An Interdisciplinary Software Engineering Process for the Development of IT Scheduling Decision Support Systems

Christos Dimopoulos (corresponding author)
European University Cyprus, Cyprus
c.dimopoulos@euc.ac.cy

Abstract: This paper builds on research work conducted by Riezebos et al. (2010) and van Wezel et al. (2010), and provides the theoretical foundations of an interdisciplinary software engineering process for the development of IT scheduling Decision Support Systems. The introduction of the proposed process is based on the imbalance that exists between the vast academic research scheduling output and the limited use of scheduling algorithms in industrial environments. It is also based on the reported preference of human schedulers to the use of ad-hoc methodologies, rather than IT scheduling systems' support, for the implementation of day-to-day scheduling tasks. The proposed process employs well-established software engineering principles, similar to the ones used for any complex software entity of non-trivial size. However, specific phases of the software lifecycle are suitably modified in order to explicitly consider human and organizational characteristics of the scheduling environment.

Keywords: Software engineering, scheduling, interdisciplinary, human and organizational considerations, Decision Support Systems

1. Introduction

While research in the area of production scheduling has flourished, a number of researchers, among them Jackson (2004), Wafler (2005), and Berglund & Karltun (2007), have identified significant problems with regards to the exploitation of these results in industrial environments. In particular, while many industrial IT scheduling Decision Support Systems (DSSs) utilize scheduling algorithms for the implementation of their functions, there exists a significant gap between the number of scheduling algorithms produced by researchers and the percentage of them used in practice. In addition, the acceptance level of IT scheduling DSSs in realistic industrial environments is reported to be low. In other words, human schedulers generally prefer to adopt ad-hoc approaches in their day-to-day scheduling decisions, despite the existence of industrial IT scheduling DSSs as support tools.

A number of researchers have debated the reasons behind these phenomena. They have argued that the traditional production research view of the scheduling environment focuses predominantly on the efficiency of solutions generated by the scheduling algorithm, rather than its applicability and user-acceptance within the realistic industrial environment. In other words, the traditional view fails to address complex human and organizational parameters that usually dictate the practical implementation of scheduling tasks within this environment (Berglund and Karltun, 2007), (Riezebos et al., 2010).

This paper proposes a novel approach to the development of IT scheduling DSSs, which addresses these considerations by integrating the design and use of scheduling algorithms within a suitably modified interdisciplinary software engineering process. The aim of the proposed process is to provide researchers, as well as practitioners (from both the engineering and IT sectors), with a framework which will lead to the engineering of efficient and user-acceptable IT scheduling DSSs.

The rest of this paper is organized as follows: Section 2 provides an overview of the scheduling process as well as a brief study of the scheduling environment from both the conventional research perspective and the realistic industrial perspective. Section 3 describes in detail the phases and the deliverables of the proposed interdisciplinary software engineering process. Finally, Section 4 discusses the conclusions, as well as future activities related to the research work described in this paper.

2. Scheduling algorithms and the scheduling environment

Scheduling constitutes one of the key activities in the day-to-day operation of industrial as well as other societal processes. For this reason, academic research in the area of scheduling has been growing rapidly over the last four decades. There have been numerous algorithms proposed for all possible versions of scheduling problems. These algorithms are based on analytical, heuristic, as well as artificial intelligence techniques.

The process of scheduling concerns the allocation of limited resources to tasks over time, under specific constraints. The general goal of scheduling is the optimization of one or more objectives defined by the decision maker (Pinedo, 1995). This definition implies that a well-defined, autonomous discrete task has to be performed by a decision-maker on a specified moment in time.

The bulk of scientific research in the area of scheduling (Slack et al., 2004) has concentrated on a technological ‘view’ of the scheduling environment, where algorithms are developed to solve well-defined mathematical models of industrial and business processes (figure 1).

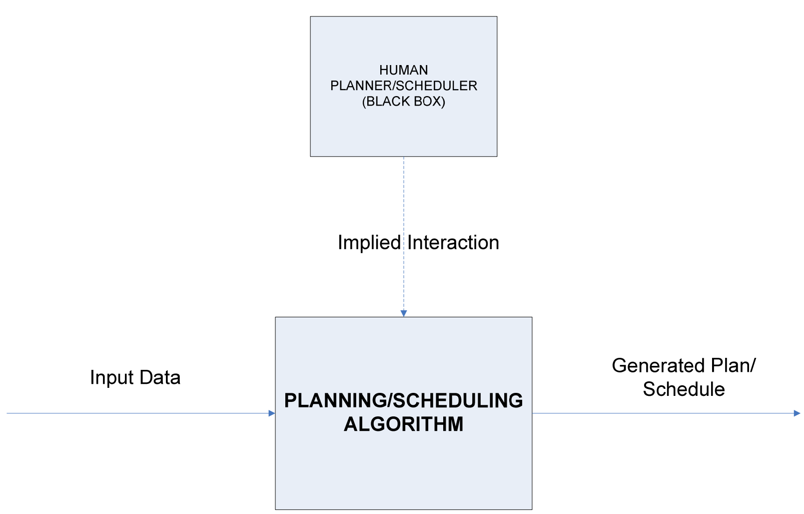

Figure 1: The conventional production research view of the scheduling environment

However, these models have been criticized for representing only a restricted, unrealistic view of the day-to-day scheduling process, with no regards to human and organizational considerations (Corbett, 1987), (Smith, 2003), (MacCarthy & Wilson, 2001). This is especially true for the area of production scheduling, where the implementation of relevant tasks is frequently based on ad-hoc procedures (Berglund & Karltun, 2007). These procedures many times result in the generation of sub-optimal schedules and the dissatisfaction of the human operator and his/her organization (Wäfler, T., 2005).

Figure 2, illustrates a more realistic view of the scheduling environment as described by Riezebos et al., 2010. This view indicates that the scheduling process is a complex interpersonal and interdepartmental process that takes place dynamically over time. Therefore the design and development of an IT scheduling DSS should explicitly consider the human, organizational and technological characteristics of this process.

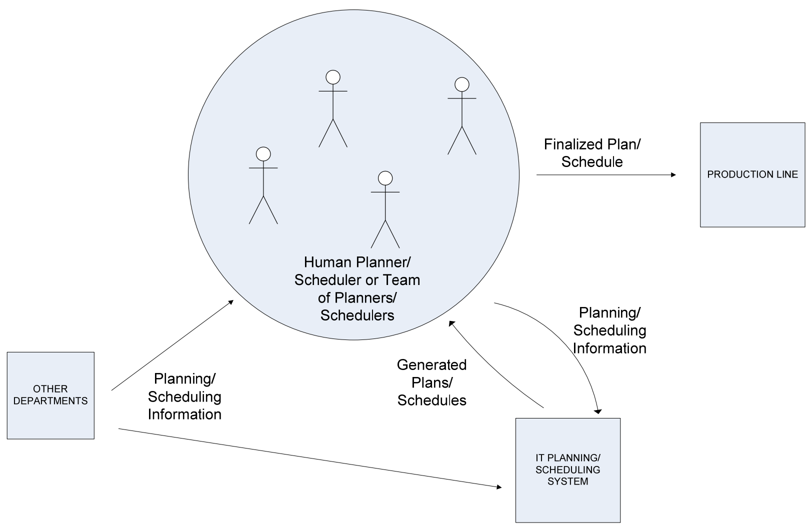

Figure 2: A realistic view of an industrial scheduling environment

The technological characteristics of the scheduling process have been discussed extensively in past. A typical example is McKay et al.’s (2002) identification of major technological issues that should be addressed by designers of scheduling algorithms in order for these algorithms to be useful in realistic production environments. These issues include the flexibility and robustness of the algorithms, the design of scheduling tasks, and the design of the user interface.

There have been several studies of the scheduling process from the human (cognitive) perspective. These studies focus mainly on the identification and analysis of scheduling tasks (Cegarra, J., 2008), (Lodree et al., 2009), and the allocation of scheduling tasks to human and machines (McKay et al., 2003a) . A limited number of organizational studies of the scheduling process have also appeared in the literature (Jackson et al., 2004). However, in general, cognitive and organizational studies have not been combined with technological studies on the implementation of scheduling DSSs.

These studies illustrate clearly that there is a need for an interdisciplinary process which will drive not only the design and use of the scheduling algorithms, but more importantly the design of the overall IT scheduling DSS that will function within the interdisciplinary scheduling environment. In the following section the theoretical foundations of a novel software engineering framework process which attempts to address these considerations are provided.

3. An interdisciplinary software engineering process for the development of IT Scheduling DSSs

The proposed interdisciplinary process employs conventional phases included in a typical Software Development Life Cycle (SDLC), namely planning, analysis, design, as well as implementation & testing. However, these phases have been suitably modified in order to address the specific technological, cognitive and organizational characteristics of the scheduling case considered. Since there are no significant changes in the planning phase of the proposed SDLC, in comparison with the planning phase of a typical software engineering methodology, we focus exclusively on the remaining three phases. It should also be noted that while these phases are described in a sequential manner, indicating the use of a waterfall-type SDLC, the same phases can be employed within the context of an evolutionary, or a prototype-based SDLC. A graphical overview of the proposed interdisciplinary SDLC, along with references to the corresponding sections of the paper where related activities are discussed, is provided in figure 3.

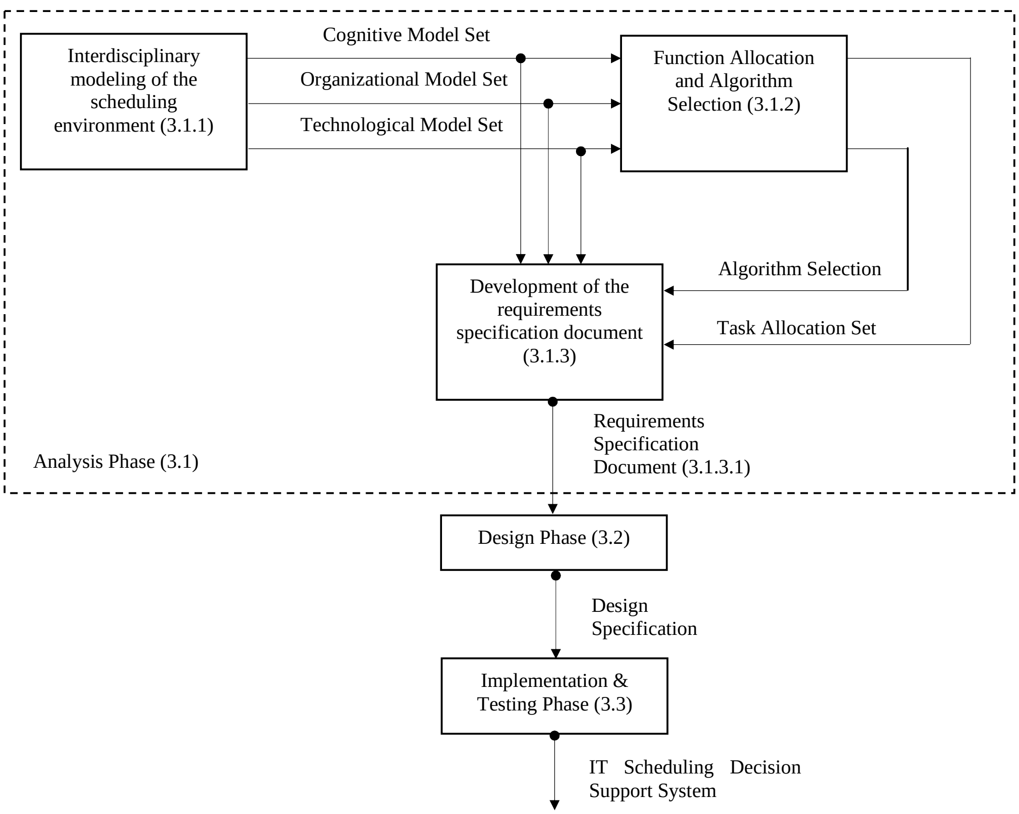

Figure 3: Overview of the proposed interdisciplinary SDLC for the software engineering of an IT scheduling DSS

The following subsections describe in detail the core phases of the proposed SDLC process for the development of interdisciplinary IT scheduling DSSs.

3.1 Analysis phase

During the analysis phase, the principle tasks that have to be performed include the interdisciplinary modeling of the scheduling process, the function allocation and algorithm selection processes, and the development of the requirements specification document. The basic analysis tool employed is the implementation of appropriate studies from the human, organizational and technological perspectives. More analytically:

3.1.1 Interdisciplinary modeling of the scheduling environment

Cognitive modeling: The analysis from the human (cognitive) perspective involves the development of a model of the scheduling environment through the implementation of descriptive hierarchical and cognitive task analysis methodologies. The result of the study will comprise a set of models which will describe the task sequences as well as the possible task strategies followed during the implementation of the process. In addition, specific objectives that are associated with the implementation of each scheduling task will be identified and recorded.

Organizational modeling: The analysis from the organizational perspective involves the development of an organizational model of the scheduling environment through the implementation of a relevant study. This study will model the following characteristics of the process:

i) The organizational and control structure of the scheduling team (number of people, team structure, decision making process).

ii) The organizational and control structure of the company and the placement of the scheduling team within this structure.

iii) The context diagram of the scheduling process (flow of information 'in' and 'out' of the process and the related actors that provide or consume this information).

Technological modeling: The analysis from the technological perspective involves the development of a technological model of the scheduling environment through the implementation of a relevant study. This study will model the following characteristics of the process :

i) The engineering infrastructure of the scheduling environment (number, type, and capacity of machines, material flow mechanisms etc.)

ii) The information technology infrastructure of the scheduling environment (existing IT systems and capabilities, software configuration etc.)

iii) The technical characteristics of the scheduling process (type of production control system, number of jobs processed per day on average etc.)

All the models constructed in the previous activities constitute an interdisciplinary view of the scheduling environment which will be exploited in subsequent phases of the SDLC process for the development of interdisciplinary IT scheduling DSSs.

3.1.2 Function allocation and algorithm selection

The function allocation and algorithm selection activities change the modeling view from the ‘as-is’ to the ‘to-be’ scheduling system. This is achieved through the allocation of subtasks to the new IT scheduling DSS, and the determination of algorithms which will be responsible for their implementation of these tasks.

Function allocation: Traditional technological approaches assume that the IT DSS should be designed on the basis of automating all scheduling subtasks. However, as it has been reported in the literature, full automation of the scheduling process does not have practical applicability. Instead, there should be a function allocation process which will determine the division of subtasks between the human scheduler and the IT system. This process will use as input the set of tasks that have been identified during the hierarchical and cognitive task analysis methodologies described in section 3.1.1. The implementation of the process will be based on criteria such as the complexity of the scheduling subtask, the need for situation awareness by the scheduler, the cost of making a sub-optimal decision, as well as other interdisciplinary objectives and factors associated with the implementation of the subtask.

Algorithm selection: Once the scheduling subtasks that will be implemented by the IT scheduling DSS have been identified, the core algorithms that will be used as a support for each subtask will be selected. This selection will require a survey of the literature which will provide a list of algorithms available for the required subtasks. The decision on using a specific algorithm for the implementation of a specific subtask will be based on a qualitative 'matching' process between the algorithm’s characteristics and the scheduling subtasks requirements. These characteristics will include:

- The algorithm’s solution generation mechanism (exact, analytic, heuristic, smart-heuristic, artificial intelligence)

- the algorithm’s speed

- the algorithm’s error rate

- the control operation mechanisms allowed by the algorithm for the human operator (e.g. no interaction (fully automatic), setting of individual algorithmic parameters off-line (semi-automatic), on-line guidance of algorithmic search (fully interactive))

- the algorithm’s ability to handle multiple objectives

It is possible that the above ‘matching’ process will fail to identify a scheduling algorithm which ‘matches’ the desired characteristics of a given task adequately. In this case, the analysts will either provide guidelines on the design of a new case-based algorithm for the scheduling subtask considered, or they will propose the suitable re-design of an existing algorithm which will lead to the desired implementation of a specific subtask.

3.1.3 Development of a requirements specification document

The activities described in sections 3.1.1 and 3.1.2 provide all necessary information for the interdisciplinary specification of the IT scheduling DSS. This information is presented technically in a novel interdisciplinary requirements specification document for the development of IT scheduling DSSs. This document will detail all functional and non-functional requirements of the system, as well as the design constraints of the implementation, in a similar way to a typical requirements specification document employed in conventional software engineering projects. A template-style description of the document and its contents is provided in the following paragraph.

3.1.3.1 A template for the interdisciplinary requirements specification of IT scheduling DSSs

i) Introduction

The purpose and the contents of the document are described.

ii) The company

A short history and a description of the company is provided. The description includes essential information on the company's profile such as the main aim and objectives of its operation, its commercial activities, the number of staff employed and the main considerations of its current business plan.

iii) Objectives of the scheduling process

This section outlines the high-level objectives of the scheduling process (managerial and departmental objectives). The implementation of the scheduling system should support the fulfillment of these objectives.

iv) The current scheduling environment

A detailed description of the current scheduling environment is provided from the human, organizational, and technological perspectives. This description is based on the findings on the modeling activities, as described in section 3.1.1.

v) Functional requirements of the IT scheduling DSS

This section describes in detail the functional requirements of the new IT scheduling DSS. In particular, it models the autonomous subtasks that will be implemented by the new system in cooperation with the human scheduler. The use-case modeling mechanism (of the software industry standard Unified Modeling Language (Rumbaugh et al., 2004)) is employed for this purpose. For each use-case identified, a template-style description of the use-case is developed. The descriptions of the use-cases provide detailed information on how specific scheduling subtasks will be implemented through the new system, including alternative flows and handling of unexpected situations. In addition, the objectives associated with the implementation of each subtask are specified.

vi) Non-functional Requirements

This section allows the specification of non-functional attributes of the new IT scheduling DSS such as:

- Usability requirements (examples include: specification of times for tasks to be implemented, required training times for users, help facilities)
- Reliability requirements: (examples include: availability of the system, expected mean time before failure)
- Performance requirements: (examples include: response time of the system, capacity of the system)

- Supportability requirements: (examples include: ability of the system to adapt to engineering and IT infrastructure changes in the production environment, maintenance procedures)

vii) Design Constraints

This section indicates any restrictions imposed on the technical implementation of the system. These restrictions might include the operating system platform on which the IT scheduling DSS will function, as well as any standards and protocols on data representation which are currently used in the production environment.

3.2 Design phase

The principal aim of the design phase of the interdisciplinary SDLC is to develop the necessary design specification documentation for the implementation of the IT scheduling DSS. The activities of the design phase will rely heavily on the results of the Analysis phase, as these have been documented in the interdisciplinary requirements specification document. The design specification for the IT scheduling DSS will consist of three main parts. In particular:

i) Design specification of the core algorithms

The findings of the algorithm selection process will define the algorithms that should be used for the efficient implementation of the specific subtasks allocated to the scheduling decision support system. Their design specification will consist of typical algorithm design descriptions such as pseudo-code or flowchart models.

As it has been indicated in section 3.1.2, one of the possible outcomes of the algorithm selection process might be the lack of a suitable existing algorithm for the implementation of a scheduling subtask allocated to the IT scheduling DSS. In this case, a new algorithm which will be able to handle the specific subtask will be designed. Its design might be based either on a custom-built development effort, or on the appropriate modification of an existing scheduling algorithm.

ii) Design specification of the Graphical User Interface (GUI) subsystem

The design of the GUI for the new IT scheduling DSS will be primarily based on the description of the use cases provided in the requirements specification document. Since the description of these use cases will be based on an interdisciplinary view of the scheduling environment, it follows that the GUI subsystem will address the required human, organizational and technological issues adequately. During the design phase of the process these use cases will be extended to include detailed information on the step-by-step interaction between the users and the IT scheduling DSS, including all the alternative and exception paths of the interaction.

iii) Design specification for the database subsystem

The operation of the new IT scheduling DSS requires the existence of a database system that will store scheduling information necessary for the implementation of scheduling subtasks by the algorithms. The identification of the necessary information will be based on the description of the use cases provided in the requirements specification document. The organizational and technological model of the current scheduling environment will indicate the current source and form (electronic, written, verbal) of this information. All previous data will lead to the formation of an Entity Relationship Diagram (ERD) data model of the new scheduling DSS. This diagram will be transformed into a relational schema which will form the basis for the realization of the database subsystem.

3.3 Implementation & Testing phase

The final phase of the interdisciplinary SDLC includes all necessary tasks for the implementation and testing of the IT scheduling DSS. The implementation of these tasks will be based on the specifications produced during the Analysis and Design phases. In particular, the following tasks will be implemented:

i) Programming tasks

These tasks will include the implementation of the code for the realization of the three main subsystems (as described in section 3.2), the implementation of the code for the integration of the subsystems, and the implementation of the code for the interface of the IT scheduling DSS with other IT systems that produce or consume information related to it (as described in the organizational model of the scheduling environment)

ii) Documentation tasks

The development of appropriate documentation is essential for the proper operation and maintenance and of the IT scheduling DSS. During this phase of the SDLC, the Installation Manual, the User Manual, and the on-line help facilities of the system will be developed. In addition, the Requirements & Design specification documents will be reviewed and finalized.

iii) Testing tasks

The last technical activity of the SDLC will concern the deployment and beta-testing of the prototype version of the IT scheduling DSS within the scheduling environment for a limited period of time. The performance of the new system will be assessed with regards to its compliance to the specified (in the requirements specification document) functional and non-functional requirements. In addition, all stakeholders of the scheduling process will evaluate the satisfaction of the low-level and high-level objectives of the decision support system (as these have been specified in the requirements specification document). This information will be utilized for the implementation of necessary improvements to the IT scheduling DSS, which will be subsequently ready for its deployment and operation within the industrial environment.

4. Conclusions / Future Research

This paper introduces a novel interdisciplinary software engineering process for the design of IT scheduling Decision Support Systems. In this way it makes an interdisciplinary theoretical contribution to the research fields of software engineering and scheduling. The aim of the proposed process is the development of IT scheduling Decision Support Systems which will provide meaningful assistance to the implementation of day-to-day scheduling tasks within a realistic industrial environment. The process employs typical software engineering phases, which are suitably modified to explicitly consider human and organizational considerations of the industrial scheduling environment considered. The use and design of scheduling algorithms is considered to be just one of the activities implemented during the overall process. This is in contrast to the conventional production research approach which implicitly anticipates the scheduling environment to ‘fit’ the designed scheduling algorithms.

The next stage of the research work described in this paper concerns the testing of the proposed interdisciplinary software engineering process through its application on the implementation of a real IT scheduling Decision Support System. The provisions of the process are currently followed in the case of new IT scheduling DSS for a company of the Cypriot SME sector. These results will be used both for the validation of the proposed process, as well as the implementation of corrections and improvements based on the experience and data that will be gathered through its application on the case study.

References

Berglund, M., Karltun, J., 2007, Human, Technological and Organizational Aspects Influencing the Production Scheduling Process, International Journal of Production Economics, 110, 160-174.

Cegarra, J., 2008, A cognitive typology of scheduling situations: A contribution to laboratory and field studies, Theoretical Issues in Ergonomics Science, 9(3), 201-222.

Corbett, J.M., 1987, A psychological study of advanced manufacturing technology: the concept of coupling, Behaviour and Information Technology, 6, 441-453.

Jackson, S., Wilson, J.R., MacCarthy, B.L., 2004, A New Model of Scheduling in Manufacturing: Tasks, Roles, and Monitoring. Human Factors, 46, 533-550.

Lodree, E. J. Jr., Geiger, C. D., Jiang, X., 2009, Taxonomy for integrating scheduling theory and human factors: Review and research opportunitie, International Journal of Industrial Ergonomics, 39, 39-51.

MacCarthy, JR Wilson (Eds.), 2001, Human performance in planning and scheduling, Taylor and Francis, London.

Mckay, K., Pinedo, M., Webster, S., 2002, Practice-focused research issues for scheduling systems, Production And Operations Management, 11, 2, 249-256.

McKay, K.N., Wiers, V.C.S., 2003, Integrated decision support for planning, scheduling, and dispatching tasks in a focused factory, Computers in Industry, 50, 5-14.

Pinedo, M. 1995, Scheduling: Theory, Algorithms and Systems, Prentice Hall, Englewood Cliffs.

Riezebos, J., Hoc, J-M., Mebarki, N., Dimopoulos, C., Wezel, W.M.C. van, Pinot, G., 2010, Design of Scheduling Algorithms, in Behavioral Operations in Planning and Scheduling, 299-322.

Rumbaugh, J., Jacobson I., Booch, G., 2004, The Unified Modeling Language Reference Manual (2nd Edn.), Wesley, Boston, MA., USA

Slack, N., Chambers, S., Johnston, R., 2004, Operations Management, Prentice Hall.

Smith, S., 2003, Is scheduling a solved problem?, Proceedings of the First MultiDisciplinary International Conference on Scheduling: Theory and Applications, Nottingham, UK, 3-18.

Van Wezel, W., Cegarra, J., Hoc, J.-M., 2010, Allocating Functions to Humans and Algorithms in Scheduling, Behavioral Operations in Planning and Scheduling, 339-370.

Wäfler, T., 2005, Human Factors in Shopfloor Planning, Scheduling, and Control, in Proceedings of the International Conference of Production Research (ICPR ’05), Salerno, Italy.