Designing Interdisciplinary Scheduling Decision Support Systems in Small-Sized SME Environments: The i-DESME Framework

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Abstract. This paper introduces i-DESME, an interdisciplinary framework for the design of IT scheduling Decision Support Systems in small-sized SME industrial environments. The proposed framework adopts a structured software engineering design approach, which has been suitably modified in order to explicitly identify and model the interdisciplinary characteristics that dictate the implementation of scheduling processes within an SME industrial environment. The framework aims to help practitioners design support systems which are not only effective, but are also being trusted and adopted for use by human schedulers. An overview of the framework's application within the environment of a typical micro-sized food manufacturing company is provided.

Keywords: Scheduling, Decision Support Systems, Function Allocation, Interdisciplinary Design, Case Studies

1 Introduction & Background

The implementation of scheduling processes in realistic industrial environments consists of a large number of interpersonal, interdepartmental tasks, which are carried out dynamically by a human scheduler (or a team of human schedulers) in cooperation with other human or non-human 'actors', including IT systems [1]. These actors exchange information in various formats (electronic, printed, hand-written, verbal), in a manner which is not necessarily standardised or coordinated. In addition, this implementation is subject to various organisational, cognitive, psychological, and sociological characteristics, which cannot be readily incorporated within a typical mathematical process model.

Since 1992, when Kerr published his seminal article on a failed implementation of a production scheduling system [2], the research community about human and organizational factors in scheduling paved the way for successful implementations of interdisciplinary DSS. More precisely, during the last decades a considerable number of researchers have questioned the usability of scheduling algorithms and the level of

adfa, p. 1, 2011.

trust placed to off-the-shelf IT scheduling decision support systems (DSS) within realistic industrial environments. In addition, IT decision support is rarely provided to human schedulers in micro and small-sized SME (Small to Medium Enterprises) industrial environments, even though SMEs (and especially micro-sized SMEs) constitute a large part of the financial basis of the industrialised world. As a result, significant research efforts in the area of scheduling are currently devoted to the investigation of the following questions:

i. *Can we design scheduling DSS which provide effective support to human schedulers in realistic industrial environments? (including micro and small-sized environments)*
ii. *Can we design scheduling DSS which are adopted and trusted by human schedulers during the implementation of scheduling tasks?*
iii. *Can we design scheduling DSS which efficiently exploit the operation of production research algorithms for the benefit of the human scheduler?*

Various approaches have been suggested for improving the efficiency, usability and adaptability of scheduling DSS in realistic industrial environments. However, a structured software development framework for their implementation which simultaneously addresses the previous considerations is considered as scientifically challenging [3] and has yet to be proposed. The research presented in this paper provides a contribution towards this goal by introducing i-DESME (i-nterdisciplinary DEsign for SMEs), a structured interdisciplinary framework for the design of scheduling DSS in micro and small-sized SME manufacturing environments. The intuition behind the development of the i-DESME framework has its origins in the works of [1] and [4,5,6,7].

The remainder of this paper is organised as follows: The activities of the proposed i-DESME framework are described in detail in Section 2. The application of the i-DESME framework for the case of a typical micro-sized manufacturing SME is overviewed in Section 3. Finally, the conclusions of this research effort are discussed in Section 4 of the paper.

2 The i-DESME Framework

2.1 Overview

The i-DESME design framework introduces a case-based structured approach to the design of scheduling DSS in micro and small-sized SME industrial environments. The main features of the i-DESME framework are the following:

i. Structured, modelled-driven software engineering approach to system development.
ii. Interdisciplinary modelling and analysis of the scheduling environment (organisational, technological and cognitive modelling).
iii. Function allocation between the support system and the human scheduler.

iv. Interdisciplinary evaluation of the suitability of scheduling algorithms for the support of specific scheduling tasks / subtasks.
v. Modelled-driven specification of the system's functional, non-functional and data requirements
vi. Modelled-driven specification of the system's architecture

The main operational phases and the information flow of the i-DESME framework are presented in figure 1.

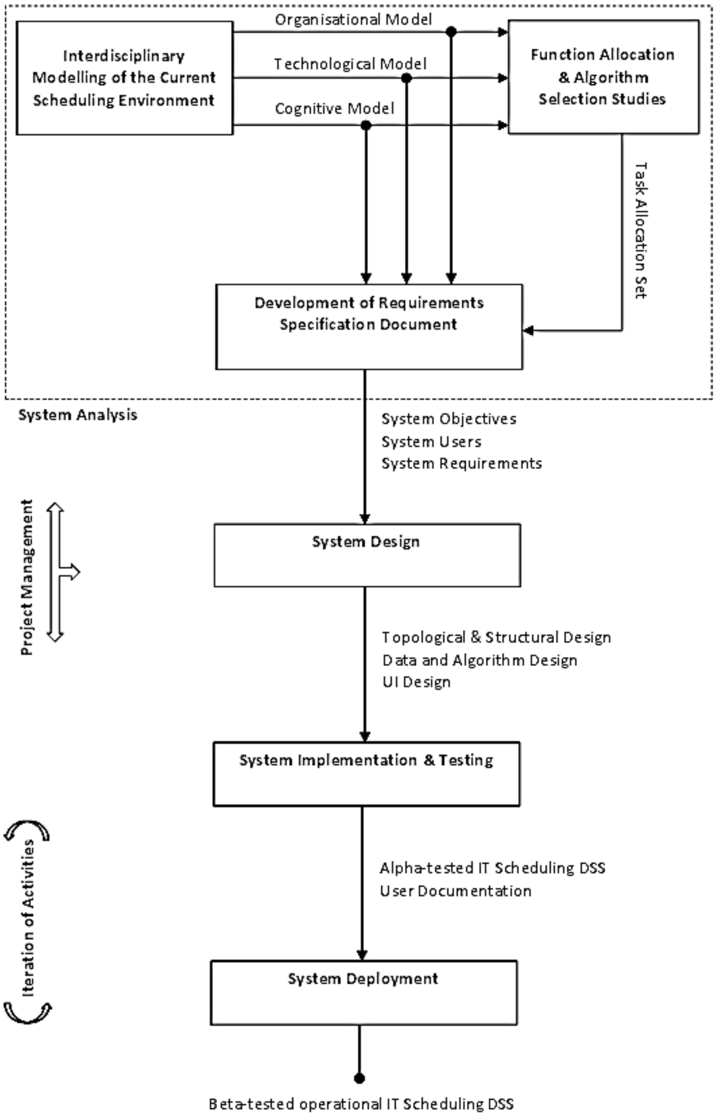

Fig. 1. Overview of the i-DESME framework

Standardised software engineering phases are defined for the development of the scheduling DSS. These phases have been suitably modified and enhanced in order to explicitly consider the interdisciplinary characteristics of the scheduling environment, the presence of the human scheduler, the possible algorithms which can provide support on the implementation of scheduling subtasks, and the allocation of functions between the human scheduler and the support system. The intuition behind this approach is that the resulting support system will provide meaningful support to the human scheduler by "fitting" the interdisciplinary characteristics of the particular scheduling environment, while simultaneously exploiting the efficiency of research scheduling algorithms that exist (or can be designed) for her / his scheduling tasks.

2.2 i-DESME phases: Analysis

The analysis phase of the i-DESME framework covers and extends the conventional scope of a typical SDLC analysis phase by suggesting the implementation of a comprehensive set of modelling, evaluation, and specification activities. In particular:

The proposed framework introduces a 3-dimensional layered approach to the modelling of the scheduling environment. The modelling of the scheduling processes starts from the external organisational layer and progress towards the inner layers utilising modelling information which is progressively generated. Organisational modelling activities primarily aim to identify the scheduling processes implemented by the company, the stakeholders of their implementation, and the flow of scheduling information in and out of these processes. Organisational charts and context diagrams are employed for this purpose. Modelling activities continue with the technological modelling of all the company's scheduling processes which have been identified during the organisational modelling layer activities. Technological modelling activities provide an unambiguous (to the largest possible extend) description of the scheduling processes' implementation using UML Activity Diagrams, mathematical programming models, and data flow diagrams. The framework's modelling activities conclude with the implementation of cognitive modelling activities, which provide a detailed examination of the company's scheduling processes from the human scheduler's perspective. Typical hierarchical task analysis and cognitive task analysis methodologies are employed for this purpose. An analytical description of i-DESME's modelling activities can be found in [8].

At the culmination of the interdisciplinary modelling activities an interdisciplinary representation of the current ('as-is') implementation of the scheduling processes within the environment of the micro / small-sized SME company has been generated. This modelling information provides the basis for the implementation of function allocation and algorithm selection studies on the future ('to-be') implementation of the scheduling processes based on the suggestions of van Wezel et al. [9]. The proposed studies initially evaluate the interdisciplinary characteristics of the tasks which are carried out by the decision maker during the current implementation of the scheduling processes. This evaluation leads to a description of the suggested control mode for the future ('to-be') implementation of these tasks. In addition, scheduling algorithms which 'fit' the characteristics of scheduling tasks are identified and their interdisciplinary characteristics are evaluated. The result of the function allocation / algorithm selection studies is a task allocation set for the future implementation of scheduling processes.

The final stage of the analysis phase shifts the focus of the framework's efforts from the current ('as-is'), to the future ('to-be') implementation of the scheduling processes within the micro / small-sized SME industrial environment. This is achieved through the iterative development of the software requirements specification document which describes unambiguously how the future implementation of these processes will take place with the aid of the scheduling DSS. The specification is generated by explicitly considering the interdisciplinary modelling characteristics of the particular micro / small-sized industrial environment. The finalized requirements specification document describes the new system's objectives, potential benefits, as well as its anticipated users and stakeholders. In addition, it specifies the system's functional (through UML Use Case Diagrams) and non-functional requirements. A detailed description of i-DESME's requirements specification process can be found in [10].

2.3 i-DESME phases: Design

The requirements specification document provides the basis for the development of the design specification of the scheduling DSS. The design specification document is developed in an iterative way, using draft artifacts as communication tools between the system developers, the system analysts and the system stakeholders. This specification focuses on generating an architectural representation of the scheduling DSS which will be able to offer the services outlined in the requirements specification document. In particular, it specifies the topological, structural, algorithmic, data and user interface (UI) parameters of the system to be implemented.

2.4 i-DESME phases: System Implementation & Testing

The specification of the support system's requirements and architecture provide the necessary input for the initiation of the framework's implementation and testing phase. Coding and documentation activities lead to the construction of the system's operational software version which will be deployed within the industrial environment of the micro / small-sized SME company. While coding activities do not directly benefit from the interdisciplinary artifacts of the proposed framework, the development of the user documentation is founded on the support system's analytic use-case descriptions, as these are outlined in the requirements specification document. The same descriptions provide the basis for the validation and verification of the DSS's functional and non-functional specifications, through the implementation of alpha-testing activities.

2.5 i-DESME Phases: Deployment

The smooth deployment of the scheduling support system within the company's environment is a crucial step towards its successful adoption by the human scheduler. The generation of trust (from the human scheduler's point of view) requires a gradual introduction of its functions within the manufacturing environment. The i-DESME framework employs the topology diagram design model for the installation and deployment of the support system within the environment. The system functions are subsequently beta-tested in off-line mode by the human scheduler using realistic production data from past production periods and the corresponding use-case descriptions. After the implementation of improvements and corrections based on the results of the beta-testing process, the scheduling DSS is ready to enter its first operational phase in the company's environment.

3 The i-DESME case-study

The i-DESME framework was applied in the industrial environment of a company which specialises in the manufacturing of food products. The target company was a family-run micro-sized SME, which has been in operation since the beginning of the 20th century. The company produces various types of traditional sweets in a purpose-built manufacturing facility. The company employs 10 workers for the implementation of its manufacturing processes.

The presentation of the full case study results is not possible within the size constraints of this paper; however, it is interesting to note some of findings of the inter-disciplinary modelling process which can be considered typical for the scheduling environment of a micro-sized industrial SME. In particular:

- No long-term scheduling processes (aggregate production planning, material requirements planning) are implemented by the company in an organised manner. Raw materials are ordered and stored in adequate quantities whenever they are available, due to the peculiarities of the local supply chain
- The principal actor during the implementation of scheduling processes is the company's CEO, who is also responsible for the implementation of most other company's business processes, facing an extremely heavy daily cognitive load
- The CEO does not employ any form of IT support for decision-making purposes.
- All scheduling information is communicated on a hand-written, non-standardised format
- The company has not developed any cost models for the implementation of its manufacturing processes
- The human scheduler (the company's CEO) utilises information during the implementation of the scheduling processes which is not readily available in a 'visible' format. The scheduler calculates this information cognitively, based on his experience

A scheduling DSS was subsequently specified, based on the previous findings. The developers and the system stakeholders agreed on a support specification with clearly articulated objectives and anticipated benefits. In particular, the aim of the new system would be to help the human scheduler make informed, reliable scheduling decisions, with a lower cognitive load, through the interactive generation and evaluation of potential scheduling solutions. The system would provide an electronic repository of all scheduling information, allowing the long-term improvement of scheduling processes. In this way, the system would offer effective support to the human scheduler for the future ('to-be') implementation of scheduling processes, while 'fitting' the characteristics of his environment and exploiting the efficiency of scheduling algorithms.

The specification of the support system's requirements provided the necessary input for the realisation of the system through the implementation of the framework's subsequent phases, namely the design, system implementation and testing phases. The final phase of i-DESME's framework concerned the deployment of the support system within the company's scheduling environment. The system was beta-tested for a limited amount of time using realistic scheduling information, operating in parallel with the existing manual system of the scheduling processes' implementation. The IT scheduling DSS has since become an integral part of the implementation of the scheduling processes within the company's environment. From a usability perspective, this stresses the usefulness of the proposed approach in order to design an adopted DSS.

It should be noted that a proper scientific evaluation of the applicability and benefits of the proposed framework will require its application on multiple industrial environments of various types and sizes, as well as the long-term operation of the developed support systems within these environments. However, the implementation of the IT scheduling decision support system for the case of a typical micro-sized SME company provides encouraging indications on the usefulness of the proposed approach in similar environments especially in relationship to the three highlighted questions, as well as valuable information for the improvement of its suggested activities in future applications.

4 Conclusions

While there are many publications about scheduling DSS, they tend to focus on the mechanical process of generating a schedule and are too limited to provide comprehensive solutions to real-world problems [4]. Indeed standardized software engineering phases have already been separately adapted for the interdisciplinary development of scheduling DSS (e.g., [5] for interface design, [9] for function allocation). But an integrated framework had yet to be proposed and unrolled in a realistic industrial environment. In this way, the i-DESME framework introduces a structured interdisciplinary model-driven approach to the development of scheduling Decision Support Systems in micro / small-sizes SME industrial environments. The application of the proposed framework leads to the development of IT scheduling decision support systems which ‘fit’ the environment of the human scheduler and can therefore be trusted and adopted for use during the realistic implementation of scheduling processes.

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