organisation. In the next section the proposed model is used to analyse different components of cooperation between human schedulers in a collaborative environment.

4. Case study
We will explore collaborative scheduling between organisations through a case study from the Middle-Eastern automotive industry. For reasons associated with confidentiality, the companies cannot be identified. The parties are a vehicle manufacturer (Mfg), which produces a wide range of passenger cars, buses, vans, and trucks, a manufacturing systems contractor (MSC), which designs and installs advanced manufacturing systems for the automotive industry, and a technology supplier (TS), which designs and manufactures specialised automotive machinery. The supplier, a sister company of the world’s biggest automotive industry, is located in another country. Mfg intends to update its production lines (e.g. paint shop, body-in-white, press line, axle line) with newer technology. MSC is responsible for transporting the technology and equipment from TS to Mfg and then installing, testing and maintaining it. Some systems are complete turnkey projects. A top-level agreement between
senior managers of the collaborating companies triggers the formation of a high-level coordinating committee. It consists of senior representatives of each company who are authorised to make decisions regarding the project, and representatives of other stakeholders such as government authorities and shareholders. The committee coordinates the planning and scheduling activities across the companies through face-to-face meetings and other forms of communication.

The first step for the committee is to define the project in technical terms, to develop common ground between parties for sharing knowledge and to produce the first-level schedule of the work. This schedule contains main activities, job sharing, major timing and important dates and the like. Besides the schedule, common information for participating parties is created, which includes material relating to resources, abilities and limitations. The first-level schedule evolves as committee members and schedulers converse. The final schedule, approved by the committee, is used by schedulers within each organisation to produce detailed local schedules for assigned tasks. Suggestions for changing or amending the schedule may come from the participating organisations, external authorities or the committee itself.

The process associated with change orders may be of three types. Changes may only affect schedules within a single organisation. Minor changes may affect schedules across organisations. Schedulers from collaborating organisations interact to consider the magnitude, scope, priority, and feasibility of changes. This interaction is between persons with different domain knowledge; by working together they complement each other’s capabilities. Once they have confirmed changes to schedules, they send information to the high-level committee. There is no major change in first-level schedule. The third type occurs when there are major changes that affect the entire project schedule. After the schedulers from the different organisations have collaborated on feasible changes, the major change orders are sent to the high-level committee for further consideration.

Collaboration and communication is multi-dimensional: amongst committee members and between committee members and schedulers located in the collaborating companies. Figure 2 shows examples of cooperative activities and considerations associated with interaction within and between groups.

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**Figure 2- Examples of interaction issues in cooperative situations from collaborative scheduling process in automotive manufacturing case study**

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1 External authorities are any unspecified sources of change that could affect the process. Examples are changes in laws, economic, industrial, and political uncertainties and the like.
These activities and interactions can be explained using the dimensions of structure, level, and form in the model of collaborative scheduling that we established in the previous section. Table 1 summarises the analysis of the activities based on the model. The double-headed arcs in Figure 2 refer to cooperative interaction, where solid and dashed arcs indicate horizontal and vertical organisational structures, respectively. The type of cooperation in situations A and D shown in Figure 2 is of the debative form, as it is between persons with similar knowledge of the whole project. The organisational structure is essentially horizontal; however, at least one member has to take responsibility for coordinating the committee’s activities. There are two levels of cooperative activities in these situations: meta and plan levels that are mostly related to long- and mid-term decisions. In situations B and E in Figure 2 committee members cooperate with schedulers in the collaborating organisations and this requires two perspectives: holistic and detailed. Whenever committee members require more information from a specific domain they call upon the schedulers. Cooperation is between persons who have different contextual knowledge; the committee member has high-level knowledge of the whole project and the scheduler has detailed knowledge in a specific field. The organisational structure is vertical and the form of cooperation is integrative. Cooperation is at the level of action, as it driven by the need for more detail on the individual or common schedule.

The third class of interaction is between schedulers of the collaborating organisations, when they cooperate with each other over scheduling details (situations C and F). Where their cooperation is based on their different domain knowledge, then their form of cooperation is integrative. However, where they share common knowledge, the form is debative. The structure of cooperation is in a horizontal form; there is no priority in the working hierarchy. Cooperative activities are at the action and plan levels.

Table 1- Classification of cooperative activities in collaborative scheduling of mentioned case study

<table>
<thead>
<tr>
<th>Cooperative Activity</th>
<th>Form</th>
<th>Structure</th>
<th>Level</th>
<th>Related cooperative activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, D</td>
<td>Debative</td>
<td>Horizontal</td>
<td>Meta</td>
<td>• Communication code generation (e.g. Producing common knowledge of the project, glossaries, common terms, …)</td>
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<td></td>
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<td></td>
<td>• Generation of models of oneself and other agents (e.g. Understand the methods and technologies used by the others)</td>
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<td></td>
<td>• Compatible representation generation (e.g. Integrating reports)</td>
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<td></td>
<td></td>
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<td></td>
<td>• COFOR maintenance and generation (e.g. Introducing their own companies: Resources, Capabilities, Production &amp; Storage capacity, Organisation, Limitations, Related history)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Common goal &amp; plan maintenance and generation (e.g. High-level schedule production)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Role allocation (e.g. Define project organisation)</td>
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<tr>
<td>B, E</td>
<td>Integrative</td>
<td>Vertical</td>
<td>Action</td>
<td>• Local interference creation, detection, resolution (e.g. Investigating feasibility and desirability of the main schedule in detail)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Goal identification on the basis of domain knowledge (e.g. Visualisation of the schedule based on the domain knowledge)</td>
</tr>
<tr>
<td>C, F</td>
<td>Integrative</td>
<td>Horizontal</td>
<td>Action</td>
<td>• Common plan maintenance and generation (e.g. Help the other parties in formulating their ideas and expectations)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Role allocation (e.g. Make final decision, based on their authority)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Local interference creation, detection, resolution (e.g. Investigating others’ capabilities)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Goal identification on the basis of domain knowledge (e.g. Detecting others’ aim)</td>
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</table>

5. Concluding remarks: Toward a framework for designing collaborative systems

The model of collaborative scheduling presented in this paper provides a means for analysing cooperative relationships in inter-organisational scheduling. Cooperative activities between persons associated with developing and maintaining schedules can be decomposed
into elements of structure, level and form. Such decomposition permits different collaborative situations (both existing and proposed) to be systematically examined and compared. The authors intend to use the model to evaluate and subsequently design (or re-design) industrial collaborative scheduling environments so as to eliminate sources of inefficiency, misunderstanding, error and conflict at both individual and organisational levels.

Reference List