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Designing a generic human-machine framework for real-time supply chain planning

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Abstract

Mixed-Initiative-Systems (MIS) are hybrid decision-making systems in which human and machine collaborate in order to produce a solution. This paper described an MIS adapted to business optimization problems. These problems can usually be solved in less than an hour as they show a linear structure. However, this delay is unacceptable for iterative and interactive decision-making contexts where users need to provide their input. Therefore, we propose a system providing the decision-makers with a convex hull of optimal solutions that minimize/maximize the variables of interest. The users can interactively modify the value of a variable and the system is able to recompute a new optimal solution in a few milliseconds. Four real-time reoptimization methods are described and evaluated. We also propose an improvement to this basic scheme in order to allow a user to explore near-optimal solutions as well. Examples showing real case of how we have exploited this framework within interactive decision support software are given.

Keywords: Linear optimization; Mixed-initiative systems; Supply chain optimization; Human-machine interaction; Tactical planning

1. Introduction

Most decision-making systems (e.g. planning or scheduling systems) found in enterprises lie on one of the following paradigms. The first one is fully automated systems. It is typically the case when an algorithm is used to find an optimal solution to the decision problem. In other cases, the planning is done by a human expert, sometimes with the help of a visual interface allowing him to get real time feedback regarding his decisions and choices. Surprisingly, quite a few optimization problems are planned manually as such. Indeed, automated planning tools are lacking of a political sensitivity or, more generally, do not take into consideration many important soft constraints that are often quite difficult to model (constraints that even human does not realize they exists before he sees a solution violating them).

Mixed-Initiative-Systems (MIS) [1,2] are hybrid decision-making systems in which human and machines collaborate in order to produce a solution. Most MIS-related research is done by the A.I. community and applies to discrete combinatorial optimization problems. The goal of our research is to propose MIS methods adapted to business optimization problems showing a linear structure, like mid-term/long-term production planning problems. Our approach may be suitable to many kind of industry as it is more problem oriented than industry oriented. It is particularly well suited for problems where human are involved in making a final decision (fine-tuning of the solution by a human is required, or human want to perform what-if analysis). In both situation real-time support by the system (instead of hour-long reoptimization) is needed.

Preliminary notions regarding MIS and supply chain optimization are provided in Section 2. The proposed Mixed-Initiative system for linear optimization is described and

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evaluated for a real-size industrial supply chain problem in Section 3. Section 4 introduces optimality tolerance for an improved flexibility in exploring solutions. Finally, Section 5 shows how we have exploited this framework within decision support software and presents recent industrial applications. Section 6 concludes the paper.

2. Preliminary notions

2.1. Mixed-Initiative Systems (MIS)

The motivation behind MIS is that human and machines show different strength [3]. Human has an implicit knowledge of the problem that cannot always be formalized. Human guidance can improve the performance of search algorithms [4]. Moreover, the decision-maker is often unaware of a constraint or an issue till he sees it in the solution proposed by the machine. In this context, involving the human in the search for the solution has some values.

The idea of involving human in model optimization can be traced back to as early as 1971 with the work of Benayoun et al. [5] in the context of multiobjective optimization. As mentioned by some authors [6,7], it is now well accepted that man-machine interaction can be valuable in solving complex optimization problems. Depending on the context, MIS provide different benefits. In some situations, the solution is produced using less computation time because the user can guide the search according to his intuition [4]. This is because humans generally outperform computers in visual perception and strategic thinking. In other contexts, the main interest is for the final solution to get a better acceptance level by decision-makers because it is more in line with informal objectives of the company/decision maker. It is also easier for decision makers to justify and improve solutions in which they participate, and they can implement their preferences and knowledge of the real world without complex and sometimes near-impossible mathematical modeling. Although in theory it is possible to increase user confidence in a solution through the use of explanation functions, building such functions is a difficult task for the designer of a decision-support system [8].

Meignan et al. [6] present an extensive review and a classification of interactive optimization methods in operations research. Their review allowed them to enumerate five classes of interactive optimization approaches. The authors explain that *interactive reoptimization* aims at adjusting the global solution when local changes are made by the user to a given solution. As all constraints are still enforced, local changes are propagated to the global solution through reoptimization [9]. Some interactive reoptimization methods are reported in [10]. In these cases, a reoptimization procedure is applied after a modification of the solution by the decision maker. This is done by freezing into the problem the modifications made by the user before optimizing again. This type of approach is not suitable when the optimization itself takes a long time. Moreover, adding constraints time and time again while interactively finding a satisfying solution can remove a lot of liberty for the solver to find solutions with good objective value. On the other hand, only fixing the last modifications made cannot ensure all previous changes made will be respected. Among examples, Williams et al. [11] are using game-based experiments to assess the potential of "human in the loop" optimization in the context of debris collection problems. In their approach, the user can adjust the multiple objectives themselves and tools are available to create a solution and give instant feedback on the solution they are building.

Most MIS- related researches target discrete combinatorial optimization problems such as timetabling [12], space mission planning and scheduling [13–15], air traffic control [16], military applications [17,18] etc. Different application domains present unique challenges. One concern is the diversity of the planning and scheduling constraints that appears in many domains. Smith et al. [19] have developed a computerized framework which allows building mixed initiative systems tailored to specific domain requirements. Their system was primarily used in the planning and scheduling of force deployment. Mixed-Initiative Systems have not yet made their way into business management systems such as those used for Supply Chain Management (SCM). We believe the main reasons are that (1) most of these situations can be modeled as linear optimization problems for which good algorithms exists, and (2) methods developed for classical A.I. planning could not easily be applied to those kind of problems.

2.2. Supply chain optimization

The goal of our research is to propose MIS methods adapted to business problems showing a linear structure model, such as supply chain optimization problems. Supply chains are formed by a set of business units that collaborate to produce goods. *Tactical supply-chain planning* consists of computing the amount of products to produced, consumed, stored or transported for each period of a given time frame with a precise objective to optimize. Common objectives are costs minimization or profit maximization [20,21]. Tactical supply-chain planning is a very important concern in the forest-products industry [22]. A single business unit produces many products at the same time from a single piece of raw material. This leads to an important interdependency between business units (e.g. forest operations supply many different types of industries at the same time, a sawmill supplies lumber to remanufacturing plants as well as chips to paper mills, etc.). Many mathematical models have been proposed [23,24] but most of the time they do not exploit decision makers' intuition and preferences.

These problems are typically solved using commercially available software like IBM ILOG CPLEX. They can solve problems having several hundreds of thousands variables in a few minutes, thanks to well-known algorithms like Dantzig's *simplex* method [25].

One shortcoming of these solvers is that they usually return one and only one solution for a given problem (defined as a set of variables, constraints and an objective function) – although thousand of alternative optimal solutions may exist. Most of the time, the returned solution is inadequate as the problem