Bus Crew Schedule System from the Perspective of Multi-Agent System and Meta-Abilities

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ABSTRACT

A bus crew-scheduling plan is the most critical part in a bus operators' operational information system (IS) as it involves large resources and cost. This paper proposes a conceptual framework for an optimum and dynamic crew scheduling by using the concept of a multi agent system (MAS) and meta-abilities. The framework suggests that meta-abilities create influencing skills, sharing attitudes and asking habits amongst the stakeholders of the bus crew scheduling system. Contrastingly, influencing skills, sharing attitudes and asking habits externalise tacit knowledge through the medium of ideas, actions, reactions and reflection. This externalised tacit knowledge in turn provides input for the system analyst to update the MAS-based crew scheduling system. It is concluded that the future focus when developing an optimum and dynamic bus crew scheduling should be toward an individual's meta-abilities development and MAS approach. There should also be an impetus towards creating the right organisational culture and infrastructure that promotes tacit knowledge externalisation and sharing within and between stakeholders.

Keywords: Bus Crew Scheduling, Multi Agent System, Meta-Abilities, Ideas, Actions, Reactions, Reflection

INTRODUCTION

One of the major operational problems that is faced by a bus operator who manages large numbers of routes, buses and crews is crew scheduling. It is hard to solve the crew-scheduling problem due to its complexity, which involves allocating huge number of crews to drive the scheduled buses. This is due to operators having to be in accordance of certain driving rules and agreements existing between Trade Unions (TU) and the company with the objectives of minimising the total shift and operational cost.

There are two main reasons why a crew schedule is immensely important. First, the expenditure upon such a system involves a large portion of a bus's operational costs. According to [1], the cost of a crew scheduling system is at least 45% of the total operational costs. This proportion is likely to rise as the shortage of bus drivers, a common phenomenon in London and the whole of the United Kingdom (UK) is considered to be increasing, and not decreasing [2]. Second, the system will determine the level of efficiency of services offered by a bus operator in fulfilling the requirements of a city council or the authority that authorised its operations.

However the main problem in developing a bus crew schedule is the achievement of optimum and dynamic schedules. An optimum and dynamic schedule enables rescheduling processes without affecting the whole schedule and can be undertaken at a low cost. Although many researchers have proposed various approaches since the 1960's [3], no one can claim that they have obtained the most optimum and dynamic schedule. The main obstacle in developing an optimum and dynamic bus crew schedule is the occurrence of unpredictable events. It is argued that the current approaches (i.e. mathematical approaches, heuristic and metaheuristics) are not capable of coping with the unpredictable events such as, no show driver and bus breakdown. This is because the approaches are based on mathematical and statistical characteristics such as, integer linear and stochastic. These characteristics in turn create a difficulty in developing optimum and dynamic schedules.

This paper will provide an alternative approach to this research issue by proposing a conceptual framework that is developed based on the concept of a MAS and meta-abilities. To the best of the authors' knowledge, the use of a MAS and meta-abilities in the context of a bus crew schedule is a novel idea.

This paper has been organised as follows. Section 2 offers a theoretical overview of crew scheduling problems. Section 3 reviews the approaches used in developing optimum and dynamic schedules. Section 4 provides the overview of multi-agent approach to bus crew scheduling. Section 5 defines the role of meta-abilities in the MAS-based system and integrates the previous theoretical understanding into one conceptual framework and a brief description of it is offered. Section 6 implicates the proposed framework in a real life setting. In section 7, the conclusions and suggestions for further research are dealt with.

THE CREW SCHEDULING PROBLEM

Initially, this section describes the terminology used in this paper. Based on literature in [2][4][5][6][7], the basic terminologies of a bus crew scheduling system are as follows:

A *depot/garage* is a parking place for vehicles that are not in use for some time. A *trip* is the movement with passengers between two relief points or depot at a specified departure and arrival time. A *deadhead* is a movement in time between two trips from a depot to the first trip and from the last trip to a depot, usually without passengers. A *relief point* is a location and time where and when a change of crew may occur. A *shift/duty* is a sequence of trips assigned to the same crew. An *idle interval* is an interval between two consecutive trips in a shift. The sum of idle intervals in a shift is a *rest time*. The sum of the durations of trips in a shift is the *working time*; and major constraints include minimum *rest time*, *idle limit* (if the idle time exceeds the idle limit, it is an interruption in a shift and the crew is considered to work a *split shift*) and *workday* (the shift hours exceeding a workday; for this, the crew is paid an overtime amount).

Referring to the above terminology, the bus crew schedule system can be described as an allocation of crews to trips within given constraints, with the aim of minimising the cost of transportation and fulfilling the requirements of a system's stakeholders. The stakeholders of the system are the management individuals, schedulers, supervisors, drivers and maintenance staffs.

However, the crew schedule task itself is perceived to be complex in nature. This is mainly due to the number of variables and constraints associated with a crew schedule task. The variables and constraints range from the amounts of time a driver is allowed to work to the availability of buses and crews. Most of the scheduling tools that are in use can incorporate constraints such as the TU rules and European Union (EU) directive on working hours related to a schedule and produce reasonable results [5][7][2]. However, most of these tools fail when dealing with unpredictable events, such as staff illness, traffic/weather conditions and staff preferences [8]. Since these events are unpredictable, it is fair to infer that crew schedules are subject to change in the day-to-day operations. Currently these changes are handled manually [2]. This means that every time an unpredictable event occurs, the schedules are altered manually. This procedure is often slow and cumbersome and does not necessarily produce the desired results [2]. Therefore, an approach that can deliver an optimum and dynamic bus crew scheduling is critical among bus operators. The next section will describes the current bus crew scheduling approaches.

MULTI-AGENT APPROACH TO BUS CREW SCHEDULING

Technological evolution has now reached a stage that enables the design and implementation of small networks of intelligent agents (IA) to be created, and to act autonomously upon the users/resources behalf. Furthermore, they are capable of competing or collaborating, depending on how best to accomplish tasks [9]. It is argued that this type of system enables IS modification and re-examination to be undertaken in a certain domain without the need to reconsider other domains. Therefore, this property (autonomous) is considered to be relevant to develop an optimum and dynamic system.

Rzevski [10] found that MAS was competent for solving resource allocation and scheduling problems. This is due to MAS being systems that contain a large number of IA and resolving tasks through the interaction of these agents. They create virtual markets in which agents with available resources negotiate with agents that demand for resources until a satisfactory balance is achieved.

Based on the aforementioned discussions, the authors propose an MAS-based bus crew scheduling system (refer to figure 1). The proposed bus crew scheduling system consists of the following components:

Bus Agent (BA) - BA corresponds to a bus that is used in operation. The BA pursues an objective to provide a service. The BA's attributes are registration number, model,

type, capacity and year. BA methods used are, ready to use, under repair/maintenance or fault.

Crew Agent (CA) - The CA represents a bus driver who pursues objectives such as, to obtain a salary and work in a safe and healthy environment. The CA's attributes are social security number, name, age, address, telephone number, year of experience, and license number. The CA methods used are, on duty, on leave and stand by.

Trip Agent (TA) - The TA corresponds to a trip and deadhead in bus operation. The TA's objective is to complete a bus route. A trip is a movement of passengers in a bus between two relief points or depot at a specified departure and arrival time. A deadhead is a movement in time between two trips without passenger. The TA attributes are route number, trip number, start point, end point, start time, end time and duration. The TA methods used are on, off and jam.

Rule Agent (RA) - The RA models the rules and regulation, and agreement with the TU. Its objectives are to follow EU rules and follow agreement with the TU. The RA attributes are rule identity, rule name, rule detail and rule date. The RA methods are new, update, edit and delete.

Schedule Agent (SA) - SA is an abstraction of the scheduling manager. That is, the SA acts as a broker/matchmaker between CA, BA and TA. The objective is to create an optimum crew schedule. The SA attributes are route number, garage, date, rota number and reference number. The SA methods are schedule, global reschedule, local reschedule and off schedule. When creating or updating the schedule, the SA has to check the compliance of the schedule with the TU agreement and EU rules.

Negotiation Process - The negotiation process is one of the key processes for the MAS to successfully achieve its goal. Various agent negotiation strategies can be employed to achieve the best practical schedule. For this research, the authors used contract net protocol (CNP) by Smith [11] as a negotiation mechanism, but with some modifications that is most suitable for a crew scheduling environment. The CNP is widely used in MAS application. The negotiation process begins by TA sending messages to SA where the requirements describing the requirements are described. SA then returns an offer to CA. Each CA will then compare the features of available trips and select the most appropriate offer, taking into consideration any specific demand that the crews may have. The exchange of messages continues until the minimum cost match is achieved. While forming the schedule, the SA will refer to RA to ensure that the schedule is legal.

The proposed multi agent bus crew schedule system is constructed with matchmaker architecture. The SA acts as a broker/matchmaker between CA, BA, RA and TA. CA and BA provide the supply of bus and driver. CA offers the supply of a driver who will drive a bus, while BA provides the service of a bus. TA is the agent of request. TA requests a bus and a driver to serve the trip. RA is an agent who ensures that the created schedule is in accordance with the EU rules (concerning driving hours, break and others) and complies with the TU agreement.

The MAS is particularly good at handling changes that inevitably occur during exceptional circumstances concerning the bus operations, such as, the no-show of drivers, bus failures or trip delays. For instance, let us assume that a driver failed to arrive on duty. The TA representing the trip that has suddenly lost a crew sends messages to CA asking about eligible drivers who can undertake the duty. In most cases the re-planning triggered by an unexpected change can be accomplished locally, without the need to reconsider the whole schedule. However, if local re-planning is not possible (e.g., if there are no free drivers who can undertake the new request), the agents begin a more comprehensive re-planning process (although still not on a global scale), which may necessitate some changes in the allocation of previously booked drivers. Throughout the allocation process the SA attempts to minimise the cost of operations by ensuring that the drivers and trips are matched in a manner such a way that no driver works a shift longer than prescribed. This situation is avoided due to the organizational attempting to avoid increasing costs incurred due to the overtime payments. The overtime payment being, usually the major cost factor.

After this description of the proposed bus crew scheduling system, the second issue of that this paper addresses described as: "what will happen if the system's stakeholders are reluctant to participate in or are against the new schedule?" To evade such problems, the concept of meta-abilities is proposed.

META-ABILITIES AND BUS CREW SCHEDULE SYSTEM

To enable the system analyst to gain input for the bus crew schedule system modification, this paper proposes the concept of meta-abilities. This is because meta-abilities motivate the individuals to participate in the bus crew schedule system development. In addition, meta-abilities enable the individual to externalise their tacit knowledge. The externalised tacit knowledge represents the continuous input for the bus crew schedule system development.

According to Saint-Onge [12], an organisation consists of knowledge existing at two levels: (1) individual level; and (2) organisational level. Further, it was asserted that while organisations do not have minds, they do have memories through the utilisation of a database. This database is built on the externalised knowledge of individuals within the organisation and forms the basis for an organisation's values and its "ways of doing things." It is argued that the embedment of externalized knowledge enable continous re-examination and modification of bus crew schedule system.

However, tacit knowledge is not easily diffused due to its transparent and subjective nature [13]. Difficulties appear in expressing or documenting knowledge that appears obvious and natural to one [14]. Further, the difficulties in diffusing tacit knowledge are also linked to language, time, value and distance. Alternatively there are factors preventing individuals from sharing their tacit knowledge or asking others for clarification including, lack of confidence, anxiety, unwillingness, confusion and being carried away by strong feelings [15].

This paper argues that systematic approaches of collecting individuals' tacit knowledge, such as metaphors or narrations, are inadequate. This is due to the nature of tacit knowledge being such that it will lead to the phenomenon where people often externalise and share it through creative and spontaneous conversations. Therefore, the creative and spontaneous diffusion of tacit knowledge requires research. To achieve this, the role of meta-abilities is essential. This is due to the development of meta-abilities resulted in individual belief, commitment, enthusiasm and perseverance to implement significant change within the organisations [15]. These changes range from introducing specific initiatives to realigning the culture and values of the organisation. Implicit in these phenomena are the existence of individuals' capability, confidence and a sense of responsibility to influence, ask and share ideas with others in an active manner. These activities represent the process of creative and spontaneous tacit knowledge diffusion.

The concept of meta-abilities was initially widely applied in the psychology area and defined as an emotional intelligence that guides the use of other kinds of intelligence and skills [16]. In the organisational development area, meta-abilities are ground in the view that an individual's effective performance is inextricably linked to his or her psychological development or maturity [15]. This is because individuals' psychology influences judgements, which in turn affects the decisions made by them [16]. Four main meta-abilities were identified in the organisational development area and they are summarised in Table 1.

TABLE 1:THE DESCRIPTION OF META-ABILITIES

Meta-abilities	Description
Cognitive skills	Includes the ability to notice and interpret what is happening in interpersonal situations; to entertain multiple perspectives and integrate them; to envision strategic futures; and to sort and analyse data. These skills allow employees to "read situations, understand and resolve problems."
Self-knowledge	Seeing oneself through another's eyes, knowing one's own motivations and values and distinguishing one's own needs from those of others. These skills allow employees to consider a range of options in their own behaviour and to make better judgements of what to do. They allow other skills and knowledge to be used more flexibly.
Emotional resilience	Includes self-control and discipline; the ability to use emotion well to cope with pressure and adversity; and balance feelings about oneself. These skills allow employees the personal robustness to direct their energies, deal with intense situations and manage challenges healthily.
Personal drive	This involves self-motivation and determination, a willingness to take responsibility and risks. This helps employees to persist, motivate others and meet targets.

Initially the development of meta-abilities resulted in improved personal influencing skills, such as communication, assertiveness, dealing with conflict, persuading and developing others [15]. Then, it was argued that meta-abilities offer a substantial contribution by making individuals more astute and insightful, able to make better judgements and to envision more alternative actions. As such, they are better equipped to navigate the difficult and dynamic organisational reality and influences effectively within the organisation. In this case, individuals are able to extend their personal sphere of influence and provide a more critical perspective. They provide greater insight and are more direct in focusing attention and asking significant questions. As a consequence, they could influence subordinates, colleagues and management, serve as role models and be more challenging. This type of interaction could develop cohesiveness in the working place. In short, they act as a spur to organisational development by influencing others – questioning implicit assumptions, exploring new possibilities and directing energies toward higher standards.

Based on the above discussion, it is argued that meta-abilities assist in building a capable and confident individual who can face the difficulties in the externalisation and sharing of tacit knowledge and in obtaining opinions from colleagues using three humanistic elements: (1) influencing skills; (2) sharing attitudes; and (3) asking habits. By utilising these humanistic elements, individuals generate creative ideas, actions, reactions and reflections. Documenting this externalised and shared tacit knowledge can develop synergistic inputs for continuous bus crew schedule system re-examination and modification. The ways in which these dimensions relate to each other are illustrated in Figure 1.

The explanation for each stage of the proposed conceptual framework is as follows:

Stage 1 – situational problems consist of external pressures such as, economic and political issues or internal pressures such as, information flow and politics.

Stage 2 – the integration of cognitive skills, self-knowledge, emotional resilience and personal drive enables individuals to produce rational solutions when facing problems.

Stage 3 – an individual externalises the rational solutions to problems using three means; namely, influencing skills, sharing attitudes and asking habit.

Stage 4 – when undertaking influencing, sharing and asking activities, individuals express their knowledge in the form of ideas, actions, reactions and reflections.

Stage 5 – staff members or knowledge stewards, such as information officer, document the externalised tacit knowledge and transform them into explicit knowledge such as, a business report.

Stage 6 – systems analysts study the documented inputs provided by knowledge stewards and codify them. By the time the inputs are transformed into codified domain within the MAS-based bus crew scheduling system, they become information for assisting organisational members in fulfilling their responsibility.

Stage 7 – by accessing the "best practices," individuals can experience new learning in the organisation.

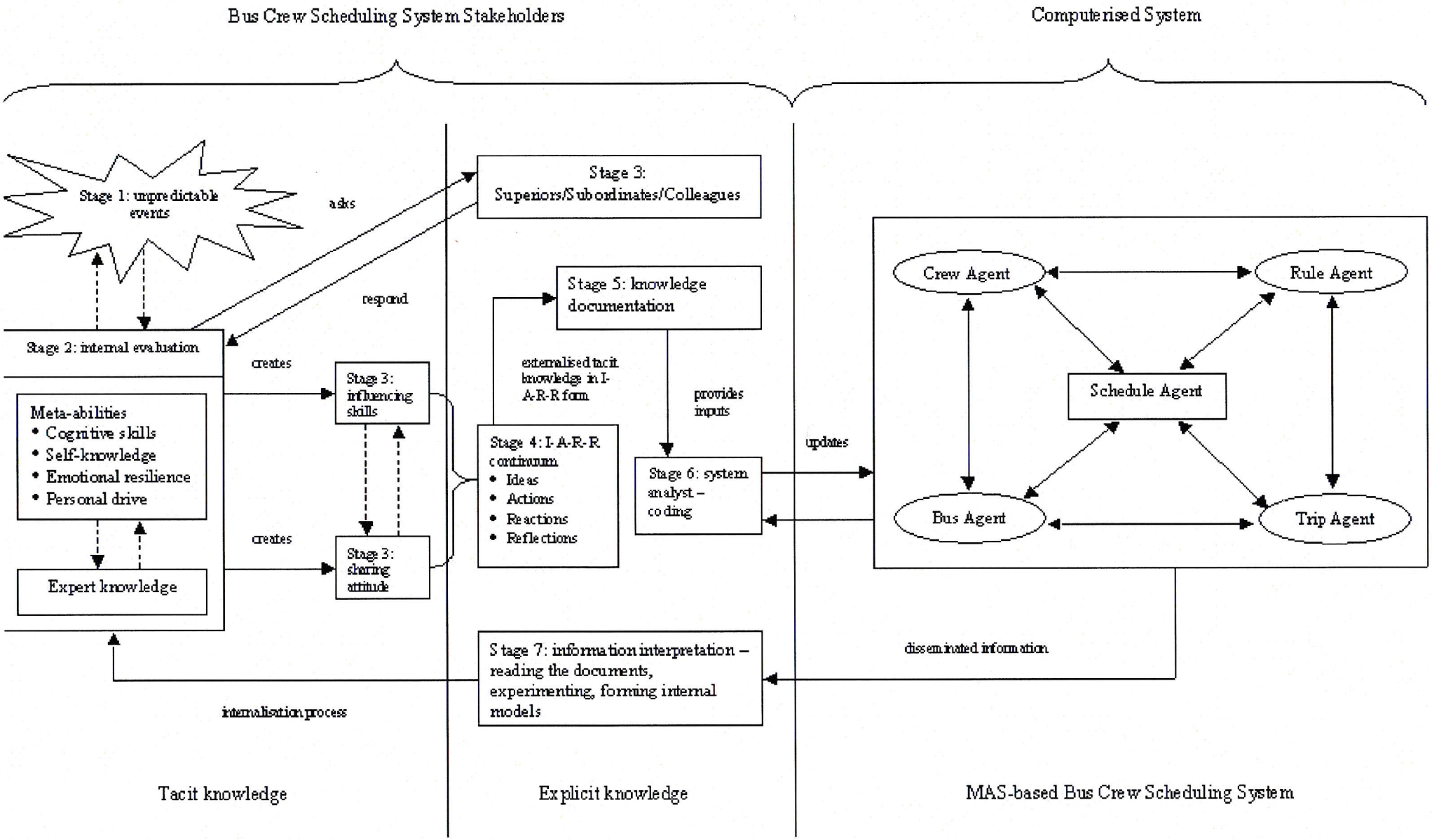

Figure 1 Proposed bus crew scheduling system architecture

After the above process, the externalised tacit knowledge becomes information that is accessed by the system stakeholders. By gaining access to "best practices," the system stakeholders can undertake their tasks effectively and consequently reduce the bus' operational costs. This activity implies the process of developing an optimum and dynamic schedule. An optimum and dynamic schedule in turn enables the bus operating company to increase its competitive edge in a highly volatile market.

IMPLICATIONS OF THE FRAMEWORK ON THE MAS-BASED CREW SCHEDULING SYSTEM

The main goal of an IS is to provide information that is useful for purposeful actions within the organisation [17]. Knowledge has been considered as one of the basic inputs for achieving this goal [18][19][20][21][22][23]. What are the implications of the above framework in the development of the bus crew scheduling system? This will be discussed in the following paragraphs.

First and foremost, the crew scheduling system development should concentrate more on the creation of externalisation, sharing and asking practices. Tacit knowledge resides in an individual's mind and is obtained through continuous individual learning and practical processes. Even the explicit knowledge such as instruction books, report and discussion documents can be argued to be the outcomes of tacit knowledge. Individual tacit knowledge can be in the form of skills, values, preferences and criteria. The system stakeholders will apply their tacit knowledge when undertaking a task. This process will slowly establish "best practices" in handling that task. To evade "reinventing the wheel" phenomena in doing that task, the need to create the right organisational culture and infrastructure in which knowledge can be shared and disseminated is important. Technology can certainly contribute in obtaining these environments by providing methods for the processing, delivery and sharing of valuable knowledge that is externalised by the system stakeholders. Therefore the focus of the people implementing the crew scheduling system might be to concentrate on providing appropriate skills to enable system stakeholders to make explicit their tacit knowledge. If this view is accepted, then the crew scheduling system might have a more legitimate focus within the human resources departments rather than IT departments.

Second, the externalisation practice is established through the individual influencing, sharing and asking commitments and capabilities and is therefore founded on the growth of individual meta-abilities. Therefore a meta-abilities development programme can be used as a development strategy for the crew scheduling system in bus operators. According to Butcher *et al.* [15], initially the development of meta-abilities results in improved personal influencing skills, such as communication, assertiveness, dealing with conflict, persuading and developing others. Then, it contributes in important ways to individuals being more astute and insightful, able to make better judgements and to determine more alternative actions. These internal qualities enable system stakeholders to make explicit their tacit knowledge effectively and efficiently. This is evident from the ideas, actions, reactions and reflection produced when facing problems. In this paper, this is termed as the "I-A-R-R continuum". The I-A-R-R continuum can be used as a basis of providing relevant and reliable information for continuous bus crew scheduling system re-examination and modification processes.

Third, the framework implies the importance of IS committee members to attend the formal or informal meeting with the bus crews and management in the organisation. The purpose of this meeting is to enable the IS committee members to acquire inputs from the bus crews and management and to update the content of the crew scheduling system accordingly. This situation illustrates that in order to maintain an effective and efficient crew scheduling operations, IS officers must gain feedback from staff members. It is argued that in managing the crew schedule system, it is not practical for IS members to just simply predict the answer for the following questions in their office: "What should happen if this is the case?" or "What will happen if...?" Instead they have to meet and interact with the bus crews and management, build good relationships with them and obtain their feedback on the schedule system performance. This cohesive style will develop synergistic inputs for continuous improvement of the bus crew scheduling system.

Last but not least, the framework implies the importance of understanding of how to make system stakeholders more accountable for the development of scheduling system. Previous literature on bus crew schedules has highlighted the extensive role of individuals [2][6][24]. However most of the literature discusses the role of human beings in a mechanistic and structural form without explaining how an individual can make explicit his or her knowledge. This paper attempts to shed the light on this matter by studying the role of meta-abilities in the diffusion of tacit knowledge within the context of bus operators. In this case, meta-abilities develop the system stakeholders' commitment and capabilities to externalise and share their knowledge in the form of I-A-R-R continuum.

CONCLUSION

This paper has described the role of MAS and meta-abilities in developing an optimum and dynamic bus crew scheduling system. MAS are a systems approach that consists of a large number of intelligent agents, resolving tasks through the interaction of these agents. MAS are especially competent for solving resource allocation and scheduling problems. Meta-abilities are the underlying learned abilities that play an important role in enabling and making effective, a wider range of managerial knowledge and skills. These abilities are needed because of the existence of factors that prevented individuals from using the knowledge and skills they have. The description of the combination of MAS and meta-abilities in developing an optimum and dynamic bus crew scheduling is summarised into one conceptual framework.

The conceptual framework is developed based on the link between MAS and meta-abilities. In the conceptual framework, the development of meta-abilities results in the system's stakeholders' influencing skills, sharing attitudes and asking habits. Influencing skills, sharing attitudes and asking habits in turn enable system stakeholders to externalise their tacit knowledge in the form of creative idea, actions, reactions and reflection. Knowledge stewards will document the externalised tacit knowledge and transform them into explicit knowledge, such as, a business report, written descriptions or instructions. The systems analysts will study the documented inputs provided by the knowledge stewards and codify them.

The whole process in the conceptual framework will ensure that the contents of the MAS-based crew scheduling system are subjected to continual re-examination and modification given the changing reality. Continuously challenging the current "company way," such scheduling systems are expected to prevent the core capabilities of yesterday from becoming core rigidities of tomorrow. Therefore the main focus of the bus crew scheduling system should be toward the system stakeholders' meta-abilities development that develop creativity and interpretivity. There should also be an impetus towards creating the right organisational culture and infrastructure that promotes tacit knowledge sharing and externalisation within and between employees.

Future directions for this research include the study of the concept of MAS and meta-abilities in other transportation mode such as, railway, flight and cargos. This is because the growth of individual meta-abilities enables an understanding of how to respond intelligently to unknown situations and go beyond the established knowledge to create unique interpretations and outcomes. On the other hand, the flexible properties of MAS enable it to be adopted in a dynamic and unpredictable business environment.

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