

A FOUNDATION FOR ANALYSIS OF HUMAN COOPERATION IN MULTI-PARTY SCHEDULING

(Special session on Human and Organisational Factors in Industrial Planning and Scheduling 'HOPS')

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Abstract

Activities involving multiple participants need to be coordinated. It requires parties schedule joint activities together. Multi-party scheduling consists of the development of schedules across organisational groups. Where uncertainty and ill-defined information are involved, human cooperation is vital in making decisions. Schedulers view a range of tasks and plans as common. However, their domain knowledge differs and they have individual goals and tasks. Hence, cooperative and individual activities must be harmonised, in a holistic framework of true collaborative state. This paper analyses the schedulers' cooperative activities when coordinating joint tasks. It sets a foundation for studying their behaviour cooperating. A model of Cognitive Work Analysis for decision-making with multiple goals is applied and extended to include interactions between collaborators. The interactions are cooperative activities, where cooperation is viewed as a process of interference management.

Keywords:

Collaborative Scheduling, Cognitive Work Analysis, Cooperation, Human Decision Making, CSCW

1 INTRODUCTION

Scheduling between organisations entails many changing parameters, high degrees of uncertainty and ill-defined information. It requires group decision making distributed across participant organisations. Decisions are based on multiple criteria that may involve conflicting (and even unstated) goals. In this environment problems are changing dynamically based on new conditions, previous state of the problem and past solutions. Therefore, problems cannot be defined independently from solutions and the problem space is changing as solutions progress. Moreover, multiple stakeholders are involved and feasible solutions cannot be produced in reasonable time. Such problems, classified as 'wicked' are not well suited to software solutions as software agents and algorithms tend to be brittle, ignoring wickedness and expensive [11], [19].

The role of humans in field scheduling decision making has been studied by numbers of researchers [13], [14], [8], [3]. These studies do not consider the scheduling of activities across work groups. Schedulers from the different parties must cooperate to develop common (global) and individual (local) schedules. A key trait of cooperation in scheduling is a common goal requiring the coordination of activities. Schedulers from the participating organisations contribute to both the coordination of collective work towards the common goal and scheduling within their own organisation. When engaged in activities towards common goals, their mindset is one of a *collaborative state*. The holistic nature of collaboration is broader than cooperation. Cooperation is the process of managing the interferences [9]. Parties can cooperate without necessarily having a common goal playing a regulation role: that is, a common purpose in not necessary [9]. Collaboration, however, embraces both common goals and tasks. While collaborators have a broader outlook than co-operators, a collaborative scenario is a constrained form of cooperation [16].

Multi-party scheduling is a collaborative activity as the participants have their own goals and tasks, while cooperating towards common goals. The development of

computerised tools for aiding collaboration requires as a precondition the analysis of human behaviour in decision making, including group behaviour.

This paper discusses theoretical concepts for analysing human behaviour in multi-party scheduling. Emphasis is placed on the common and individual goal-structures of the collaborating parties, which is based on Higgins' model of Cognitive Work Analysis [7]. Development of common and individual schedules is explored in relation to the completion of the goal structures and formation of group knowledge among participants.

2 COOPERATION IN COLLABORATIVE STATE

A model of collaborative scheduling, developed by the authors, is applied in this paper [17]. It includes individual and group goals and tasks, domain and group knowledge, group roles and cooperative processes among schedulers. Figure 1 depicts a simple representation of the relationship between individual and group domains in the model.

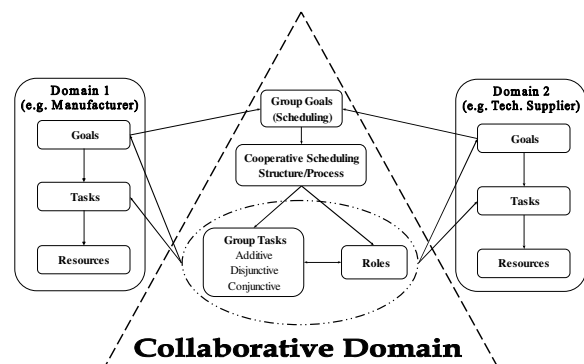


Figure 1: Collaborative Scheduling Model [17].

While the collaborating parties from different domains work together, they pursue their own goals. They also

create group goals collaboratively. To meet their common goals, they identify group tasks cooperatively. These tasks are used to define individual tasks and the roles of each party. All work is coordinated towards common goals, while each party attempts to satisfy its own organisational goals, but within a collaborative framework. The interaction between participants is cooperative when they work simultaneously in their own domain and collaborative state. Hoc defines cooperation as the management of interferences; Two parties are cooperating when “each one strives towards goals and can interfere with the other on goals, resources, procedures, etc.” while “each one tries to manage the interference to facilitate the individual activities and/or the joint task when it exists” [9]. For him, cooperative activities are classified into three levels: Action, Plan and Meta. At the action level, cooperative activities are associated with local interference management, which includes interference creation, detection, resolution and anticipation. Cooperative activities at the plan level concern the elaboration and updating of a shared understanding of the problem space by the participants. Hoc calls this a Common Frame Of Reference (COFOR) in regards to contextual representation and goals, plans and knowledge. When the mode of scheduling is collaborative, this common understanding is the group knowledge, which does not exist before collaboration and is formed during it. COFOR is similar to ‘vocabulary schema’ in collaborative engineering [6], and ‘mutual knowledge’ in cognitive science [12]. At the plan level, cooperative activities concern the maintenance or elaboration of a representation of the process under control, control activity, common goal or plan, and function allocation. The parties update their common understanding of the problem space and models of other parties. Although this understanding might be used to manage interferences when parties cooperate at action level, planning activities themselves do not directly cause interference. Cooperative activities at the Meta level encompass the integration of long-term issues. Updating common communication code, compatible representation and model of partners are of the main activities in Meta-level cooperation.

Cooperative activities can be classified by the form of occurrence. Schmidt [22] identifies three types of cooperative activity: augmentative, debative, and integrative. In the augmentative form, all parties have similar domain-knowledge expertise. They cooperate with each other to solve workload problems. The group task is divided into similar subtasks (e.g., scheduling by humans using similar contextual information at comparable levels of organisational authority). The debative form occurs when parties have similar expertise and cooperate on a unique task by comparing their outcomes (e.g., human schedulers working on a common schedule but applying different contextual information). For the integrative form, participants have different expertise and cooperate on different (and complementary) subtasks of a joint task (e.g., human schedulers at different levels of authority using similar contextual information and looking at the problem from different abstraction levels).

Collaborative scheduling between organisations is briefly explored in the next section.

3 CASE STUDY

The findings from an automotive case study are used to demonstrate aspects of collaborative scheduling. For confidentiality reasons, the companies are not identified. A vehicle manufacturer (Mfg), which produces a wide range of cars, aims to update its production lines (e.g., paint shop, body assembly line, die & press and axle lines) with newer technology. Specialised automotive

machinery is sourced from a technology supplier (TS) that designs automotive equipment. A manufacturing systems contractor (MSC) is responsible for transporting the equipment from TS to Mfg and then installing, testing and maintaining it. Collaboration between companies begins with a top-level agreement between senior managers. This triggers the formation of a high-level steering committee to coordinate planning and scheduling activities across the companies. Its members are full-authorised representatives of each company and representatives of other stakeholders. Committee members define the project in technical terms and produce a master schedule of the work. This schedule contains main activities, job sharing, major timing and important dates and such like. Schedulers of Mfg, TS and MSC then develop local schedules for each company. However, this is not a one-way process in which the master and detailed schedules are produced without amendment. The master schedule evolves as committee members and schedulers converse. To facilitate scheduling at both local and global levels, there is cooperation between committee members and field schedulers and also between field schedulers. The final schedule, approved by the committee, is used by schedulers within each company to produce detailed local schedules. Suggestions for amending the schedules may come from the participating organisations, external authorities or the committee itself. There are three types of cooperative activities as shown in Figure 2:

1. **Type A:** Committee members work together to produce the master schedule. They approach the problem with similar general knowledge. Scheduling representatives from Mfg, TS and MSC discuss issues relating to the entire project and make decisions not in detail. Technical engineering niceties are not considered as they look at the problem from a high level of abstraction taking a holistic perspective in decision making. This cooperation is mainly of a debative form and usually occurs at the Plan and Meta levels.
2. **Type B:** Committee members cooperate with related field schedulers in Mfg, TS and MSC operational sites. This cooperation is mainly for elaborating and updating group knowledge. Persons cooperating perceive the problem from different abstraction levels: company’ representatives from high-level and field schedulers from an operational perspective. This type principally occurs when the party who needs information from another initiates the activity. Most activities are integrative in form and occur at the plan level.

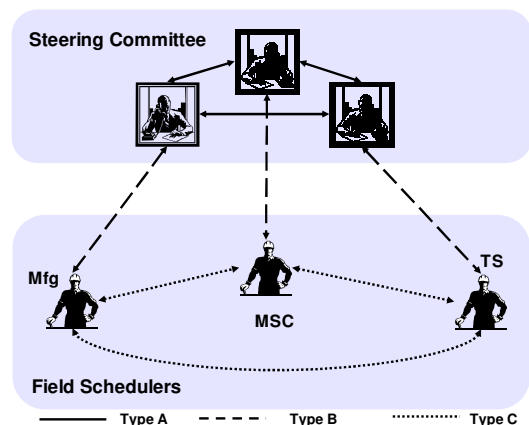


Figure 2: Cooperation between schedulers.

3. **Type C:** Field schedulers cooperate with each other when developing local schedules for Mfg, TS and MSC or suggesting amendments for the master schedule. Although, they work at the same level of abstraction, their expertise differs as they work on different tasks. Cooperation has an integrative form. Predominantly, they perform the work in unison towards goals at the action level. Yet, they cooperate with each other in enhancing their group knowledge of the work at the plan level.

Some examples of each type of above mentioned cooperative activities are provided in Table1.

4 DYNAMIC SCHEDULING AND GOALS

When schedulers work together to develop master and detailed schedules, their cooperation concerns the elaboration and maintenance of group knowledge as the environment changes. Scheduling tasks in both the collaborative and local domains progress as group knowledge becomes enhanced and more complete as schedules evolve. The dynamics of a scheduling task is therefore entwined with the formation and revision of common and individual goals. The importance of this relationship is reflected in models for collaborative work in other fields. For example, a similar evolution of the vocabulary schema applied to collaborative engineering design [6]. Similarly, Windischer and Grote's [23] collaborative planning model, used to study the critical success factors in inter-organisational planning at 136 small- and medium-sized organisations, includes characteristics of individual and collaborative domains. The creation of a collaborative plan necessitates:

- Communication of anticipated events
- Knowledge of conditions in the reference action field
- Lateral agreement on goals
- Exchange about the availability of alternatives
- Recognition of the adequacy of the common goal

The above are cooperative activities associated with the elaboration and maintenance of group knowledge. Anticipation of events requires parties having models of each other formed through Meta-level activities. Knowledge about field conditions is clearly towards the elaboration and maintenance of group knowledge at the plan level. Since Windischer and Grote's model is based on action regulation, it can be inferred that recognition of the adequacy of goals entails goal amendment and adjustment. This is a cooperative process at the plan level to maintain group knowledge. Exchange of alternative options also occurs when schedules cooperate to manage interferences at the action level.

The importance of shared understanding in human collective works is common: for example, COFOR in air traffic control [10], 'common ground' in communication field [2], and 'situation awareness' in teamwork [1], [20], [4]. However, situation awareness is only part of the shared understanding of a group. As schedulers work together, they also share information and behaviour beyond environmental awareness. Their knowledge extends to the others' goals, plans, tasks, and meta-knowledge [10]. This awareness goes beyond the attributes of the physical situation and the group knowledge is an enhanced, enriched form of individual knowledge. This knowledge is created during collaboration and formed by participants sharing knowledge.

Common and individual goals are central to group knowledge: through collaboration they are formed, called upon and reformed. Schedulers come together to work as a group to do a joint task. All have their own representation of the problem. Before collaborating, each scheduler seeks to meet their own individual goals based on their own representation of the problem (individual knowledge). However, developing schedules is a recursive task, where schedulers cooperate with each other to develop the components of the collaboration that form the master plan and detailed schedules. To study dynamic aspects of schedulers' goal setting and

Table 1: Examples of cooperative activities in collaborative scheduling in the case study

Cooperative Activity	Form	Level	Example
Type A Cooperation among the steering committee members	Debatative	Meta	Producing definition and glossaries for press and die, body in white, paint shop, final assembly, trim and logistics, power train, and spot-welding lines.
		Plan	Developing the master schedule for the whole project. It includes major activities in mechanical, electrical, chemical etc disciplines. Defining major organisational breakdown structure of the project that allocates major activities to three organisations: manufacturer, technology supplier and systems contractor Providing general history, main capabilities, storage capacities, list of main suppliers, human resources information etc of each company.
Type B Cooperation between committee's members and field schedulers	Integrative	Plan	Field schedulers in MSC gives technical engineering details about time and resources needed for installing axle line (for Peugeot 206 new line), which the MSC representative in the steering committee is looking for. While checking scheduled activities for body assembly line in design for jigs, fixtures and body handling system between stations, field scheduler in TS seeks information from tandem, transfer, progressive, blanking, slitting and spotting press-line from the committee representative as it is relevant.
Type C Cooperation among field schedulers	Integrative (Debatative)	Plan	MSC scheduler informs Mfg and TS schedulers that they have added an extra shift work to finish the installation of monitoring and CCR (Central Control Room) systems for the Peugeot 206 new PTED paint shop on scheduled date.
		Action	Field scheduler in TS asks MSC scheduler about the possibility of delay in delivering of assembly synoptic drawings for body assembly factory for three months (due to some changes). Having closely similar engineering knowledge, MSC scheduler is able to anticipate the probable side effects of changes. He asks if these changes are going to affect the shop master sheets. He mentions that if the former changes cause the latter ones, it is impossible as MSC has already started foundation construction.

attainment, a previously developed model in Cognitive Work Analysis [7] is used, which is influenced by Action Regulation Theory [5]. In his model of human scheduling, Higgins sees scheduling as having a cyclic hierarchical goal-action structure. To achieve a goal, subordinate goals are identified during action, which are higher-level goals for their own subordinate goals in the structure. Schedulers operate based on their immediate goals to achieve higher level goals, see Figure 3.

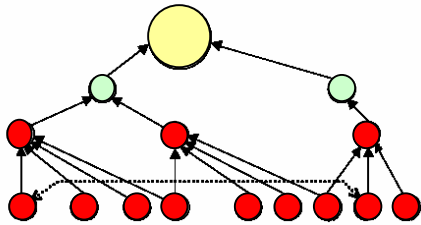


Figure 3: The scheduling goal structure [7].

The scheduling goal structure is not established at once. It is developed during action. Schedulers first become aware of the problem space and make the highest level of their own goal structures. Then, during action, schedulers construct the lower level subordinate goals to achieve the higher level goals.

In collaborative states, schedulers work together cooperatively to clarify the problem and to identify aims, potentials, restrictions etc. Aware of the situation and other's knowledge, they develop a highly-abstract level of group knowledge. As cooperation continues, they define group goals, based on their individual goals and group knowledge. They interact with each other, make interferences and manage them at the Action level so that they can elaborate the higher levels of group goals related to the knowledge at the Plan level.

A similar goal structure exists for the collaborative domain. The group goal-structure is formed through cooperative activities and is based on the individual goal-structures. There is a hierarchical relationship in the group goal-structure. The lower-level group goals are formed in sufficient detail for the production of master schedules for each party. The group goals at the lower levels in the master schedule provide a base for each party to build up the intermediate and operational levels in their own goal structures. This is where each party develops an operational schedule for its own organisation.

As scheduling is dynamically entwined with the elaboration and maintenance of group knowledge, the goal structures are dynamic. The relationship between the group and individual goal-structures (and schedules) is a recursive and cooperative process. Therefore, as schedulers change their goals and schedules the master schedule and perhaps the group goals may be amended. The relationship between group and individual goal structures through cooperation is depicted in Figure 4.

Cooperative activities differ in each step of the developing goal structures and schedules. Schedulers work together in different levels and forms of cooperation, while looking at the problem from different abstraction levels. The study of their cooperative behaviour is a two dimensional analysis: interference management at Action, Plan and Meta levels and the Debative, Augmentative and Integrative forms of interaction.

The automotive case study can elucidate the different types of cooperative activities during collaborative scheduling. The first activity of the steering committee when it started its work was to cooperatively establish high-level goals of the group, based on the individual

members own goals. This cooperation is of type A of cooperative activities (Figure 2). They defined the first level of the goal structure through debative cooperation while they look at the problem from a holistic view. This cooperation deals with long term agreements at the Meta level and the elaboration of common understanding at the Plan level. Examples of these activities include the production of project glossaries and common terms, and defining the Organisational Breakdown Structure (OBS) of the project. The intermediate and lower levels of the group goal structure are needed for the master schedule. The members of the committee therefore needed to build up a more complete model of the problem space. This required contextual and technical information that had to be acquired through cooperation with field schedulers (type B, Figure 2). Because persons interacting had different knowledge at different levels of abstraction, they needed to clarify the meaning of various factors. These activities were of an integrative form and were at the Plan level. The investigation of the feasibility and desirability of the details of particular master activities depended upon the domain knowledge of each participant is an example of integrative activity. The master schedule developed from the completed group goal-structure. This common schedule for the entire project was used by the field schedulers to construct the local schedules for the Mfg, TS and MSC. The schedulers from each company used this schedule to compose their individual goal structures, which were the lowest level of group subordinate goals. Clearly, the highest level of an individual party's goal structure is much more affected by its own domain than the collaborative domain. All field schedulers are principally responsible for their own domain. 'Making the highest profit for the company' for example, is a local ultimate goal, which is affected by the company's managerial policies and goals. To achieve this goal, one subordinate goal might be 'cooperating with the other companies' in the collaborative domain. Field schedulers cooperated with each other at the same level of abstraction in integrative and debative forms (type C, Figure 2).

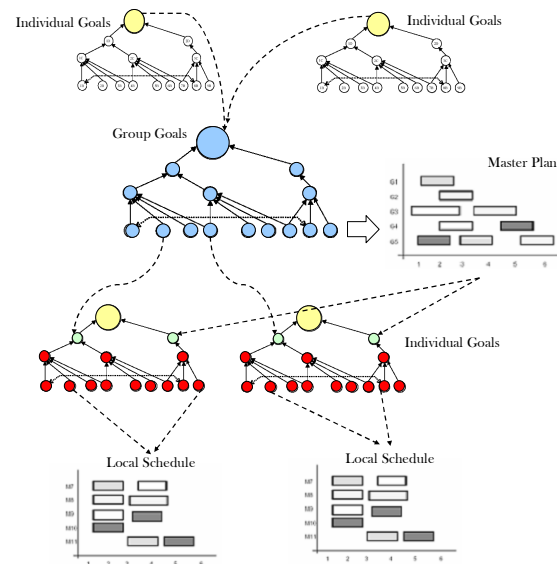


Figure 4: The relationship between the group and individual goal structures and schedules.

Most cooperative activities occurred at the Action and Plan levels. Assisting other parties to formulate their ideas and expectations, and decision making based on

their authority are examples of cooperative activities for these situations. However, as scheduling is a recursive task, they cooperated with the committee members to clarify the details of the schedules. Yet again cooperation was type B, integrative in form and at the Plan level. Detailing technical information of the master schedule's tasks is an example of this type.

5 SUPPORTING SCHEDULERS

The collaborative view of multi-party scheduling is useful for designing both computer-supported tools for scheduling and automated systems. Its major advantage is the consideration of cooperative activities as a component of a holistic collaborative state. The model provides an analytic framework that accentuates the importance of handling and dealing with scheduling in its entirety or wholeness entwined with the goal structures and the group knowledge at large. It can be used to construct the requirements for the development of software that can support and sustain the decision making of human schedulers within collaborative environments. Below are some guidelines for designing computer-supported tools in multi-party scheduling that are based on the model.

5.1 Supporting cooperation

To support cooperation there needs to be functionality in the software that upholds cooperative activities at the different levels (Action, Plan and Meta) and different forms (debative, augmentative and integrative). The scheduling tasks for a particular application must be analysed in regard to the different levels of abstraction invoked when schedulers cooperate during interference management or the elaboration and maintenance of group knowledge. Whether participants have different or similar knowledge has to be identified. As shown in the case study, the structure of the joint tasks and group roles are the key elements in this analysis. The structure of cooperation can be either *horizontal* or *vertical* [15]. Where the structure is horizontal, participants have the same organisational authority and maintain similar roles in the group. A vertical structure applies when the parties work at different levels of authority in their own (or common) organisations and are assigned different roles. In the automotive case study, cooperative activities of the types A and C have a horizontal structure whereas the type B has a vertical structure.

5.2 Goal structures support

Scheduling between multiple parties needs to be supported by an appropriate representation of the group and individual goal structures. Cooperative development of the schedules is not restricted to individual domains and goals. It is entwined with the goal structure for the group and those for the other parties. Schedulers need support in a way that helps them to retain collaborative goals, while staying committed to their own organisation's goals (individual goals). This support must be at appropriate goal levels. For example, in different types of cooperative scheduling tasks in the case study (A, B and C), different levels of the group and individual goal structures are invoked. Of course, each person should be supported by relevant group goal-structure based on his/her organisational responsibility and authority. *Trust* issues are also needed to be considered as participants may not want to share private confidential goals and resources.

5.3 Group and individual knowledge support

Group knowledge requires the sharing of information. It is entwined with the scheduling tasks and features in the tools that can elaborate and maintain suitable information

for supporting skill-, rule- and knowledge-based problem-solving [18]. This would support participants in retrieving, reusing, revising and retaining relevant information to solve problems associated with individual domains and group domain at large.

As a part of the group knowledge, schedulers' situation awareness needs supporting. Schedulers must have available invariant sets of information about collaborative work, the organisations involved, glossaries, history, etc. These static data are from both their own and other parties' domains and must represent information at appropriate levels of abstraction. Also dynamic attributes of the environment must be captured and represented in a way that assists schedulers to make inferences regarding uncertain and unstated information associated with changes in managerial policies, unanticipated incidents, unpredictable conditions etc.

As another part of the group knowledge, models of the collaborative partners must be provided in such a way that schedulers not only know about what other parties have done but also be aware of goals and plans of other participants. Therefore, they should have access to information regarding resources, activities, current tasks, and plans/goals of other parties to help them to anticipate events. This is missing in many collaborative systems, i.e., a cooperative relationship is instantiated only when triggered by one party transmitting state changes to others.

5.4 Collaborative feedback is needed

Feedback is a crucial component of computerized tools. To provide participants with information they may use to improve their performance, the accomplishment of tasks and performance results must be reported to the participants. Schedulers must receive information about their activities that relate to achievement of their goals. It should not be restricted to their own individual goal structure. In a collaborative state, supplementary feedbacks are also needed about the performance of other parties. The completion of tasks in the collaborative domain, which is associated with the '*scheduling-goal structure*,' is also required by schedulers. As schedulers cooperate, they need to know what happens across the whole collaborative field. In the collaborative state, schedulers must know how they should perform to help other parties to achieve their goals in a more efficient way. In facilitating the tasks of the other parties, a scheduler has to relate to the group goal structure. Therefore, a scheduler's task is not finished until the group task has finished.

6 SUMMARY

This paper presents a foundation for the analysis of the behaviour of multiple human schedulers who coordinate their activities in performing joint scheduling tasks between organisations. Scheduling is characterized by: conflicting goals, ill-defined information, high levels of uncertainty, and dynamic situations. Moreover, group decision making brings more complexity to the distributed scheduling, which makes problems *wicked*. To cover all requirements of the joint task, schedulers need to cooperate with each other in coordinating their activities. To support schedulers with tools, this cooperation has to be analysed. For this purpose, a previously developed model of Cognitive Work Analysis for scheduling with multiple goals is applied to collaborative environments with multiple participants involved in scheduling between the parties. The cognitive model is extended to include interactions between parties using a collaborative scheduling model.

Through a case study from the automotive industry, the scheduling behaviour of planners is analysed using the collaborative scheduling model. Individual and group knowledge, task, roles and goals are identified and cooperative activities are classified according to Hoc's definition of cooperation [9]. The concept of goal structure [7] provides the foundation for studying the relationship between group and individual goals and scheduling. The importance of a cyclic relationship between scheduling tasks and common and individual goal structure, enriched through cooperation, is discussed. Other collaborative work models are also studied that represent the entwined relationship schedules and goals. Examples of the case study are provided to show how this relationship is affected by the level (Action, Plan and Meta) and form (debative, integrative and augmentative) of the cooperative activities.

The foundation presented in this paper, provides a framework for a comprehensive and systematic understanding of collaboration on which to develop software for supporting human-human and human-computer collective work. It is argued that schedulers need decision supports not only in cooperative processes but also by in a holistic state of mind: collaboration. It is articulated that *collaborative thinking* needs to be maintained among participants as they strive towards their individual goals and facilitate the partners' goal achievement in entangled with the group goal structure. Some aspects of collaborative decision tools are highlighted that comprise supports for cooperation, group and individual goal structures, group knowledge and collaborative feedback. Further studies are needed to develop a detailed analysis of schedulers' cooperative activities, an exhaustive study of group and individual goals to elucidate the relationship between them. The foundation presented, is a basic step to a '*Collaborative Model Human Scheduler*'.

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