Automated Bus Crew Rescheduling for Late for Sign-On (LFSO) Event using Multi-Agent System

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Abstract—**Unpredictable events (UE) are major factors that cause crew rescheduling to be performed. One of the UE is when a crew is late for duty. In this research, it is termed as Late for Sign-On (LFSO). When LFSO occurred, the reschedule is needed to make sure available crew take the duty. Currently, there is no automated mechanism to handle the LFSO. Real time rescheduling approaches mostly are not supported due to static schedules constraint. Mathematical approaches require extensive computational power therefore delayed the real-time results. Meanwhile, manual rescheduling is prone to error and not optimum. This research objective is to develop a new approach in automating the crew rescheduling process using multi-agent system. The agents dynamically adapt their behaviour to changing environments quickly and find solutions via negotiations and cooperation between them. Experiment is conducted using AgentPower simulation tool. The result concluded that the proposed technique is capable to reschedule quickly. The distribution of a duty also plays a major role in achieving rescheduling success.**

Keywords—**Bus crew scheduling, crew rescheduling, multi-agent Ssystem, agent system.**

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I. INTRODUCTION

BUS services play a pivotal role in a city and represent the largest component of the public transport network, and more so than trains, have the greatest reach potential [1-3]. Cities such as London, New York, and Paris have 700, 298, and 246 routes served by 6500, 4860 and 3860 buses respectively [4][5]. Bus services usually operate in unpredictable environments, where unpredictable events (UE) such as crew absenteeism, vehicle breakdown, demand variation, and temporary traffic congestion take place at any time [6-8]. In the occurrence of UE, crew schedules will be affected. Crew schedules is a report of assigned driver duties according to the bus schedule for a certain scheduling period [9-11]. Usually, bus operators are not penalised if the delay is due to traffic related problems, such as congestions, but they are penalised if it is related to mechanical or crew problems [2]. Therefore, the smooth management of vehicles and crews is usually the responsibility of bus operators and they should manage their vehicles and crews properly so that no service disruption will occur, otherwise they will be penalised.

Crew schedules show crew activities (in this research crew refers to bus drivers) in detail, from sign-on until sign-off. In the occurrence of UE, the timing of activities in crew schedules will be affected. For example, if a crew comes late, it will cause delay not only at sign-on time but also possibly to driving time, relief time and sign-off time depending on the level of lateness. Thus, how can the effect of UE to crew schedules be overcomed or minimised? One method is "crew rescheduling" [12-15]. The method means if UE take place, crew schedules will remain the same, however, the assignment will be changed. The missing or unavailable crew's duty (because of UE) will be assigned to another available member.

Most of the current approaches, which are based on static schedules [8], do not provide the capability of rescheduling in a real time scenario. They have the ability to reschedule but a new complete schedule is produced without concerning the real time situation [16-18]. Although there are efforts in managing UE, attention is paid only to vehicle schedules [4][1-3]. There are few researches proposed rescheduling when a crew or a bus is late but there are a few assumptions in their research that are not feasible in a real world situation [5-7]. For example, passengers have a higher priority than crews so there is a possibility of crews violating European Council (EC) driving hour rules, and the assumption that bus operators have unlimited crew resources is not possible in the real world. In practice, crew or bus rescheduling is manually managed based on supervisors' capabilities and experiences in managing UE. They often employed common sensed and past experienced that blended in messy, sometimes inconsistent, and not well-understood way [16]. For example, the current practice in Taiwan [19], is that experienced dispatchers (supervisors) use their intuition and knowledge to manage abnormal conditions in an ad hoc manner. This is more or less common practice in the rest of the world. This research argued that manual crew rescheduling has many deficiencies that are hard to reschedule and result in slow decisions when many UE happen at the same time, possibly breaking the EC driving hour rules, and that the decisions are not optimum in the use of crew resources. Thus, this research proposed to an automated crew rescheduling to overcome these deficiencies. It focuses on UE that disrupted crew schedules and proposed an Automated Crew Rescheduling System to minimise the effect of UE to crew schedules. A Multi-Agents System (MAS) is used to implement the proposed system.

II. METHODOLOGY

This section explains the methodology for automated crew rescheduling system using MAS. The architecture of the proposed system has two agents that are Crew Agent (CA) and Duty Agent (DA) as shown in Fig. 1. CA represents a crew, and DA corresponds to a duty that needs to find a crew in the unpredictable event occurrences. There is a virtual world where agents interact, communicate and negotiate. In this virtual world, there are resource and demand agents. A demand agent represents a task or work to be done. A resource agent represents someone or something that can fulfil the task. In this system, DA is the demand agent whilst CA is resource agent. This is due to the fact that the duty is a task that needs to be done while the crew is the resource able to fulfil the task.

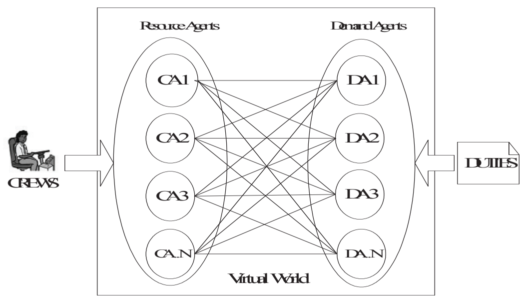

Fig. 1. Architecture for crew MAS rescheduling

CA represents a crew that works for a bus company. Crew objectives are to get a salary and to work in a safe and healthy environment. Crew main responsibility is to drive a bus according to a prescribed schedule. A crew has five activities SignOn, Drive, Relief, SignOff, and StandBy. SignOn is the time for a crew to start a duty, Drive is when a crew drives a bus, Relief is when a crew takes a break, SignOff is when a crew finishes his/her duty on a day, and StandBy is when the state of a crew is in standby mode. A crew has permission to read crew schedules, duty assignment, and their crew details. A crew is not allowed to drive continuously for more than 4.5 hours, must at least take a relief equal or more than 45 minutes, and total driving hours in a day should be equal to or less than 10 hours in a day. A DA corresponds to a duty that results in the loss of its driver because of UE such as lateness, delay, or unavailable. A DA's objective is to find a crew that will drive the duty. A DA's responsibility is to make sure that a crew takes the duty. Attributes for a DA are number for the route, number of the duty, start and end time for the duty to be covered, total time that need to be covered, a minimum required time to cover the duty and time when the late-crew is ready.

In the proposed architecture, agents interact in a virtual world in which agents representing available resources negotiate with agents representing demands for resources until a satisfactory matching is achieved. Each time an agent receives a message, it immediately knows what reasoning procedure it must activate in order to set up the most appropriate answer or action, or what kind of update it has to perform in its domain specific knowledge. TABLE I provides a list of these messages, together with a short description of them.

TABLE 1 MESSAGE PASSED IN AGENTS INTERACTION

Message Type	Sender	Receiver	Description
reqDriver	DA	CA	Sent whenever a duty needs a driver.
respond	CA	DA	Sent as soon as a crew received a request from a duty.
detailsSpecs	DA	CA	It conveys information about the details specification of a duty.
beginMatching	CA	DA	Sent to initiate a negotiation
noMatch	DA	CA	Sent to inform that there is no match because the crew does not fulfill the duty's requirement.
reserved	DA	CA	Sent to inform that the crew is reserved to take the duty.
acceptMatch	DA	CA	Sent to inform that the crew is accepted to take the duty.
declineReservation	DA	CA	Sent to inform that the crew reservation is rejected because there is other crew that is more suitable to take the duty.

The matching process is initiated by a demand agent, which in this case is a duty agent (DA). Fig. 2 shows the sequence of messages in different scenarios of matching process between DA and CA. Fig. 2(a) shows the sequence of messages between a DA and CAs in the scenario when there is a match. It starts when a DA needs a crew to take his/her duty because the original driver is late or not available. The DA sends messages to all the CAs requesting a driver (reqDriver message). In return, CAs will respond to the DA (respond message). Then the DA sends detailed specifications of the duty (detailsSpec message). CAs that are available (in this case CA2 and CAn) for the duty will respond and matching will start (beginMatching message). If the CA matches the requirement, then DA will put CA into reserved (reserved message). DA will continue the matching process with the next CA and put CA into reserved if it fulfils the requirement. After all negotiation, DA will make the decision to choose the best option. The one that is chosen (in this case CAn) will receive an acceptance message from DA (acceptMatch message). In regards to the rest of the CAs in reservation, the DA will send a rejection message (declineReservation message). Fig. 2(b) shows the same scenario with the only difference that there is no match because all CAs which are available (in this case CA2 and CAn) do not satisfy requirements. When CA details do not match a DA's requirements, the DA will send noMatch message to the CA.

Late for sign-on (LFSO) refers to a crew arriving late to start his/her duty. The first condition specifies that the crew agent (CA) must sign-on (sign-on) before or at the time specified (minimum required time) by the duty agent (DA). The second condition is that the starting time of the first work (start time 1) of CA must be later or equal to the late-crew ready time (late crew ready time). If both conditions are satisfied, there is a match between demand agent (DA) and resource agent (CA). The condition indicates that the CA with the latest sign-on time (Sign On) will be the best match.

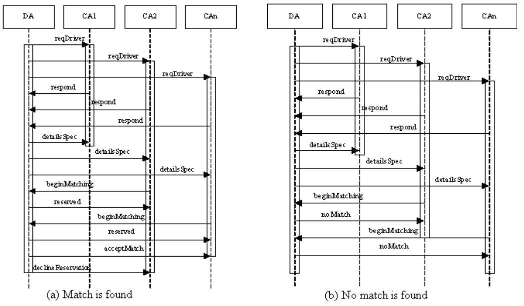

Fig. 2. Sequence of Messages when (a) Match is Found and (b) No Match is Found

III. RESULT AND DISCUSSION

According to interviews with bus companies in London [xx], there are different types of schedules. For the experiments, three different types of schedules are used: a large schedule consisting of 88 duties, a medium schedule consisting of 51 duties and a small schedule consisting of 23 duties. In this testing the researchers use the term distribution to refer to the number of duties in an hour. The researchers believe that the higher the number of duties in an hour, the higher the possibility of finding a match in crew rescheduling. The researchers also classify three different distributions: maximum, median (average), and minimum. For every type of schedule (large, medium, and small), a duty is chosen from maximum, median and minimum distributions. TABLE II shows the total number of duties sign-on by hour for large, medium and small schedules.

TABLE II: DATA GROUPING FOR THE EVENT OF LFSO AND DFSO

Sign-On	Large	Medium	Small
3:00:00	3	0	0
4:00:00	7	4	1
5:00:00	8	10	2
6:00:00	14	6	2
7:00:00	5	5	1
8:00:00	7	0	5
9:00:00	1	5	0
10:00:00	4	1	0
11:00:00	4	1	2
12:00:00	7	2	2
13:00:00	6	5	0
14:00:00	6	4	1
15:00:00	5	0	3
16:00:00	8	4	2
17:00:00	3	4	1
18:00:00	0	0	1
Total	88	51	23

The matching simulation is done by AgentPower simulation tool. Rescheduling capability is measured by the number of success in rescheduling (number of matched) and time is measured by the time taken for rescheduling. The best result is a high number of matches with minimum time taken for rescheduling and without or less minutes late. Fig. 3. illustrates the number of matched LFSO in different schedule types and duty distributions.

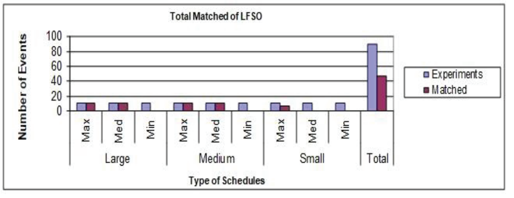

Fig. 3. Number of LFSO Matched in Different Schedule Type and Distribution

The result in TABLE III show that the rescheduling is 100% successful (10 out of 10) in large-maximum duty, large-median duty, medium-maximum duty, and medium-median duty, while in small-maximum duty it is 70% successful (7 out of 10).

TABLE III and Fig. 1 reveals that the distribution of a duty plays a major role in determining rescheduling success, regardless of the size of the duty. The average time taken for every rescheduling process is dependent on the type of schedule, as the large schedule takes more than 3 seconds, the medium schedule between 1 to 2 seconds and the small schedule less than 1 second. This is because the bigger the schedule the more number of duties, and the more time it takes in the matching process. Based on researchers' knowledge, the minutes late are dependent on the distribution of the duty, but the results show that this is not always the case. The table shows average minutes late for large-maximum duty is

0.1 minutes, large-medium duty is 3.5 minutes, medium-maximum duty is 5.1, medium-median duty is 2.6 and small-maximum duty is 15.14. The value for medium-maximum (5.1) is surprisingly high compared to medium-median (2.6) because it supposes that the late minutes are low when the distribution is high. Thus, equal distribution of duties in an hour also influences the possibility of finding a match.

TABLE III: RESCHEDULING ANALYSIS FOR LFSO

	Large Schedule			Medium Schedule			Small Schedule		
	Max	Med	Min	Max	Med	Min	Max	Med	Min
Total Experiments	10	10	10	10	10	10	10	10	10
Total Successful Matched	10	10	0	10	10	0	7	0	0
Percentage of Successful Matched (%)	100	100	0	100	100	0	70	0	0
Total Time for Successful Matched (S)	32.10	30.92	-	15.44	14.94	-	5.46	-	-
Average Time for Successful Matched	3.21	3.09	-	1.54	1.49	-	0.78	-	-
Total Minutes Late	1	35	-	51	26	-	106	-	-
Average Minutes Late	0.1	3.5	-	5.1	2.6	-	15.14	-	-

TABLE IV shows the number of matches in the event of LFSO at different times of day. The results show that the number of matches is 3, 6 and 2 for early, midday and late respectively.

TABLE IV: THE ANALYSIS OF LFSO AT DIFFERENT TIMES OF DAY

Schedule Types		Early		Midday		Late		Total	Total	Match
	T	E	M	E	M	E	M	E	M	(%)
Large	15:00	2	0	2	2	2	0	6	2	33.33
	20:00	2	0	2	2	2	0	6	2	33.33
Medium	15:00	2	1	2	1	2	1	6	3	50.00
	20:00	2	1	2	1	2	1	6	3	50.00
Small	15:00	2	1	2	0	2	0	6	1	16.67
	20:00	2	0	2	0	2	0	6	0	0.00
	Total	12	3	12	6	12	2	36	11	30.56

TABLE IV produced total match which is considered small (11 out 36 or 30.56%). There are two reasons why the match is low; the numbers of crew that sign on at the peak hours are few and the duties are not distributed evenly. The numbers of crew that sign on at different times of day according to schedule are: large schedule; early (13), midday (16), and late (3): medium schedule; early (10), midday (11), and late (4): small schedule; early (8), midday (3), and late (3). From the numbers it is shown that the numbers of crew signing on at the late time are very low. Therefore, the match is very low for the late time. Another reason, as mentioned earlier, is the distribution of duties. The large schedule has a large number of crew signing on at the early time but still the number of matches is zero. Further investigation reveals that the distribution of duties is not equal in the large schedule; thus, it decreases the matches.

IV. CONCLUSION

In this research, MAS was proposed as a tool to implement the automated crew rescheduling system because MAS can provide a quick solution in real-time and in uncertain environments. The proposed architecture consists of two types of agents that are the duty agent (DA) and the crew agent (CA). CA represents a crew, and DA corresponds to a duty that needs to find a crew. The agents perform the rescheduling process through negotiation between them. Based on the experiments it can be concluded that MAS is suitable for automating the crew rescheduling process and is capable of quick rescheduling. It also revealed that the distribution of a duty plays a major role in determining rescheduling success.

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