Shift Scheduling for the Effective Management of the Ageing Workforce*

Ioannis Chatzikonstantinou[1] [0000-0002-8282-928X], Aris Papaprodromou[1], Maria Loeck[2], Rosa Carreton[2], Sofia Segkouli[1] [0000-0001-7862-0451], Andreas Triantafyllidis[1] [0000-0002-6938-8256], Dimitrios Giakoumis[1] [0000-0003-1844-186X], Konstantinos Votis[1] [0000-0001-6381-8326], and Dimitrios Tzovaras[1] [0000-0001-6915-6722]

[1] Information Technologies Institute, Center for Research and Technology Hellas, 6th km Harilaou-Thermis road, Thessaloniki, Greece
http://www.certh.gr

[2] Asociación Nacional de Empresarios Fabricantes de Áridos, Plaza de las Cortes, 5 -7º, Madrid, Spain

Abstract. Aiming to address the needs of the ageing workforce in the context of shift work, we introduce a Participatory Work Orchestration Support Tool, with the aim of supporting decision making in deriving the periodic shift schedule of an organization. The proposed tool comprises two main components, an extensive and intuitive web-based platform that enables managers to gain an overview of their workforce and schedule, and an optimizing shift scheduler that works in the background to propose suggestions to the managers to improve scheduling, based on considerations of worker welfare and specifically targeting the ageing workforce. Preliminary testing of the tool in simulation yields encouraging results.

Keywords: Shift Scheduling · Ageing Workforce · Decision Support Tools · Participatory Scheduling.

1 Introduction

Shift scheduling is an integral part of any business or organization that operates on shift work as it is a very complex issue, especially when many shifts and large number of workers of various skills are involved. The aim of shift planning is to establish schedules for all activities and to assign each activity to a specific employee as effective planning helps in reducing labor costs while improving efficiency and employee satisfaction [1]. In addition, shift scheduling also needs to comply with certain labor regulations and each organization's rules and policies. Despite its advantages, unrestricted application of shift work is detrimental

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to various aspects of human health and well-being, among which the biological rhythm, sleep and social life of workers in general [2]. In addition, shift work leads to a number of clinical and non-clinical problems while at the same time being responsible for delaying human performance and increasing the likelihood of accidents at work . In order to meet organization production needs, without sacrificing health and well-being of an increasingly ageing workforce, it is mandatory to consider an approach to shift management that is respectful to both health- and regulation-mandated constraints, as well as individual preferences of the workers.

Aiming to address the needs of the ageing workforce in the context of shift work, a Participatory Work Orchestration Support Tool has been developed, which is addressed to organization managers, and with the aim of providing sufficient decision support tools to improve management of the ageing workforce. The developed tool comprises two major components: The first is an intuitive web-based manager platform, which facilitates workforce and shift management, with a focus on the needs of the ageing workforce, and also aiming to facilitate transfer of knowledge within the organization. The platform enables organization managers to visualize at a glance organization schedule and cumulative figures regarding their workforce occupation, as well as interact and respond to worker requests.

The second is an optimizing shift scheduling decision support tool, which works in the background, providing schedule suggestions to managers, in order to further facilitate decisions in complex scenarios. With respect to shift schedule optimization, we formulate the shift scheduling problem as a Mixed-Integer Linear Problem, which incorporates a single objective and multiple constraints, derived in accordance to established shift scheduling literature, but adapted to the specifics of managing the ageing workforce.

With respect to the shift schedule optimizer we validate the results of our proposed approach in synthetic scheduling data, and with respect to the web platform, we present the results of an Acceptance Study. Future validation plans involve a pilot trial, in the context of the AgeingAtWork project [3], to be carried out in one of end user premises, involving managers and workforce.

2 Related Work

This section presents a brief review of the state of art in the field of workforce orchestration and scheduling, addressing the need for orchestration solutions to enhance ageing workers' well-being, health and workability.

The mathematical problem associated with orchestrating a workforce within an organization is known as the shift scheduling problem. In it's basic form, the shift scheduling problem involves determining the number of employees to be assigned to various shifts and the timing of their breaks within the limits allowed by legal, union, and company requirements [4]. This problem definition has been variably extended and altered to address specifics in different applications and industries, considering a constantly changing repertoire of constraints, objectives and problem parameters, that align with trends in legal and organizational requirements and considerations [5].

In [6] authors report on a novel Binary Integer Goal Programming (BGP) model for the Shift Scheduling Problem with days-off preferences, applied to scheduling of shifts for power station workers. The problem formulation presented in the study considers a detailed, real-world set of rules and common practices used in the power industry. In addition, several soft constraints are introduced, stemming from organization practices. This study is of high relevance, as it includes worker preferences as an integral part of the model, and may form the base for further extending and incorporating age-related objectives and constraints.

In [7], authors report on a Genetic Algorithm-based approach to the homecare staff scheduling problem which involve identifying the optimal assignment of caregivers to outpatients with the aim of minimizing travel times on different means of transportation.

In [8] authors consider the problem of staff scheduling in a security department where workers work in shifts to cover a 24h per day operation. The problem formulation presented in the study considers physical workload balancing (e.g. avoiding consecutive workdays and "heavy" shifts), as well as satisfaction of worker preferences, which is introduced as the sole objective in the problem linear model formulation. Authors present scheduling results that balance worker's physical workload and good satisfaction of worker preferences.

In [9] authors report on the problem of staff scheduling in a pharmacology research company, considering workload sharing equity as the primary criterion. Workload equity, as a criterion, also accounts for soft skill levels and preferences of personnel. As an example, the paper outlined the workload of two nurses, one of which is more confident in writing medical reports than the other. Equity in this case is achieved by assigning additional clinical tasks to the employee with less administrative capabilities, while at the same time relieving the other of such tasks to better focus on medical report writing. Authors use constraint programming and a series of problem-specific search strategies in order to achieve objective value improvement.

In [10] authors address the aspect of operational variability in organizations, which is inevitably introduced as unforeseen external factors contribute to changes in the organization requirements or resource availability over time, thus mandating changes in staff scheduling. In particular, three types of variability are considered: Uncertainty of capacity, uncertainty of demand and uncertainty of arrival. Authors propose a problem formulation, the Integrated Personnel Shift and Task re-Scheduling Problem (IPSTrSP), which aims to address static and dynamic scheduling needs in an integrated manner. They propose a metaheuristic algorithm that relies on solution perturbation and local search, to provide with reactive optimization in the face of unexpected scheduling changes. Authors present an extensive section with experimental results and parametric analyses on different parameters of the proposed algorithm.

In [11] authors present a Mixed Integer Programming (MIP) formulation for the problem of preference-based staff scheduling. The problem at hand comprises hard constraints (e.g. restrictions on working hours, vacations, training sessions etc.) and soft constraints (e.g. minimum allowable staff levels, maximum on-duty hours for each employee, employee requests etc.). The aim thus is to minimize soft constraint violation while satisfying hard constraints. Authors demonstrate that allowing near-optimal solutions using the proposed MIP model in fact results in well-performing solutions that are on par with manually generated schedules.

In [12] authors propose an optimization approach for train crew scheduling considering the fair distribution of unpopular tasks within the organization. In particular, a triplet of objectives is considered, namely minimization of schedule costs, minimization of schedule unfairness and minimization of schedule unpopularity. Authors present an extensive review of the notion of fairness in the context of scheduling, and go on to propose a constructive algorithm based on column generation to solve the scheduling problem, on instances that are taken from real-world scenarios.

Despite the wealth of related works, there is a need to cater to requirements concerning the ageing workforce, which is not fully covered in the existing state of art. The present work strives to contribute to this through the proposed Participatory Work Orchestration Support Tool, by introducing the elements of participatory management, through enabling requests of workers to be answered by managers, and introducing an intelligent optimizing decision support system, which makes suggestions based on a comprehensive range of decision criteria, including schedule fairness and ageing workforce-specific objectives and constraints.

3 Architecture

The architecture of the proposed Participatory Work Orchestration Support Tool follows the Model-View-Controller paradigm. An overview with key components is displayed in Figure 1. Four main components are distinguished: The first is the Manager Platform Front-end, which undertakes the Human-Machine interfacing task and organizes and displays information to the user, in this case the organization managers. The second is the Platform Controller, which is responsible for data aggregation and communication with the shift scheduling optimization module. The Shift Scheduling Optimization Module is responsible for generating optimal schedules based on constraints imposed by the managers and organization. Finally, the Model store includes all relevant information regarding the workforce and organization operations. In the following sections, the two key components of the Participatory Work Orchestration Support Tool, namely the Manager Platform and the Shift Scheduling Optimization module are presented in greater detail.

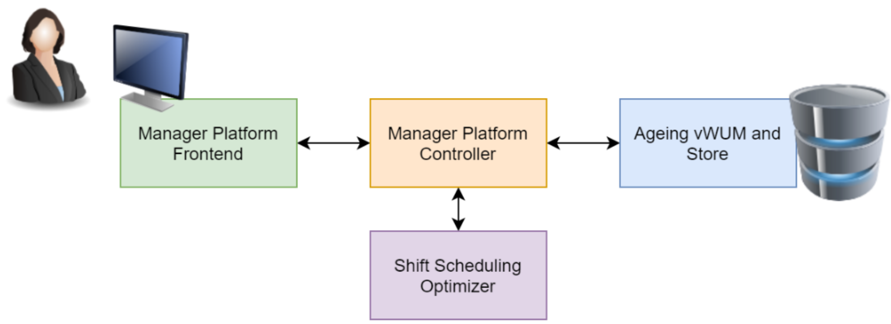

Fig. 1. The architecture of the proposed Participatory Work Orchestration Support Tool.

4 Manager Platform

The Work Orchestration platform is the first component of the Participatory Work Orchestration Tool that allows managers to receive an overview of the current situation regarding their organization shift and task assignments, and act on it to better adapt it to the needs of the organization and individual workers. The work orchestration platform is a web application that includes a number of separate views, all integrated into a main dashboard, each of which highlight a different aspect of the work organization schedule.

The main dashboard includes a series of overview panes on top, which highlight the main characteristics of the organization schedule: Workers, tasks, stations, remote sessions and worker requests. The manager can click on each pane to view a detailed view of each section.

In addition to the top panes, in the main section a series of views exist that give further insight into organization schedule. These can be selected via tabs on top. The first view is the Task-Shift table (Figure 2), which provides a Gantt chart-style depiction of the weekly tasks assigned to each shift as well as individual worker assignments. Each row corresponds to an instance of a task to be performed, and each column to a specific shift in a day. The cells in the table show where each task is scheduled to be performed, and to which worker the task is principally assigned. By hovering over the task assignment, it is possible to see details about the task, the skills required and the assigned worker.

Another view is the Weekly Shift view (Figure 3), which provides a more detailed breakdown of worker status for each shift. Columns in this display reflect shifts organized by day, while rows represent individual workers. Different situations can be visualized using distinct visual markers, allowing for a quick overview of the organization task assignments. In addition to the worker/task assignment overview, by hovering over the table cells the manager is able to obtain additional information regarding the particular assignment, such as the task being assigned, the state of the task etc.

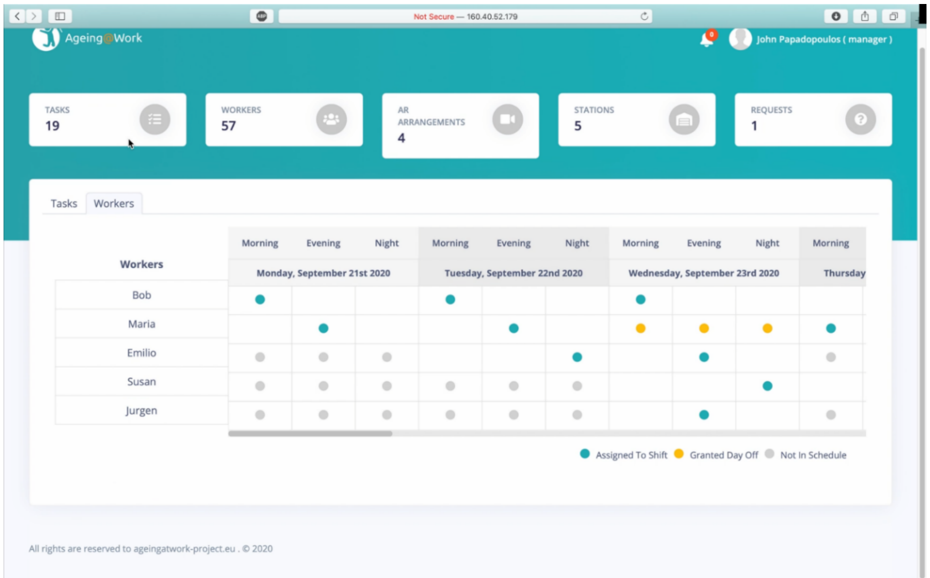

Fig. 2. The task-shift table view of the proposed Participatory Work Orchestration Tool.

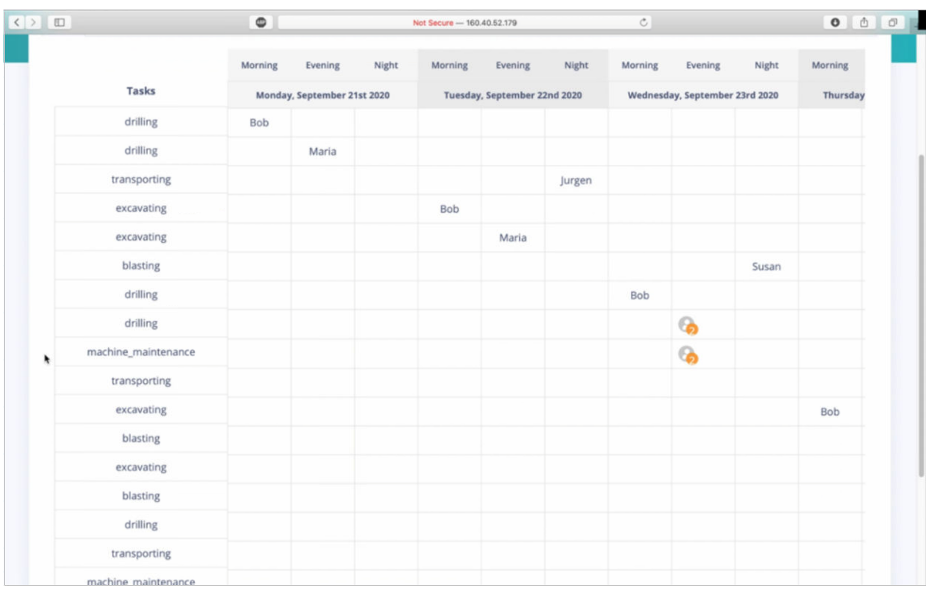

Fig. 3. The weekly shift view of the proposed Participatory Work Orchestration Tool.

5 Shift Scheduling Optimization

Shift scheduling is an integral part of any business or organization that operates on shift work as it is a very complex issue, especially when many shifts and large number of workers of various skills are involved. The aim of shift planning is to establish schedules for all activities and to assign each activity to a specific employee as effective planning helps in reducing labor costs while improving efficiency and employee satisfaction [13]. In addition, shift scheduling also needs to comply with certain labor regulations and each organization's rules and policies.

5.1 Problem Formulation

We formulate the shift scheduling problem as a Mixed-Integer Linear Problem, which incorporates a single objective and multiple constraints, derived in accordance to established shift scheduling literature, but adapted to the specifics originating from the goals defined in the AgeingAtWork project.

The main objective is to minimize worker assignments to shifts, subject to constraints related to production, safety and legal aspects. To model production-related constraints, we assume that in each shift a number of tasks need to be completed. Each task requires one or more skills. Each worker is associated to one or more skills in many-to-many relationships. As such, the main production-related constraint in scheduling is to ensure that workers with the required skills are present in each shift to successfully complete the corresponding tasks. Safety constraints stipulate minimum number of workers present during each shift, as well as presence of workers with safety-related skills. Finally, legal constraints limit the individual worker assignments on a daily, weekly and monthly basis, and prevent overnight continuous shifts. In addition to the essential problem definition outlined above, we consider a number of additional aspects that are outlined hereby.

Shift difficulty and fairness Fairness of shift schedule is a term that has been proposed to highlight the need of including the inevitable differences in difficulty that characterize each shift throughout the day and week. Factors determining shift difficulty may depend on the specifics of the organization or not. For instance, night shifts carry an intrinsic difficulty due to the time they occupy, which may lead employees to develop issues with sleep, or to socialization problems. On the other hand, specific shifts in an organization may include tasks of varying complexity, which is a factor affecting the perceived difficulty of the shift.

Remote work The AgeingAtWork project introduces a suite of tools aimed at remote collaboration, which allow flexible assignment of senior, experienced workers, who can be assigned to work from home or standby roles, while younger workers undertake tasks in the facility, under the remote guidance of seniors. These tools obviously introduce novel opportunities for shift scheduling, which are exploited in our approach. To the extent that shift scheduling is involved, this enables senior workers to be assigned to remote shifts, which are considered lighter load, while on-site workers can undertake multiple tasks that they are not experts in.

Shift preferences Workers can indicate their preferences regarding shift assignments, which are then considered in the generated schedule. This is performed by adjusting the difficulty factor of preferred shifts, thus guiding the scheduling algorithm to select them.

5.2 Mathematical Definition

Considering the following sets:
W, the set of workers
T, the set of tasks
H, the set of shifts
D, the set of days
S, the set of skills
, the following problem parameters:
K_{st}, parameter indicating task t needing skill s
P_{sw}, parameter indicating worker w having skill s
Q_{thd}, parameter indicating presence of task t in day d and shift h
U_{wd}, parameter indicating worker w unavailable in day d
and the following decision variables:
W_{whd}, worker w assigned to shift h in day d
R_{whd}, worker w assigned to remote work in shift h in day d
F_{wd}, worker w assigned day off in day d
$G_{df,max}$, aux variable representing the max assignment shifts of any worker
, minimize:

$$G_{df,max} \tag{1}$$

s.t.:

$$K_{st} \times Q_{thd} \leq \sum_{w \in W, h \in H, d \in D, s \in S} (W_{whd} + R_{whd}) \times P_{sw}, \forall s \in S, t \in T \tag{2}$$

$$W_{whd} + R_{whd} + F_{whd} = 1, \forall w \in W, h \in H, d \in D \tag{3}$$

$$\sum_{h \in H} W_{whd} + \sum_{h \in H} R_{whd} \leq 1, \forall w \in W, d \in D \tag{4}$$

$$W_{wnd} + W_{wm(d+1)} \leq 1, \forall w \in W, d \in D, n = H_{-1}, m = H_0 \tag{5}$$

$$U_{wd} + W_{whd} + R_{whd} \leq 1, \forall w \in W, h \in H, d \in D \tag{6}$$

$$\sum_{w \in W} W_{whd} \geq \sum_{t \in T} Q_{thd}, \forall h \in H, d \in D \tag{7}$$

$$\sum_{w \in W} W_{whd} \geq c_{W,\min}, \forall h \in H, d \in D \tag{8}$$

$$\sum_{w \in W} W_{whd} \leq c_{W,\max}, \forall h \in H, d \in D \tag{9}$$

$$G_{DF\,\max} \geq \sum_{h \in H, d \in D} (W_{whd} + R_{whd} \times Z_{remote}) \times Z_h \times Z_d, \forall w \in W \tag{10}$$

Equation 1 is the objective function that seeks to minimize the assigned tasks to workers. Inequality 2 ensures each task in a shift can be performed by at least one worker. Inequality 3 ensures no worker is assigned to multiple states at the same time. Inequality 4 ensures each worker only gets a maximum of one shift assigned per day. Inequality 5 ensures no worker gets consecutive shifts i.e. assigned to morning shift after a night shift. Inequality 6 ensures no worker is assigned to a shift on an unavailable day. Inequality 7 ensures for each shift there are at least as many workers as tasks. Inequality 8 ensures there are at least workers in each shift. Inequality 9 ensures there are at most workers in each shift. Inequality 10 is an auxiliary constrain that ensures the objective function variable corresponds to the max worker assignment. The above problem is solved using an open-source branch-and-cut mixed integer programming solver, CBC [14].

6 Experimental Results

6.1 Simulated Scheduling Data

This application example focuses on highlighting the potential of the AI-enabled shift scheduler in identifying favorable shift schedules, which ensure organization functional requirements, and at the same time satisfy worker preferences, to the extent possible given the scheduling problem definition. In order to illustrate this application, we assume the following scenario: A rapid-prototyping unit within an organization has 7 workers that tend two machines: A 3D printer and a Computer Numerical Control (CNC) router. Each of the two machines requires a different set of skills to operate; some skills are common (such as e.g. some safety-related skills), but others are unique. Workers also have different skill sets, depending on their specialization.

Here we consider a team of two 3D print technicians, three CNC technicians, and two safety technicians. In order to highlight the flexibility of the approach, we have designated one CNC technician and one 3D print technician to also have safety qualifications. In accordance to the tasks, a 3D print technician is

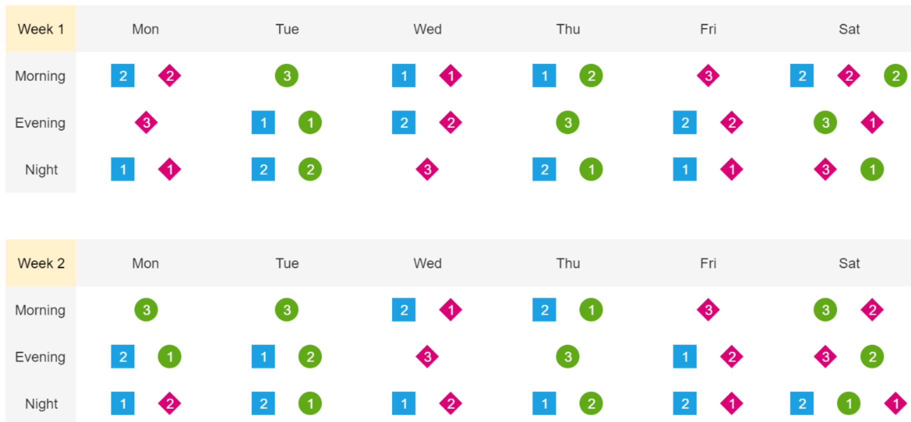

Fig. 4. Bi-weekly schedule generated by the Participatory Work Orchestration Tool for a team of seven workers.

required to operate the 3D printer, a CNC technician similarly is required to operate the CNC machine, and at least one safety technician needs to be present at all times. Each working day has three shifts: Morning, evening and night. Night shifts are considered the most challenging ones, with high difficulty rating, and morning shifts the easiest ones, with low difficulty rating. A two-week schedule is considered, with six working days, except Sunday. Saturdays are considered undesirable days, so they have greater difficulty rating. Assuming the above scenario, a MILP problem has been formulated, for determining the two-week shift schedule. The objectives, as outlined in subsection 5.2, are to maximize schedule fairness, subject to constraints as outlined in the same subsection. The schedule was successfully generated and the resulting task distribution is shown in Figure 4. We observe that all constraints (e.g. no consecutive shifts, no more than a single shift per day) are observed, and in addition, it was possible to distribute "difficult" shifts (e.g. night shifts or weekend shifts) efficiently, maximizing schedule fairness.

6.2 Acceptance Study

An acceptance study regarding the Participatory Work Orchestration Support Tool was held from May 2021 to June 2021. The surveys were conducted entirely online after presenting the tool via video demonstrations and screenshots. As such there was no need to make personal contact with the respondents, reducing the dangers associated with the ongoing COVID-19 outbreak. Google forms were used to make the surveys accessible. The profiles of participants ranged among several groups, including directors, company owners, healthcare and safety specialists, and persons committed to teaching or research in mining fact, which enhanced the validity of acceptance findings.

A total of 36 persons were contacted for the acceptability studies, with a median age of 52 and a male/female ratio of 21/15. Perceived Ease of Use (PEU), Perceived Usefulness (PU), Behavioural Intention to Use (BI), and Self-efficacy questions were used to assess technology adoption, according to the dimensions of the Technology Acceptance Model [15].

An overview of the survey results is available in Table 1. Results indicate a strongly favorable disposition of the respondents towards the engagement with work orchestration tools. With respect to PEU, more than 85% or respondents expressed agreement or partial agreement to questions of ease of learning to operate the tool, ease of learning to command the tool and ease of becoming skilled with the tool. In addition, with respect to PU, more than half of the respondents completely agreed on the tool's usefulness in assigning task per worker, supporting daily tasks, putting worker skills to work and overall improvement of time and quality of work. For the same questions a total of 80% of the respondents expressed either complete or partial agreement. With respect to the sole BI question, more than 70% of the respondents expressed complete or partial agreement, while for the sole SE question, the percentage was more than 90%.

7 Discussion and Conclusion

This work aims primarily to address the needs of the ageing workforce in the context of shift work, a form of work that is commonly employed in industrialized society. Towards this aim, a Participatory Work Orchestration Support Tool has been developed, which is addressed to organization managers, and with the aim of providing sufficient decision support tools to improve management of the ageing workforce. The platform enables organization managers to visualize at a glance organization schedule and the status of their workforce, respond to worker requests, and get intelligent suggestions for schedule improvement through an optimizing shift scheduler module.

The proposed tool has undergone preliminary validation, in the form of an Acceptance Study, as well as simulated benchmarks of the scheduler-generated shift schedules. Both forms of validation concluded into encouraging results, demonstrating on one hand an overall positive acceptance and on the other hand capability of generating promising and sound shift schedules.

From a development standpoint, the next steps of the research involve on further elaboration and enrichment of the visual overview provided to organization managers through the manager platform, as well as development of the shift scheduler with the aim of generating even more relevant results, taking into account a more detailed picture of worker preferences and shift difficulty. In addition, from a validation standpoint, we aim to extend the validation of the proposed solution to studies performed in end-user premises, with the aim of further consolidating the contribution of the proposed tool based on real data.

Table 1. Survey results

Question	Completely Agree	Somewhat Agree	Neutral	Somewhat Disagree	Completely Disagree
Perceived Ease of Use (PEU)					
Learning to operate this tool would be easy for you	41,6%	50%	5,6%	2,8%	-
You would find it easy to get this tool to do what you want it to do	30,6%	55,6%	11%	2,8%	-
It would be easy for you to become skilful in the use of this tool	36,1%	47,2%	13,9%	2,8%	-
Perceived Usefulness (PU)					
Using the information of vacations and absences provided in the tool would help you effectively assign tasks per worker, saving time and cost	52,8%	36,1%	11,1%	-	-
Using the Work-Scheduling tool daily notifications would be a good practice to support workers' daily tasks	58,3%	30,6%	11,1%	-	-
Using this tool, the overall time and quality of your work would be improved	55,6%	27,8%	13,8%	2,8%	-
Using this tool better exploitation of workers skills would be possible	55,6%	25%	13,8%	5,6%	-
Behavioral Intent (BI)					
If you could use this tool it to support you at your work, you would appreciate working with it	41,7%	33,3%	25%	-	-
Self-Efficacy (SE)					
You can use this tool if someone shows you how to do it	52,8%	38,9%	8,3%	-	-

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