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Dynamic workforce allocation in a constrained flow shop with multi-agent system

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ABSTRACT

The present work addresses the problem of real time workforce scheduling in assembly lines where the number of operators is less to the number of workstations.

The problem is faced developing a two-steps procedure made of (i) a centralized scheduling based on a constraint optimization problem (COP) for initial operator scheduling, and (ii) a decentralized algorithm performed by a multiagent system (MAS) to manage workers in case of unforeseen events.

In the proposed MAS architecture, Agents represent the operators trying to find local assignments for themselves. The system is validated with a simulation model and implemented with a hardware infrastructure in a real assembly line of electromechanical components. The main original contribution of the paper consists in proving – by means of both validation through a simulation model and test in a real assembly line of electromechanical components – that (1) multi-agent systems could be successfully adopted to solve a workforce scheduling problem, and (2) a combined approach consisting of centralized + distributed approach would provide better results compared with the application of one of the two approaches alone.

1. Introduction

In the last decade innovations in resources planning systems have allowed the improvement of production performances, through the optimal usage of physical and human resources. An example of human resources management can be found in workforce assignment problem.

Generally speaking, an operator scheduling problem is characterized by the operators assignment constrained to requirements of a certain number of operators per time slot and regulations of workforce utilization.

This COP is addressed with centralized approaches, which fail when dynamic events occurs, forcing to re-schedule the workforce several times.

In this context, the MAS approach can play a key role because Agents are able to interact, cooperate and negotiate tasks dynamically.

The present paper proposes an approach for workforce assignment in a U-shaped line where the number of operators is less than the number of workstations. The main point of this study is the flexibility of MAS applied to workers assignment problems, as well as to investigate the previous real applications of workforce management. The problem is approached in two main steps. In the first one we front the COP of operator scheduling for all the workstations with a *centralized solution* (*CS*). Then a *decentralized solution* (*DS*) is performed with MAS to support the CS in case of unforeseen events. The main original feature of the MAS conceived is that the Agents are the operators trying to find local solution assignments for themselves.

Provided that MAS is proved to be an optimal solution for workforce scheduling [1,5,44], our findings provide insights on: (i) how MAS can be adapted when scheduling is related to workers, and (ii) how a decentralized solution computed by MAS can be fast and effective in solving the workforce scheduling problem.

Communications between workstations is made through two dedicated buses and a central server. The system is validated through a discrete event simulator of the line.

The paper is organized as follows. After literature review, sections three and four describe the approach, its main components and the industrial case. The COP is discussed in section five;

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in section six we present the MAS for the DS. The last sections are related to discussions and conclusions.

2. State of art

2.1. Multiagent systems

A MAS can be intended [2] as a network of problem solvers in which each agent performs a particular function for other agents and this function gives it resources to survive. Agents are able to interact each other by reacting to external changes of environment working together toward shared goals [3]. Each agent might have unique skills and capabilities, and the team would like to balance its workload to be most effective [4,46].

In 2000s MAS has been widely adopted in industrial and manufacturing applications Leung et al. [47].

After the seminal work by Lin and Solberg [6], many other shop-floor control systems based on MAS were proposed for simpler problems, expanding to larger set of manufacturing scenarios [7,8,42].

When MAS are adopted in manufacturing, each machine is equipped with a software agent who represents the entity [9]. In job-shop scheduling Aydin and Fogarty [10] implemented a modular simulated annealing algorithm, with MAS running on distributed resource machines. Bajai et al. [11] developed an agent-based simulation environment to evaluate the impact of two negotiation factors and the due date slack.

More recently Homberger [12] presented an evolution strategy for the resource-constrained project scheduling problem, as well as its integration in a MAS to solve the decentralized resource-constrained one.

Raselo [13] used MAS to manage different information from the supply chain and from the internal/heterogeneous planning and supervision system. MAS have been seen as a base for agile reactions to unexpected events. Brandolese et al. [14] applied MAS to the capacity allocation problem at Supply Chain level extending the focus from the single factory to a network of companies.

MAS applications to workforce organization seems to be a less explored area. Among the few works partially addressing workforce organization through MAS, noteworthy is the paper of Brennan et al. [43], providing a control scheme for Manufacturing Workcells and a framework of self-organized agents. Another application of MAS in workforce management is the one of Chiu [15], with an intelligent Multi-Agent Information System infrastructure. A patent of Leamon [16] assesses a method of scheduling in a single or multi-site skills-based, applied in call centers.

2.2. Workforce organization

Workforce organization/scheduling aims to find employees arrangements to match time-varying customer demand for service [1]. According to Thompson [17], the traditional approach of workforce scheduling may consist of (i) staff requirements based on the demand; (ii) schedule shifts to meet staff requirements; (iii) real-time control to cover staffing requirements.

Existing researches on workforce scheduling may be grouped according to the type of goals:

- *Employees satisfaction and skills*: Alsheddy and Tsang [18] developed an algorithm to solve bi-objective optimization problems maximizing both organizational objectives and employees' satisfaction levels. Valls et al. [19] managed the problem of Skilled Workforce Project Scheduling Problem (SWPSP) by a hybrid genetic algorithm. SWPSP considers many real problems faced by the service centers such as client-company services. Celik et al. [20] proposed a novel modeling framework that enables an optimal workforce assignment of tasks considering both the short-term (e.g., productivity) and long-term aspects (e.g., robustness against loss of key personnel).
- *Wokforce dimensioning* has been addressed by Huq et al. [21] with mixed integer linear programming for a flow-shop to minimize makespan and workforce sizing. Naveh et al. [22] discussed a constraint programming approach for workforce identification problem. Their solution bridges the gap between the need for high-quality matches and timeliness, but it has limitations in the need of frequent maintenances of the model.
- *Workforce assignment in assembly lines*: Pappert et al. [23] focused the attention on heavy machine assembly scenarios where workers are the major resources. Alwadood et al. [24] presented a workforce schedule model for maintenance to minimize the average total time of maintenance services, maximizing the completed jobs. Noack and Rose [25] applied an optimization heuristic to a simulation-based approach to improve workforce utilization.
- *Workforce assignment in telephone centers*: Applications of workforce assignment can be found for telephone call centers where the uncertainty of arrival rates generates a relevant impact over scheduling [26–28,49]. Here the aim is to allocate and update the workforce to answer the incoming calls in the shortest times.

2.3. MAS and workforce scheduling

It is widely demonstrated that MAS can serve the needs of real-time distributed manufacturing environments [29,30].

MAS applications can also be found for the problem of workforce organization, but they are considerably of lower number. Brennan et al. [43] partially addressed this issue discussing the agent selection problem. Sabar et al. [31] presented a MAS approach for personnel scheduling in an assembly center with to minimize operational costs and personnel dissatisfactions.

On staff management, Tsang et al. [32] examined the resource exchanges with intelligent agents. Mousavi et al. [33] described a Resource Allocation Framework for Workforce Management.

Applications related to workforce scheduling do not consider dynamic events and their management in terms of reallocation procedures due to unforeseen events. The most part adopt centralized approaches which, albeit being able to provide optimal solutions, have poor performances in terms of responsiveness and re-configurability [7]. Main facts related to both machine and workforce scheduling problems are summarized in Table 1.

By analyzing the above Table 1, several similarities can be found in terms of goal and features (e.g., failure rate and human error).

Table 1
Machine/workforce scheduling comparison.

	Machine	Workforce
Goal	Schedule jobs over machines	Schedule manpower over machines
Resources	Machine	Manpower
Optimization criteria	Makespan; flow time; WIP; setup times; tardiness; lateness; throughput	Idle time; employees satisfaction; workers' balancing workload
Features	Machine availability; fixed production rate; machine failure rate	Human errors; variable production rate; skills; training; workers' motivation; boredom
Constraints	Job routing; due date	Overload; timetable worker constraint; maximum established dates