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Multi Agent System (MAS) for Bus Driver Duty Reassignment in the Event of Late for Second Piece of Work (LSPW)

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Abstract. Unforeseen (abrupt, sudden, unanticipated, unexpected) incidents (UI) are events that occurs without notice causing interruptions to public transport services. In the operation of bus services, one of the sources of UI are bus drivers. For example, if a bus driver comes late for his/her duty it delays scheduled departures thereby causing a ripple effect on the entire schedule. There are three types of driver lateness that are; Late for First Work (LFFW), Late for Break (LFB), and Late for Second Piece of Work (LSPW). This paper will only discuss the possible solution for a LSPW event. When a LSPW happen, the predefined schedule remains the same however the duty needs to be reassigned to another driver that is available. Currently, a supervisor at the bus depot uses a manual way to complete duty reassignment and there are no automated ways of reassignment. Manual duty reassignments are slow and prone to errors. The objective of this paper is to propose an automated duty reassignment in the event of a LSPW using Multi-Agent System (MAS). MAS is dynamic, able to adapt to varying situations and quick at finding solutions through negotiation and collaboration between the agents. Experiment were conducted using the AgentPower simulation tool. The results concluded that the proposed technique is effective for duty reassignment in the event of LSPW.

Keywords: Bus Driver Scheduling; Duty Reassignment; Bus Driver Scheduling; Multi-Agent System.

1. Introduction

Public transport services such as buses, trains and taxis normally operate in volatile situations and random events or unforeseen incidents (UI) are bound to occur. UIs such as a driver is not coming for work, vehicle failure, and road traffic congestion can happen at any time [1-2]. This research focuses on UI events related to bus drivers. In the literature, three types of UIs are defined, namely: delay, lateness, and unavailability [3-5]. Lateness denotes a driver being late for his/her duty or going and coming back from breaks. In the literature three types of lateness are defined and these are Late for First Work (LFFW), Late for Break (LFB), and Late for Second Piece of Work (LSPW) [6-8]. This paper presents a proposed solution to manage the LSPW problem. LSPW is concerned with drivers being late for his/her second piece of work either after a relief due to an emergency or an event that that delays the driver from arriving on time. In the occurrence of a LSPW, the driver's schedules will be affected therefor changes or duty reassignment must be done to ensure the services still run on time.

In literature most of the current approaches to create bus driver schedules are static and does not account for duty reassignment when a LSPW occur[1, 3, 9-11]. The current approaches do not have the capability to reassign the replacements in the duty schedule and new complete set of duty schedule has to be produce to compensate for any LPSW occurrences. These were often constructed without any considerations of the current UI event [10, 12-15]. [16] writes that unforeseen events are particularly due to problem with the vehicles, driver sickness and/or other such things that renders the pre—planned schedule non-infeasible. According to [17], unexpected events areis solved by revising real time schedules using mathematical models then forwarding these changes to the inspectors and drivers via communication systems.

This research proposes an automated driver duty reassignment in the event of a LSPW by applying the concept of Multi-Agent Systems (MAS). MAS is a system composed of a population of autonomous agents, which interacts with each other to reach a common objectives. MASs is are being used for solving problems in other scheduling domain such as manufacturing, education, logistic and for meeting scheduling [4, 18-21].[22] reported that the general advantages of a MAS includes extensibility, fault tolerance and scalability and while also stating that another benefit of a MAS is their ability to capture autonomy in distributed systems and dynamic environment. The advantages of applying MAS for problem solving from meta-heuristic perspective are the possibility of offering higher computational speeds to overcome a critical problem by adopting inherent asynchrony and parallelism in agents [23,28]. The second advantage is probably solving the problem from the in aspect of developing hybrid algorithms. [24] identified the major benefits of MAS as: 1) Individuals application – specific nature and environment; 2) local collaboration among individuals that can be modeled and investigated; 3) sublayers could be adopted to overcome difficulties in modeling and computation. In a study conducted by [25], it was shown that MAS is capable of solving complicated dynamic distributed problems by learning communication and networking via task driven features. [26] found other benefits of MAS in which they are able to provide robustness, scalability, configurability and outright performance over typical centralized or hierarchical systems. Drawing on the concept of multiple agents working together in solving problems, [27] revealed that MAS can to resolve scalability issues by simply adding more agents.

For the experiments, two assumptions were made: 1) no violation is to be made of on bus driver rules on relief time which is forty five minutes, and 2) the maximum driving hours for each driver must not exceed nine hours. When a late event occurs, a minimum of five minutes is needed for a bus drivers to be ready for work after sign-in, five minutes to start break, five minutes to start second work after break, and five minutes for sign-off after completing the second work.

2. Methodology

This section describes the methodology to automate the bus driver duty reassignment in the event of LSPW by applying the concept of MAS. The proposed architecture is depicted in Figure 1.

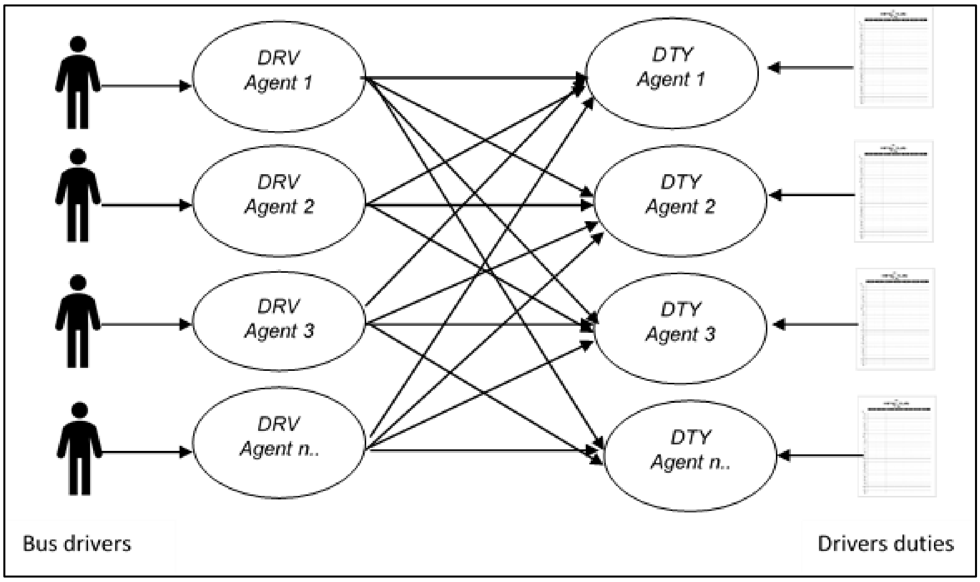

Figure 1. Architecture for MAS Duty reassignment

This system is based on the concepts autonomous agent ~~architecture~~ where an agent is not controlled other agent [18]. Two agents are identified as the main types. These are Driver Agent (DRV agent) and Duty Agent (DTY agent). These agents represent the real world with specific goals and objectives. They can communicate, cooperate, coordinate and negotiate to achieve their own goals. DRV agent represents a bus driver, and DTY agent corresponds to a duty that requires a driver because the original driver is late, or unavailable. In MAS, a~~A~~ virtual world is a place with resources and populated by demand agents where they negotiate, interact and communicate. In this system, DTY agents are the demand agents~~-~~and DRV agents are the resource agents.

DRV agents represents a driver for a bus company with the objective~~s~~ to earn wages and work in a healthy and safe environment. The drivers duty is to drive buses to a predetermined location according to their duty schedule. Five main activities of a bus driver are; Sign In, Driving, Break, Sign Off~~,~~ and Stand By. Sign In is an action where a driver reports for his/her duty, Driving is when a driver drives a bus according to the schedule, Break is when a driver is taking a break from driving, Sign Off is when a driver reports at the depot to finish off his/her duty for that day. Stand By is the state of a driver that is in standby mode to replace any unavailable driver. A driver must have a bus driving license, are in a healthy condition to drive and must be capable of understanding duty schedules and duty assignments. A bus driver is not permitted to drive nonstop for more than four and half hours. He/She should take a break for forty-five minutes before continuing for the second piece of work. In a day, a driver cannot exceed ten hours driving. These rules are the driving hour rules enforced by the European Union.

A DTY agent represents a duty that is not taken because a designated driver is late or unavailable due to a UI. A DTY agent's objective is to make sure there will be a driver that will ~~take~~take over the duty when required. The DTY agent ~~met~~ fulfils its objective by searching available drivers that are not driving at that time to substitute unavailable drivers. If DTY agent cannot find a ~~match~~match, then a decision has to be made to take a standby driver.

In this research, the matching process is triggered by DTY agents. A DTY agent needs to find a suitable driver (DRV agent) to take on a duty when the driver for that duty is unavailable. The DTY agents sends messages to DRV agents asking if any driver is available for a particular time. DRV agents that are ~~which is~~ available at that time will reply to the DTY agents. Consequently, the DTY agent sends a more specific and detailed information~~s~~ of the duty. The DRV agents will the read the details and check their individual schedules. If DRV agent is available during the particular time, then it will respond and the matching process starts. If any DRV agent matches the DTY agent's requirements, then the DTY agent will put the DRV agent into reserve~~d~~. The matching process continues to run until there are no DRV agent that can fulfil~~s~~ the DTY agent's requirements. When more than one DRV agent ~~is~~ that matches the requirements, then the DTY agent decides by choosing the optimal solution. The chosen DRV agent will receive an acceptance message from the DTY agent and DRV agents that are not chosen receives a rejection message.

3. Result and Discussion

The simulation is based on the data in [15]. The data was taken from three bus companies that are based in London. There data consisted of three types of duty schedules namely large (90 duties), medium (50 duties) and small (20 duties). In this simulation, an LPSW affected duty was chosen based on the distributions of the schedule (maximum, median, and minimum). The agent's~~s~~ simulation were applied using the Agent Power simulation tool. The results were measured by the number of matches ~~ing~~ and time taken to complete the duty reassignment. The best result is achieved when the number of matches are~~is~~ high with the less time it taken~~s~~ in completing the duty reassignment.

Table 1 to Table 9 shows the results of duty reassignments in the event of a LSPW. As an example, Table 1 shows the result of LSPW reassignments for a LARGE-MAXIMUM schedule. The first column shows the lateness of the driver in minutes, from 15 minutes to 55 minutes. The second column shows the time taken for the late-driver to be ready after taking consideration of LSPW. The third column shows the time it takes to do the reassignment. The fourth column shows the ID of the drivers that are involved in the reassignment process. The fifth column shows the delays caused on the bus schedule in minutes after taking into consideration the reassignment. The last column shows the number of drivers involved in the reassignment process. In the first row, it shows that the driver is late by 15 minutes; and the late-driver is ready for the second piece of work at 14:23:00; the reassignment process took 1.90 seconds and driver with the ID 14 (the late-driver) will take driver 223's duty, and driver with the ID 223 will take driver 14's duty. Two drivers are involved in this reassignment process.

Table 1. LSPW – LARGE-MAXIMUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	14:23:00	1.90	14,223	0.0	2 drivers
20 m	14:28:00	1.87	14, 223	0.0	2 drivers
25 m	14:33:00	1.92	14, 223	0.0	2 drivers
30 m	14:38:00	1.97	14, 223	0.0	2 drivers
35 m	14:43:00	1.99	14, 223	0.0	2 drivers
40 m	14:48:00	1.92	14, 16	0.0	2 drivers
45 m	14:53:00	1.88	14, 19	0.0	2 drivers
50 m	14:58:00	1.88	14, 19	0.0	2 drivers
55 m	15:03:00	1.92	14, 19	0.0	2 drivers

Table 2. LSPW – LARGE-MEDIUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	22:22:00	1.71	26, 211	0.0	2 drivers
20 m	22:27:00	3.44	26, 211, 212	0.0	3 drivers
25 m	22:32:00	3.52	26, 211, 212, 23	0.0	4 drivers
30 m	22:37:00	1.76	26, 211, 212, 23	0.0	4 drivers
35 m	22:42:00	1.78	26, 211, 212, 23	0.0	4 drivers
40 m	22:47:00	1.75	26, 211, 212, 23	0.0	4 drivers
45 m	22:52:00	1.79	26, 211, 212, 23	0.0	4 drivers
50 m	22:57:00	3.36	26, 211, 212, 23, 217	0.0	5 drivers
55 m	23:02:00	1.71	26, 211, 212, 23, 217	0.0	5 drivers

Table 3. LSPW – LARGE-SMALL schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	16:29:00	NA	No Matching	NA	NA
20 m	16:34:00	NA	No Matching	NA	NA
25 m	16:39:00	NA	No Matching	NA	NA
30 m	16:44:00	NA	No Matching	NA	NA
35 m	16:49:00	NA	No Matching	NA	NA
40 m	16:54:00	NA	No Matching	NA	NA
45 m	16:59:00	NA	No Matching	NA	NA
50 m	17:04:00	NA	No Matching	NA	NA
55 m	17:09:00	NA	No Matching	NA	NA

Table 4. LSPW – MEDIUM-MAXIMUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	15:21:00	1.25	16, 18	0.0	2 drivers
20 m	15:26:00	1.23	16, 18	0.0	2 drivers
25 m	15:31:00	1.20	16, 18	0.0	2 drivers
30 m	15:36:00	1.23	16, 16	0.0	2 drivers
35 m	15:41:00	1.16	16, 14	0.0	2 drivers
40 m	15:46:00	2.33	16, 14, 15	0.0	3 drivers
45 m	15:51:00	1.15	16, 14, 15	0.0	3 drivers
50 m	15:56:00	1.19	16, 14, 15	0.0	3 drivers
55 m	16:01:00	1.16	16, 14, 12	0.0	3 drivers

Table 5. LSPW – MEDIUM-MEDIAN schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	12:28:00	1.17	25, 8	0.0	2 drivers
20 m	12:33:00	1.13	25, 8	0.0	2 drivers
25 m	12:38:00	1.23	25, 8	0.0	2 drivers
30 m	12:43:00	1.12	25, 8	0.0	2 drivers
35 m	12:48:00	1.16	25, 8	0.0	2 drivers
40 m	12:53:00	2.31	25, 8,9	0.0	3 drivers
45 m	12:58:00	1.20	25, 8, 9	0.0	3 drivers
50 m	13:03:00	1.23	25, 8, 9	0.0	3 drivers
55 m	13:08:00	1.18	25, 8, 13	0.0	3 drivers

Table 6. LSPW – MEDIUM-MINIMUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	17:52:00	NA	No Matching	NA	NA
20 m	17:57:00	NA	No Matching	NA	NA
25 m	18:02:00	NA	No Matching	NA	NA
30 m	18:07:00	NA	No Matching	NA	NA
35 m	18:12:00	NA	No Matching	NA	NA
40 m	18:17:00	NA	No Matching	NA	NA
45 m	18:22:00	NA	No Matching	NA	NA
50 m	18:27:00	NA	No Matching	NA	NA
55 m	18:32:00	NA	No Matching	NA	NA

Table 7. LSPW – SMALL-MAXIMUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	21:26:00	1.27	O, T	15.0	2 drivers
20 m	21:31:00	0.52	O, T	15.0	2 drivers
25 m	21:36:00	1.06	O, T, P	23.0	3 drivers
30 m	21:41:00	0.60	O, T, P	23.0	3 drivers
35 m	21:46:00	0.53	O, T, P	23.0	3 drivers
40 m	21:51:00	0.61	O, T, P	23.0	3 drivers
45 m	21:56:00	NA	No Matching	NA	NA
50 m	22:01:00	NA	No Matching	NA	NA
55 m	22:06:00	NA	No Matching	NA	NA

Table 8. LSPW – SMALL-MEDIAN schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved

15 m	13:27:00	NA	No Matching	NA	NA
20 m	13:32:00	NA	No Matching	NA	NA
25 m	13:37:00	NA	No Matching	NA	NA
30 m	13:42:00	NA	No Matching	NA	NA
35 m	13:47:00	NA	No Matching	NA	NA
40 m	13:52:00	NA	No Matching	NA	NA
45 m	13:57:00	NA	No Matching	NA	NA
50 m	14:02:00	NA	No Matching	NA	NA
55 m	14:07:00	NA	No Matching	NA	NA

Table 9. LSPW – SMALL-MINIMUM schedule

Minutes of late	Late-driver ready time	Reassignment time	Reassignment of driver (ID)	Late in minutes	Number of drivers Involved
15 m	11:01:00	NA	No Matching	NA	NA
20 m	11:06:00	NA	No Matching	NA	NA
25 m	11:11:00	NA	No Matching	NA	NA
30 m	11:16:00	NA	No Matching	NA	NA
35 m	11:21:00	NA	No Matching	NA	NA
40 m	11:26:00	NA	No Matching	NA	NA
45 m	11:31:00	NA	No Matching	NA	NA
50 m	11:36:00	NA	No Matching	NA	NA
55 m	11:41:00	NA	No Matching	NA	NA

Table 10 and Figure 2 show the duty reassignment analysis for LSPW where 100 percent matches~~d~~ were attained in large-maximum, large-median, medium-maximum, and medium-median schedules. The average time for the reassignment process was 1.93 seconds to 2.26 seconds in the large schedule~~,~~ and 1.31 seconds to 1.29 seconds in the medium schedule. Correspondingly, there were no delays or effectively 0 ~~no~~ minutes late in the large and medium schedules. Further investigations revealed that the starts of the second piece of work is equivalently and rationally spread over the hours. Most duties started more than six minutes after the first work. Therefore, it allows the duty reassignment to find its matches without modifications.

Table 10. Duty reassignment analysis for LSPW

	Large			Medium			Small		
	MAX	MED	MIN	MAX	MED	MIN	MIN	MAX	MED
Total simulations	9	9	9	9	9	9	9	9	9
Total matched	9	9	0	9	9	0	0	0	0
Matched percentage	100%	100%	0%	100%	100%	0%	0%	0%	0%
Time taken	19.27 s	22.57s	NA	13.09s	12.95s	NA	NA	NA	NA
Average time	1.93s	2.26s	NA	1.31s	1.29s	NA	NA	NA	NA
Total minutes	0.00s	0.00s	NA	0.00s	0.00s	NA	NA	NA	NA
Average minutes	0.00s	0.00s	NA	0.00s	0.00s	NA	NA	NA	NA

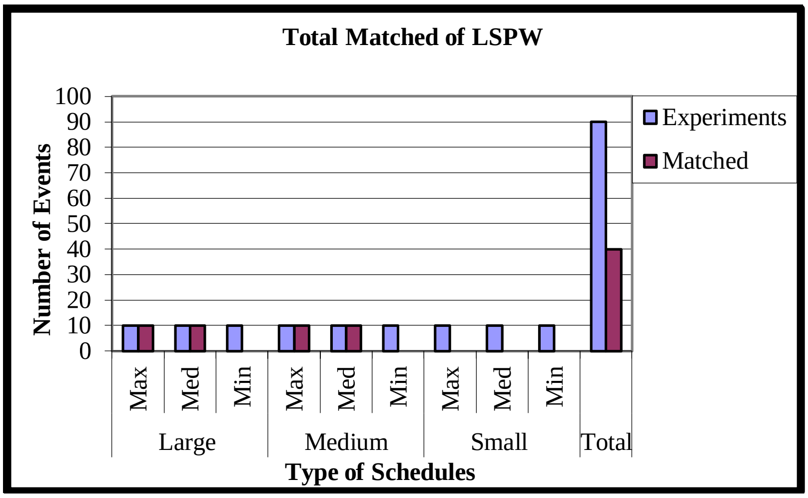

Figure 2. Total matched for LSPW event

4. Conclusion

UI in public transport is an event that occurs without notice in many cases will cause interruptions to public transport services such intra or inter-city bus services. This paper discussed ~~an~~ automated duty reassignment by applying a Multi-Agent System (MAS) in the event of a LSPW. The results show that our technique is capable of effective duty reassignment in the event of LSPW. The proposed approach has the potential to be expanded into similar scheduling domains, such as workforce scheduling, staff scheduling, nurse rostering, truck driver scheduling and air crew scheduling. Although our proposed approach was meant for bus crews, there are similarities in all types of human resource scheduling. When dealing with human, problems such as lateness, delays and unavailability are common.

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