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An approach based on constraint satisfaction problems to disruptive event management in supply chains

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ABSTRACT

This work introduces a generalized model for evaluating and restoring feasibility in the execution of supply chain processes. The model was designed to provide automation to the disruption management function of Supply Chain Event Management (SCEM) systems. The repair mechanism is based on a constraint satisfaction problem that can be automatically instantiated from self-contained descriptions of the ongoing schedules without previous knowledge of the supply chain structure. The proposed mechanism intends to make surgical modifications to the current schedule which do not affect the economical and operational considerations and the allowed changes are limited to the space of slacks already included by the original schedule. This level of repair can be safely delegated to automated systems and would facilitate the design of collaborative inter-organizational business processes to manage events along the supply chain. A case study validates the applicability of the proposed models.

1. Introduction

Enterprises engaged in collaborative planning processes create and maintain production and distribution schedules synchronized with the schedules of other members in the supply chain. During the execution, disruptive events affecting the schedules and their synchronization usually occur. To increase the ability of the supply chain to respond minimizing the impact of these disruptions, Scheduling Systems generate schedules prescribing some sort of resource reservation which might be able to absorb variability during execution such as buffers of material, resource capacity and time. These slacks are used to avoid the need of a new scheduling task, which can be costly and time consuming since all enterprises involved in the supply chain should agree on new synchronized schedules.

As schedules are affected by disruptive events they require an execution control process capable of disruption management. Current Supply Chain Management Systems lack of systematic approaches to disruption management. In practice the decision process taking place given the disruption is loosely structured, managers are seldom supported by systematic methodologies to cope with the problem caused by the disruption, and when they do, the solution is usually a full re-scheduling task.

Information systems that support execution control processes capable of disruption management have been called Supply Chain Event Management (SCEM) Systems (Masing, 2003; Zimmermann, 2006). SCEM systems should provide functionality for: capturing/predicting disruptive events that could affect the schedule execution; checking if schedules are still feasible after the occurrence of a disruptive event; and searching for solutions to locally repair schedules affected by a disruptive event (Guarnaschelli, 2012).

Focusing on the last two functional requirements, this paper presents a model driven development approach (Hailpern and Tarr, 2006), to automate the activities of *feasibility checking of schedules* in presence of disruptive events and *repairing of disrupted schedules* using a mechanism based on constraint satisfaction models.

The approach proposes a reference model as a platform independent meta-model, which allows the representation of ongoing schedules previously generated by the Scheduling Systems of the supply chain partners. When representing the availability of resources and the specification of supply process orders (SPOs), the reference model provides systematic elements to capture the slacks of the original schedules in a way that is suitable for analyzing feasibility in presence of disruptive events. This common representation for schedules allows the analysis of concurrent execution schedules from different business partners in a supply chain.

From an instance of this reference model a constraint satisfaction problem (CSP) for schedule feasibility checking and repairing

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can be automatically derived through a model-to-model transformation. Based on this CSP, a mechanism for the automatic repair of disrupted schedules is implemented. This mechanism is able to check if the schedules are still feasible after the occurrence of a disruptive event, and then, to search for solutions using scheduled slacks, avoiding the triggering of a new process of rescheduling and coordination among the Scheduling Systems of the supply chain partners.

The changes to be introduced in a schedule to restore its feasibility are limited by the slacks on resources and orders. The aforementioned repair mechanism keeps unchanged every economical and operational target set when schedules were created. The objective is to absorb as many disruptions as possible within previously agreed operational slack without resorting to a new rescheduling task.

This paper is organized in the following way. Section 2 discusses related works. Section 3 describes a component-based architecture of a collaborative SCEM system which is the information system framework for the models proposed here. Section 4 presents a reference model for disruptive event management. Section 5 presents a constraint satisfaction model for feasibility checking and repairing of schedules. Section 6 presents a mechanism for the automated repair of disrupted supply processes. Section 7 describes the implementation details of the transformation engine. Section 8 presents an empirical validation of the approach through a case study, and Section 9 presents conclusions and future work.

2. Related works

The subject of this work is mainly related to three research areas: event management in complex software systems; rescheduling of manufacturing and distribution processes; and SCEM systems.

Disruption management in the execution of supply processes can be seen from the perspective of exception handling in complex software systems such as Workflow Management Systems, Process Management Systems and Self-healing Systems. In Workflow Management Systems, the support for exception handling goes from the definition of exception handlers and methods for the specification of exceptional behavior to classification and forecasting of exceptions (Hwang and Tang, 2004; Song and Han, 2003; Yuan et al., 2008). In Process Management Systems the definition of exception handlers invoked under given conditions provide support for given types of exceptions (Hamadi et al., 2008; Weske, 2007). Self-healing Systems are intended to provide support for diagnosing faulty situations and selecting and/or searching for recovery strategy (Friedrich et al., 2010; Griffith et al., 2009). While these approaches are useful frameworks for managing exceptions of general business processes, the nature of disruptions in the specific domain of supply chain processes need to be further exploited to build more powerful corrective actions to re-establish feasibility at the same time the disruption is being handled. Inspired in these approaches, the proposal of this work provides this additional feature by capturing, in a systematic way, the aspects of the supply process feasibility needed to automate a reparation mechanism.

Rescheduling is the current practice for facing disruptions during the execution of production and distribution processes. In the literature, different formulations for manufacturing rescheduling problems have been reviewed (Aytug et al., 2005) and different strategies to restore schedule feasibility are evaluated (Pfeiffer et al., 2007).

Rescheduling research works on distribution processes consider logistics networks and the underlying transportation resources with a set of assumptions on the behavior of the vehicles and loading and unloading on depots as in the work of (Li et al., 2009a, b).

Rescheduling approaches as the mentioned above are mainly devoted to provide centralized decision making and largely dependent on typified processes. They cannot be easily extended to collaborative multi-organizational supply chains. They are suitable for supporting the individual rescheduling task of each sub-node in the supply chain but provide rather little support to help restoring a collaborative execution schedule. An approach that supports supply chain operations coordination based on a distributed search algorithm inspired by constraint programming has been proposed by (Gaudreault et al., 2012).

Supply Chain disruption management has been discussed in specific industrial contexts. A proposal for rescheduling under disruptions is introduced in the work of (Arief Adhitya and Karimi (2006)). It addresses the event management problem by the previous definition of a cause-effect graph between supply chain entities; upon this graph a rescheduling strategy is introduced. This strategy requires knowing the formulation of the scheduling models of every supply chain partner. In contrast, our approach does not make any assumptions on the supply chain structure and does not require any knowledge about the methodologies used to build schedules. The repair mechanism is fully functional through an automated transformation from the schedules, output of the scheduling systems, and the support for new processes or partners is automatic.

The schedule repair methodology described in this paper should not be considered a rescheduling approach but a subordinate decision problem suitable to be delegated to an autonomous repair mechanism with the aim of systematizing the usage of the slacks already provided in the original schedule

Therefore, the degrees of freedom in our approach are constrained within the original schedule slacks and should never require a re-assessment of the performance measures. For this reason, the feasibility model is only involved with capturing the requirements of the scheduled supply processes and their relationship with the availability profile of the resources.

This reduction of scope in the decision problem is the key enabler of a generalized formulation that can be applied to any sort of supply process and is intended to perform as an autonomous supervisory component in the execution control layer. A failure in the repair will always fall back on a re-scheduling.

Research in SCEM systems has mainly been focused in addressing the monitoring, the capture and the communication of disruptive events. The ability to exert corrective control actions has been identified as an area barely explored (Bearzotti et al., 2008; Zimmermann, 2006). In this sense, a method based on multi-agent negotiation of previously defined recovery plans for searching solutions to disruptions was presented (Cauvin et al., 2009). This approach does not take into account the planned availability of resources versus the resource utilization by orders, therefore the decision support is limited to give recommendations to a decision maker that will analyze them and relies on the previous definition of generic recovery plans. Autonomous disruptive event management functions for automatically deriving repair actions fully executable are not provided.

A summary of DM (Disruption Management) related works is shown in Table 1.

3. Business process and architecture for a collaborative SCEM system

Both the repair mechanism and the constraint satisfaction problems derived from instances of the proposed reference model