4.1.6

ICTM2005

Information and Communication Technology in Management

INTERNATIONAL CONFERENCE ON INFORMATION AND COMMUNICATION TECHNOLOGY IN MANAGEMENT 2005

"Challenges and Prospects"

REFEREED PROCEEDINGS

23-25 May 2005

Hotel Equatorial, Melaka, Malaysia

Organized By:

Faculty of Business and Law, Multimedia University

MULTIMEDIA UNIVERSITY

Refereed Proceedings of the ICTM 2005

"Challenges and Prospects"

Organised by
Faculty of Business and Law
Multimedia University, Melaka, Malaysia

CONCURRENT SESSIONS - DETAILS

Session 1F

Track	:	Improved Processing Methods, E-Modelling and Computer-Based Simulation
Venue	:	Meranti
Session Chair	:	Dr. Paul Yeow Heng Ping Faculty of Business and Law Multimedia University, Malaysia

Computer simulation: a system dynamic perspective
Mohd Rozaini bin Mohd Rejab
Ridhwan Fontaine
Multimedia University, Malaysia

An Efficient Algorithm to Find Second Best Shortest Path
Shahana Yasmin Chowdhury
Mohammad Erfanul Hoque Siddiqi
International Islamic University, Chittagong, Bangladesh.

A Study on the Computerized Revenue Collection System of Local Authority: A Case of Perlis, Kedah and Penang
Yurita Yakimin bt Abdul Talib
Marlina bt Mohd Lazim
Mohamad Sharofi Haji Ismail
University Utara Malaysia, Malaysia

A Multi-Agents System for Dynamic Bus Crew Scheduling
Abdul Samad Shibghatullah
Tillal Eldabi
George Rzevski
Brunel University, United Kingdom
Sazalinsyah bin Razali
Kolej Universiti Teknikal Kebangsaan Malaysia (KUTKM), Malaysia

Degree Bounded Spanning Tree for Outerplanar Graph
Mohammad Erfanul Hoque Siddiqi
Shahana Yasmin Chowdhury
International Islamic University, Chittagong, Bangladesh

A Multi-Agents System for Dynamic Bus Crew Scheduling 4.1.6

Abdul Samad Shibghatullah [1]
Tillal Eldabi [2], *George Rzevski* [3], *Sazalinsyah Razali* [4]

Abstract

Bus crew scheduling problem is remarkably difficult to solve because of the large number of resources that need to be allocated, very complex rules for the allocation of crew shifts, high cost of overtime and unpredictability of the urban traffic and crew availability. Current schedulers are reviewed and critiqued. The paper considers an alternative approach to the bus crew allocation based on the use of Multi-Agent Systems (MAS) capable of real-time scheduling and dynamic re-scheduling whenever unpredictable events and change of resources or demands occurs. This paper proposes a conceptual framework for an optimum and dynamic crew scheduling by using the concept of MAS.

1.0 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 companies 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 Meilton (2001), 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 (Kwan et al., 2004). 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, no one can claim that they have obtained the most optimum and dynamic schedule (Li & Kwan, 2003). 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, 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 the mathematical and statistical characteristics such as, integer programming and stochastic (Section 4.0 will discuss detail on previous solutions). These characteristics in turn create a difficulty in developing optimum and dynamic schedules.

[1] Research Student, School of Information Systems, Computing and Mathematics, Brunel University, Uxbridge, UK
[2] Senior Lecturer, As above.
[3] Professor, As above
[4] Lecturer, FTMK, Kolej Universiti Teknikal Kebangsaan Malaysia, Melaka

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

This paper has been organised as follows. Section 2 gives an overview of operational planning process in a bus operator. Section 3 describes the theoretical overview of crew scheduling problems and unpredictable events. Section 4 reviews the current approaches used in developing the crew scheduling system and provide a brief critique. Section 5 provides the overview of MAS approach to bus crew scheduling and describes the proposed framework. In section 6, the conclusions and suggestions for further research are dealt with.

2.0 Operational Planning Overview in a Bus Operator

There are four major operational planning in a bus company. There are; timetabling, bus scheduling, crew scheduling and crew rostering. Currently most of the processes are treated independently but there are attempts to integrate bus and crew scheduling into integrated process (see Haase & Friberg, 1999; Freling, Huisman, & Wagelmans, 2001; Freling, Huisman, & Wagelmans, 2003). In this research, the researcher treats them as an independent process.

Timetabling is the process to determine the bus at which, or within which, buses are to take place. There are few inputs that scheduler should know; the stops, frequency and the time for bus to travel between stops. The stops are the place where the bus will stop on particular route. The stops maybe a compromise between of fast direct links and meeting local needs, such as diversions to visit shopping centres or to cover housing area. The frequency, determine how frequent the bus covers that route in different times; such week days, week end, rush hour or night time. Normally, the frequency is more during the peak hour than night time. The time for bus to travel between stops also important. In different time, the travel time is varied; depending on the traffic and demand.

The next process after timetabling is bus scheduling. Bus scheduling is the process of allocating buses to the trips. Trip is a bus movement between specified start and end location at a specified departure and arrival time. This process will determine how many buses are needed to serve particular route and its depends upon the nature of the service required. If buses are to be operated along a number of routes at reasonably high frequencies, the scheduler can take advantage of relationships between routes to achieve efficient linking of arrivals and departures at terminal. The resulting bus schedules will involve little dead running time (i.e. buses scheduled to run empty), or wasted time at terminals. In rural situations where journeys are scheduled for a wide variety of routes, often with relatively infrequent services, the problem is to produce a bus schedule which minimises the amount of dead running

Having established bus workings for the given timetable, the next step for the scheduler is to split the bus running times into crew duty workings. The objectives of crew schedule are to make sure that all the bus is covered by the driver and try to minimise the duty as possible. In United Kingdom, there are few constraints that the scheduler should note; EU Drivers' Hours Rules; and Labour Agreement Rules. Labour agreement rules are the rules agreed upon between the staff union and the company. Normally the labour agreement rules are complying with EU driving rules. The final schedule is almost always a form of compromise between the various aims. The next section will discuss detail on this process.

Having established a set of duties for each day of the week, the next task is to build these into a duty roster for the week. These rosters need to allow for staff rest days, equitable working periods and conformation with agreements. A roster consists of a list of rotas covering all drivers. Drivers may rotate through the whole list, or work the same rota every week, depends on the agreements. The resulting rosters are printed in conventional form for presentation to staff. Hours payable are calculated and supplied to the wages office.

The four processes is a sequential process but often the process involves much backtracking. In the next section, crew scheduling will be described in detail.

3.0 The Bus Crew Scheduling Problem

Before delving deeper into the theoretical issues of the research, it is beneficial to initially understand the terminology applied in this research. Based on literature (Wren & Wren., 1995; Fores, Proll, & Wren., 2000; Wren et al., 2003; Li & Kwan, 2003; Kwan et al., 2004), the basic terminologies of a bus crew scheduling system are as follows (Refer to Figure 2.1):

1 A *depot/garage* is a parking place for vehicles that are not in use for some time;
2 A *trip* is the movement with passengers between two relief points or depot at a specified departure and arrival time;
3 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;
4 A *relief point* is a location and time where and when a change of crew may occur;
5 A *shift/duty* is a sequence of trips assigned to the same crew;
6 An *idle interval* is an interval between two consecutive trips in a shift;
7 The sum of idle intervals in a shift is a *rest time*;
8 The sum of the durations of trips in a shift is the *working time*; and
9 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 scheduling problem can be described as an allocation of crews to trips within given constraints and with the aim of minimising the cost of transportation and fulfilling the requirements of the stakeholders. The stakeholders are the local authority, management individuals, schedulers, supervisors, drivers and maintenance staffs.

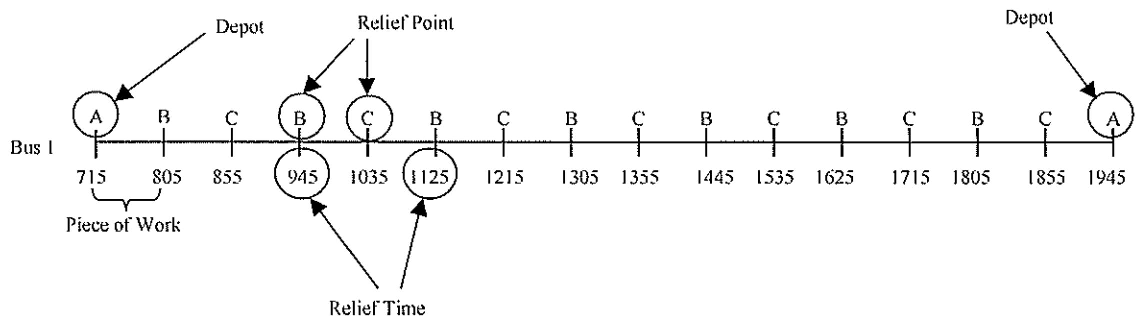

Figure 1: Representation of A Bus Journey In A Day

There are lots of possible schedules but the main objectives are to minimise the total number of duties and the total duty costs. According to Fores, Proll, and Wren (2000), the minimisation of the total number of duties is regarded as more important since there are many costs which depend directly on the number of crews regardless of their wages.

Duty costs depend on the combination of work that they contain, incorporating the hourly wage and including penalty costs for undesirable features such as long or unsociable hours. The overall duty preference should also be considered, which may include a requirement that a limit is put on the number of duties of a certain type.

3.1 Labour Agreement Rules

One of main constraints that involve bus crew scheduling problem is Labour Agreement rules that exist between (1) the Transport and Workers' Union and bus operators and (2) European and UK directive governing the working condition. The main purpose of these rules is to ensure that drivers do not work unacceptable duty; hence the rules provide rigid guidelines on the construction of duties. Typically these rules govern the following issues;

1. Maximum and minimum total working time in a day; a week and a month;
2. The paid allowance for signing on and off at the depot;
3. Time for signing on and off at the depot;
4. The total spread over;
5. The maximum time a driver can work without a meal break;
6. The minimum and maximum length of a meal break;
7. The shift pattern (i.e. number of days break when changing from a day shift to a night shift).

Having this agreement rules, that is a challenge to find an optimal schedules especially when it involves large resources of crews and bus to serve the high frequency route in urban area.

3.2 Operational Issues: Unpredictable Events

In a daily operation, a crew schedule is subject to change due to unpredictable events, especially in the high-frequency route in a busy city. The occurrence of the events will surely disrupt the services. Table 1 shows an example of weekly major delay report due to unpredictable events by one of the major bus operator in London. In the UK, the occurrence of unpredictable events are categorised into four, which are traffic, staff, mechanical and others (Copley et al., 2003). Examples include the absence of staff members without ample notice, the occurrence of staff sickness whilst on duty, vehicle breakdown in the middle of the road and traffic jams due to an accident or road closures. The following paragraphs will discuss detail of each category.

Traffic
Traffic is the passage of people or vehicles along routes of transportation. Road maybe closed and congested due to many factors, such as, accident, road works, special events, heavy rain, snow, signal failure, and etc.

Staff
Most of company has problem in recruiting the new staff, since the career as bus driver is not attractive in terms of pay compare to train or truck driver. Sometimes, the company has to hire part-time driver to cover the duties. The uncertainty problems happened when staff sick on duty and staff not report for the duty. Whenever these problems happened, they have to replace with the spare driver. But, because of the short of driver, they cannot replace the absent or sick driver.

Mechanical
This reason, although not that much but still likely to happen. Although, the maintenance is taken care but there are cases when the bus breakdown during the operation. When it is happen, they have to call the depot, wait for the other bus and transfer to the passenger to that bus. Sometimes it takes time due to the condition of traffic.

Others
Some others reason reported are; road closure due to a man jumped from building, assault to driver, terrorist alarm, marching and etc. Although this is unlikely to happen, still it contributes to the uncertainty factor in bus operation.

Table 1: Major Delays Weekly Report (Example)

DAY	ROUTES	TIME PERIOD	REASON FOR DELAYS
SATURDAY 03/07/04	57	0930 - 1630	Coombe Lane-Road works, delay 8-24"
	Central Ldn	1100 onwards	Pride March
	220	1130 - 1445	Fulham Palace Rd – Traffic, delays 20-45"
	33/265	1130 - 2000	Roehampton Lane – Traffic, delays 10-25"
	Bath Rd TW6	1300 - 1530	Routes 81/222/H32/H98 – Traffic, delays 15-30"
	120	1710 - 1815	Norwood Rd – Assault, delays 60"
	Bath Rd TW6	1830 - 2030	Routes 81/222/H32/H98 – Traffic, delays 20-35"
	120 H32	2000 onwards	South Rd – Traffic, delays 35-50"
SUNDAY 04/07/04	Hslow Bus Stn	0030 – 0140	RTA outside Bus Stn exit
	Bath Rd	1000 – 1600	Routes 81/222/H32/H98 – Traffic, delays 10-42"
	9	1400 – 2000	Knightsbridge – Traffic, delays 15-20"
	120/H32	1400 onwards	South Rd Southall - Traffic, delays up to 35"
	222	1800 onwards	Bath Rd / Sipson Rd - Traffic, delays 20-30"
	440	1905 – 2001	Bollo Bridge Rd – Road closed following RTA
MONDAY 05/07/04	72	0730 – 0815	Roehampton Ln – Road works, delays 20-25"
	267/391/H91	0830 – 1300	Chiswick High Rd – Auto Traffic Signals, delays 10-35".
	Twickenham	0950 – 1600	Heath Road – Road works, delays 15-20"
	120	1515 onwards	South Rd Southall – Traffic, delays 20-30"
	265	1545 – 1700	Roehampton Ln – Traffic, delays 8-23"
	57	1700 – 2000	Tooting High St – Traffic, delays 15-27"
	371	1720 – 2000	Rmond Quadrant – Accident, delays 12-20"
	Kingston	1730 – 2000	Town Centre – Traffic, delays 10-30"
	220	1800 – 1919	High St NW10 – Traffic, delays 15-45"
	H32	1815 onwards	Western Rd – Traffic, delays 15-25"
	440	1835 – 1926	High St W3 – Road closed, man jumped from building
	440	2343 – 0216	Acton Ln/Pk Royal Rd – Rd closed firearm incident

***RTA = Road Traffic Accident**

In the UK, the term of "scheduled-kilometres lost" is used to define the effect of unpredictable events on the bus service. In London, LBL (London Buses Limited) produces a performance report on a quarterly basis and the latest report (third quarter of 2003/04) stated that 3.4 % scheduled-kilometres were lost due to the mechanical faults

(0.5%), staff problems (0.7%) and traffic occurrences (1.8%). The reasons for this phenomenon are the cancellation of the bus service due to no crew and/or conductor, no suitable vehicle is available, mechanical breakdown and traffic congestion. Other reasons are such as, demonstrations and road closures associated with the visit of foreign leaders, roadwork and increased loadings.

The bus operator will not be penalised if the scheduled-kilometres is lost due to traffic instances but will be penalised if it is related to mechanical or staff problems (London Transport Users Committee, 2001). The vehicles and staff are under the control of the private bus operators. This illustrates that private bus operators should manage their vehicles and staff properly so that no service disruption will occur. To face any emergency, the bus operators normally provide spare vehicles and staff whereby they are at the stand-by condition in the garage.

From the aforementioned discussions, it is argued that the system that is dedicated to solve the unpredictable events problem must be embedded with the elements of dynamic capability of real time scheduling. This characteristic in turn enables the system to re-schedule whenever unpredictable events happened. This type of schedule is coined as the optimum and dynamic bus schedule. This concept will be conceptualised into a framework. However, before delving deeply into the proposed conceptual framework, the descriptions and definitions of the current scheduling approaches are initially offered.

4.0 The Current Bus Crew Scheduling Approaches

In this section the paper will discuss the current approaches to tackle the aforementioned unpredictable events in order to develop an optimum and dynamic schedule. It is observed that most of the current approaches that were developed to tackle the unpredictable events dealt with planned changes rather than being independent by themselves. The current solution used in bus crew scheduling are grouped into three main groups; which are, heuristics, metaheuristics and mathematical programming. The classifications are not distinctive because it is usual to find that some mathematical programming approaches may involve heuristic techniques to some extent; some metaheuristic approaches may involve mathematical programming, etc. This section discusses each group of approaches into detail and limitations of these approaches with regard to managing the unpredictable events. The following subsections present the three groups used in bus crew scheduling.

4.1 Heuristics

By the 1980s the early methods for crew scheduling problems were mainly heuristics based. This is because the computer was not powerful enough to run the mathematical solvers, and the techniques in the mathematical solvers were also not as advanced as nowadays. Many of the approaches are first to construct an initial schedule by using a heuristics process, and then attempt to improve the schedule by making limited alterations.

The example of heuristic based techniques are TRACS (Techniques for Running Automatic Crew Scheduling) was developed at University of Leeds (Parker & Smith, 1981), RUCUS (Run Cutting and Scheduling) in America by The Mitre Corporation (Bennington & Rebibio, 1975;Bodin, Ball, & Greenberg, 1985), HOT (Hamburg Optimisation Techniques) in Germany (Hoffstadt, 1981; Daduna & Mojsilovic, 1988) and COMPACS (COMPuter Assisted Crew Scheduling) at University of Leeds (Wren, Smith, & Miller, 1985)

The heuristics were useful in some applications, since they were customized for individual companies and thus could be fully tailored to meet the specific requirement for individual company. The drawbacks of these approaches are they were not easily portable to other companies and had to be considerably modified to fit new conditions. Furthermore they were not suitable for general optimisation (Wren & Rouseau, 1995). In regard to the operational problems presented in section 3.3 we find that heuristics cannot handle the unpredictable events problem. The purely heuristics approaches were subsequently abandonment with the emergence of mathematical programming approaches and metaheuristics.

4.2 Metaheuristics

Metaheuristics is a top-level general strategy which guides other heuristics to search for feasible solutions in domains where the task is hard. Metaheuristics have been applied to bus crew scheduling problems since 1990s. Examples of metaheuristics approaches used in bus crew scheduling are Tabu Search (Cavique, Rego, & Themido, 1999; Shen & Kwan, 2001), genetic algorithms (Kwan, Wren, & Kwan, 2001), fuzzy genetic algorithms (Li & Kwan, 2003) and ant system (Forsyth & Wren, 1997).

Tabu search is an iterative technique that moves step by step from an initial solution towards a solution close to the global optimum. Cavique, Rego, and Themido (1999) used tabu search to reduce the number of pre-generated shifts. The algorithm iteratively removes some inefficient shifts and sometimes their adjacent shifts from the current solutions and then applies the re-cutting algorithm to construct shifts to repair the broken schedule. The result was found very efficient at improving the initial solution after the first few iterations, but then found it difficult to make further improvements.

Shen and Kwan (2001) developed HACS, which also used a tabu search to get rid of infeasibility shifts and fulfill the objectives. Four neighborhoods structures were applied namely: swapping two links, swapping two spells, inserting one spell, and recutting blocks. The first three concentrate on refinement of links with fixed relief opportunities, while the last one considers variable active relief opportunities while links are reconstructed. HACS starts from a rough initial solution, and can deal with complex problems by simply adjusting the cost function and the penalty function to the rules stipulated in specific problems.

Genetic algorithms are based on the mechanics of genetics and natural selection, and represent the search space as a coded population of potential solutions (Goldberg, 1989). The population is then manipulated according to the survival of the fittest principle, providing good practical solutions. Wren and Wren (1995) present driver shifts as a series of consecutive trips in a given day or a specified period of time. In this case, the frame of reference is the string of shifts in a target period of time during which scheduling is to be performed. The solution is produced by generating an initial set of solutions followed by repeatedly generating offspring sets until the desired solution emerges. The initial set is generated by randomly varying the order in which shifts are considered for discarding. The evolution to the next generations is processed by taking the units in chronological order whilst taking the corresponding shifts in random order. Offspring are usually generated by mating two or more values from the previous generation.

According to Wren and Wren (1995) the credibility of this method would be better established if it was tested for larger population. The authors believe that this method would be workable for larger population if intelligently biased evaluation was incorporated. The method was subsequently modified by Li and Kwan (2003) by incorporating fuzzy set theory. They used greedy heuristic method to collect sets of shifts. These sets are then evaluated using fuzzy set theory. A genetic algorithm with fuzzy evaluation is processed repeatedly in a number of steps. The objective is to find a shift cover with minimum cost using the minimum number of shifts. The genetic algorithms are used to fine tune the objective by evaluating the structure using multi starting points. This is done repeatedly in five steps. This method is based on the same problem formulation as in Wren and Wren (1995). The main finding is that the approach produces a near-optimal weight distribution for large size real life problems.

The ant system was developed by Dorigo, Maniezzo, and Colorni (1995) based on behaviour of ants searching for food, which can be modelled into a search algorithm. The fundamental idea is that, when ants move, they leave pheromone trails that can be detected by other ants and slowly evaporate over time. Forsyth and Wren (1997) used ant system to find optimal solution from pre-generated shifts. Each ant will create a solution at each iteration. A heuristic approach is used to select relief opportunities, and then the ant chooses a shift from the set that start at that relief opportunity. The process repeats until the entire tasks are covered. Unfortunately, this method does not produce satisfied results.

The metaheuristics approaches were very useful in producing good results compare to heuristics. However, in regard to the operational issues presented in section 3.3 we find that metaheuristics are not able in handling the unpredictable events problem.

4.3 Mathematical Programming

Mathematical programming approaches work on the definition that each variable represents a shift, and constraints represent piece of work that need to be covered. Set partitioning models therefore attempt to cover each piece of work with exactly one shift, and set covering models allow pieces of work to be over covered. Since the number of potential valid shift for any problem is typically very large, most systems incorporate heuristics or metaheuristics to eliminate shift which are unlikely to be used in good schedules, and so the reduced model can solved much faster. Examples of mathematical programming approaches used in bus crew scheduling are IMPACS (Integer Mathematical Programming for Automatic Crew Scheduling) by Parker and Smith (1981), TRACSII (Techniques for Running Automatic Crew Scheduling, Mark II) which is the successor system to IMPACS (Willers, Proll, & Wren, 1995; Fores, Proll, & Wren, 2001), HASTUS (Lessard, Rousseau, & Dupuis, 1981; Blais & Rousseau, 1988) and EXPRESS (Falkner & Ryan, 1992).

Mathematical approaches were the most appealing in terms of commercial prevalence. Most of the scheduling packages in the market use mathematical approaches, such as TRACS (Smith, 1986), EXPRESS (Falkner & Ryan, 1992), and HASTUS (Blais & Rousseau, 1988). According to Wren (2004) (the well-known researcher in bus and crew scheduling), integer programming combine with heuristics is the best near-optimal solution currently. This fact supported by the fact that most of the prominent scheduling packages use this method. Nevertheless, mathematical approaches do not support the real time reschedule.

Huisman and Wagelmans (2004) had proposed a dynamic integrated bus and crew scheduling system that will reschedule the crew and bus simultaneously, whenever unpredictable events or late occur. Several rescheduling could occur in a single day. The method used mathematical programming and stochastic programming. The method produced good results but there a few assumptions in the research that are not feasible in a real world. First, the passengers have a higher priority than crew. Thus, there is a possibility of violation of the crew rules whenever a bus late occur before the break time. The crew has to shorten the break or not take a break just to make sure the bus operate on-time. Although this is appropriate to guarantee the bus services run smoothly, the EU driving rules should not be broken. Furthermore, this is not acceptable to the crew. Second, a trip can only start late due to a delay of the vehicle and thus not due to the crew. This assumption is not real due to the fact that crew is one of the courses of unpredictable events. Third, the number of vehicles and crews is unlimited. This is not possible. Most of the time, bus company has a limited number of bus and crews.

In summary, although mathematical methods have been employed very elegantly, yet more research is needed to develop approaches that would effectively cope with the dynamics and uncertainty of the scheduling problem. Other disadvantages of using mathematical programming approaches are that optimality is limited to the set of duties generated, and the scheduler has little control over the process after initially setting up any constraints. The scheduler may also wish to add further constraints depending on the resulting schedule.

It is argued that the aforementioned approaches are inadequate to be a basis for developing optimal and dynamic schedules due to their static characteristics. To tackle the above issue this paper proposes a MAS approach to bus crew scheduling that is able to reschedule the crew in a certain period of time, such as, in a day, a week, a month or a year, without disrupting the whole schedule. The definition and descriptions of the proposed MAS scheduling framework are provided in the following sections.

5.0 Multi-Agent System (MAS) 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 to act autonomously upon the users/resources behalf, furthermore they are capable of competing or collaborating, depending on how best to accomplish tasks (Wooldridge, 2002). MAS are systems that contain a large number of these IA, resolving tasks through the interaction of these agents. MAS are especially competent for solving resource allocation and scheduling problems. It creates virtual markets in which agents representing available resources negotiate with agents representing demands for resources until a satisfactory matching is achieved (Rzevski, 2002).

Recently, the MAS paradigm has grown into a major research area. MAS have become significantly important in many aspects of computer science since the introduction of distributed intelligence and interaction. MAS seem to be a natural metaphor for understanding and building a range of what were called artificial social systems (Wooldridge, 2002). They represent a new way of analysing, designing, and implementing complicated and distributed software systems. The increasing of the MAS research interest can be justified by the following reasons (Nwana, 1996; Ferber, 1999; Oliveira, Fischer, & Stepankova, 1998; Weiss, 1999; Shen, Norrie, & Barthes, 2001, Rzevski, 2002):

• In the real world, individuals work in teams and physically or functionally distributed (air traffic control, manufacturing systems, human resource management system, etc.).
• Complex systems are beyond direct control. They operate through the cooperation of many interacting subsystems, which may have their independent interest, and modes of operation.
• The complexity of real-life problems dictates a local point of view. When the problems are too extensive to be analysed as a whole, solutions based on local approaches are more efficient.
• Centralised structures are difficult to maintain and reconfigure, inflexible, inefficient to satisfy real-world needs, costly in the presence of failures, and the amount of knowledge to manage is very large.
• A need for integration of multiple legacy systems and expertise.
• Distributed systems allow fast detection and recovery from failures; and the failure of one or several agents does not necessary make the overall system useless.
• Scalability and flexibility. Because MAS are open and dynamic structures, the system can be adapted to an increased problem size by adding new agents, and without affecting the functionality of the other agents.

In this paper, we propose a framework for crew scheduling system based on MAS paradigm as shown in Figure 2. This framework provides a unified environment in which several agents are integrated. It supports integration with the current systems. The framework consists of three divisions, namely, user, MAS crew scheduling system, and existing scheduling system. User is the person who is responsible in constructing the schedule in a bus operator. The existing system consists of the scheduling engine and the database. Between them is the proposed system which is MAS crew scheduling system.

The proposed MAS crew scheduling system consists of Scheduling Agent (SA), Crew Agent (CA), Bus Agent (BA), Rule Agent (RA), Trip Agent (TA), Traffic Agent (TFA), Interface Agent (IA), and Communication Agent (COA). As shown in the figure, the system is constructed with matchmaker architecture. Schedule Agent (SA) acts as a broker/matchmaker between CA, BA, RA, TA, and TFA. CA and BA are providing the supply. CA gives the supply of crew that will drive a bus, while BA provides the service of bus. TA is agent of request. It requests a bus and a crew to serve the trip. RA is an agent that ensure the schedule created are according to the EU rules (concerning driving hours, break and others) and comply with the TU agreement. TFA is an agent that provides the information on the traffic such as traffic congestion and road closed. IA interacts with the user, receiving user tasks and specifications and delivering results. COA allows the system to interact with the existing system. The next paragraphs describe more detail on objectives, attribute and state for each agent, and a brief on negotiation process.

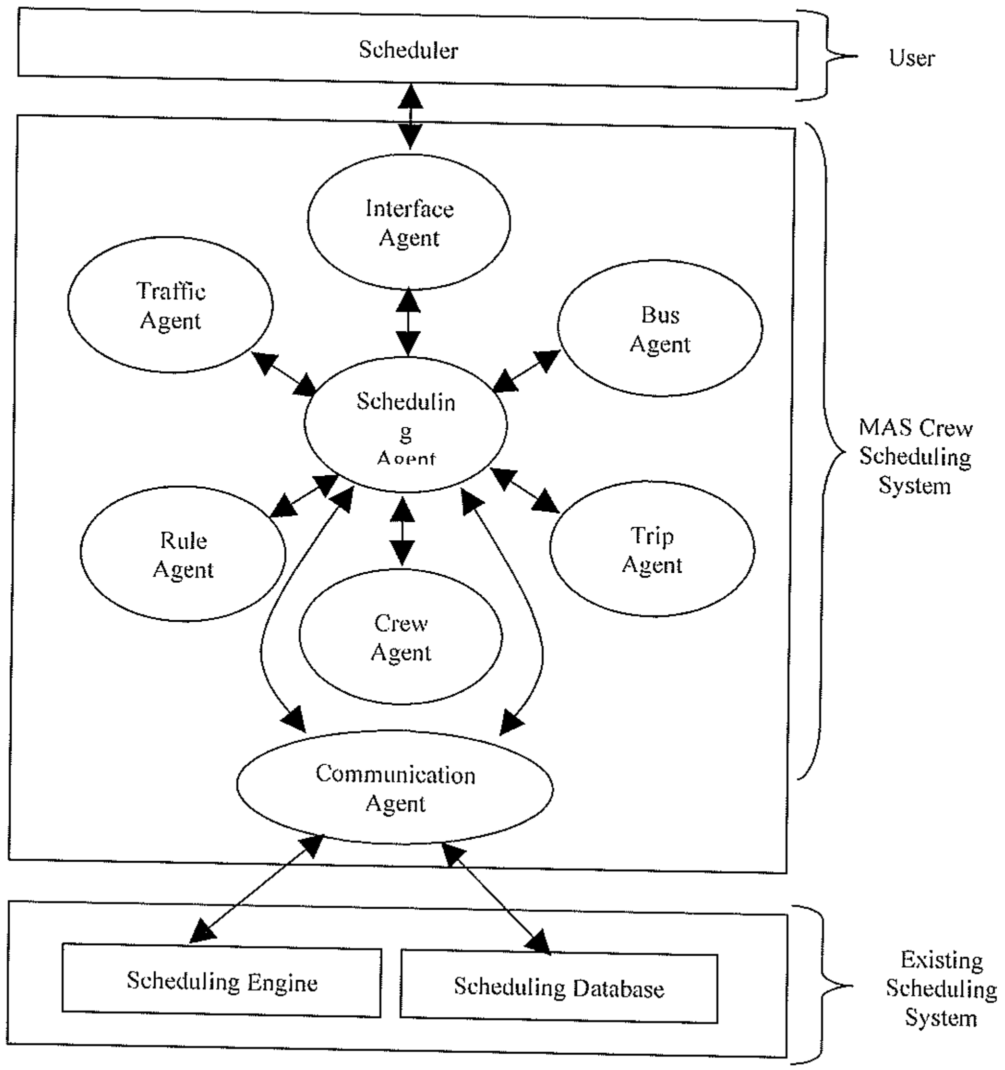

Figure 2: The Proposed MAS Crew Scheduling Framework

Bus Agent (BA)

BA is corresponding to a bus uses in operation. BA pursues an objective to provide service. Its attributes are registration number, model, type, capacity and year. BA methods are in used, ready to use, under repair/maintenance or fault.

Crew Agent (CA)

CA is representing a bus driver who pursues objectives such as obtain a salary and work in a safe and healthy environment. Its attribute are social security number, name, age, address, telephone number, year of experience, and license number. CA methods are on duty, on leave and stand by.

Trip Agent (TA)

TA is corresponding to a trip and deadhead in bus operation. TA objective is to serve the bus route. A trip is movement with passengers between two relief points or depot at a specified departure and arrival time, while a deadhead is a movement in time between two trips without passenger. TA attributes are route number, trip number, start point, end point, start time, end time and duration. TA methods are on, off and jam.

Rule Agent (RA)

RA models the rules and regulation, and agreement with the TU. Its objectives are to ensure that the crew follow drivers' hours rules and follow agreement with staff union. RA attributes are rule identity, rule name, rule detail and rule date. RA methods are new, update, edit and delete.

Traffic Agent (TFA)

TFA is an abstraction of traffic in every route that the bus operator served. Its objective is to update the latest information on the traffic situation. TFA attributes are route number, route name, date, time, and reference number. TFA methods are normal, congested, heavy, and closed.

Scheduling Agent (SA)

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

Interface Agent (IA)

IA models the interaction between the user and the system. Its objectives are to receive user tasks, deliver the task to SA, and present the results to the user. IA attributes are request number, request description, request command, date, and time. IA methods are receive, deliver, reject, and process.

Communication Agent (COA)

COA is responsible to communicate with the existing system. Its objectives are to receive tasks from SA, executed the tasks, and deliver the results. COA attributes are task number, task description, date, and time. COA methods are receive, deliver, reject, and process.

Negotiation Process

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. In this research, we use contract net protocol (CNP) by Smith (1980), but with some modifications that suit the crew scheduling environment. The allocation negotiation may start by TA sending messages to SA describing their requirements. SA then broadcasts an offer to CA. Each CA would then compare features of available trips and select the most appropriate offer taking into consideration any specific demand that the crews may have. Exchange of messages continues until the minimum cost matching is achieved. While forming the schedule, SA would refer to RA to make sure the schedule is legal.

MAS are particularly good at handling changes that inevitably occur during bus operation such as no-show of drivers, bus failures or trip delays. 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 of eligible drivers asking them if anyone could 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 that can undertake new request), 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 SA attempt to minimise the cost of operation by making sure that drivers and trips are matched in such a way that no driver works a shift longer than prescribed, the overtime payment being usually the major cost factor.

6.0 Conclusions

This paper has described the bus crew scheduling problem, and then review the current approaches i.e. heuristics, metaheuristics and mathematical programming. It is argued that the current approaches are inadequate to be a basis for developing optimal and dynamic schedules due to their static characteristics. This paper proposes a conceptual framework based on MAS approach. MAS are especially competent for solving resource allocation and scheduling problems. The conceptual framework provides a unified environment in which the existing system and MAS crew scheduling system are integrated.

Further work involves the design and implementation of each agent. There are many difficult issues that need to be addressed. These include how to control the negotiation/communication process between agents when unpredictable events happened in a large number simultaneously. Deadlock might happen when hundreds of agents sending and receiving messages while negotiating to repair the disrupt schedule. A control mechanism is needed to prevent this deadlock.

References

Bennington, G. & Rebibio, K. (1975). Overview of RUCUS vehicle scheduling program (BLOCKS). In D. Bergmann & L. Bodin(Eds.), *Preprint: Workshop on Automated Techniques for Scheduling of Vehicle Operators for Urban Public Transportation Services.*

Blais, J.Y. & Rousseau, J.M. (1988). Overview of HASTUS current and future versions. In J.R. Daduna & A.Wren(Eds.), *Computer-Aided Transport Scheduling* (pp. 175-187). Berlin: Springer-Verlag.

Bodin, L.D., Ball, M.O. & Greenberg, J. (1985). Enhancements to the RUCUS II crew scheduling system. In J.M.Rousseau(Ed.), *Computer Aided Scheduling of Public Transport 2*(pp. 279-294) North-Holland.

Cavique, L., Rego, C. & Themido, I. (1999). Subgraph ejection chains and tabu search for the crew scheduling problem. *European Journal of Operational Research*, *50*, 608-616.

Copley, G., Dodgson, J., Bright, M., Coombe, D., Davidson, B. & Barrett, G. (2003). *Second assessment report: 10 year transport plan monitoring strategy*. Hertfordshire: Commission for Integrated Transport.

Daduna, J.R. & Mojsilovic, M. (1988). Computer-aided vehicle and duty scheduling using the HOT programme system. In A.Wren(Ed.), *Computer-Aided Transit Scheduling* (pp. 133-146). Berlin:Springer-Verlag.

Dorigo, M., Maniezzo, V. & Colorni, A. (1995). Ant system: optimisation by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics,26*, 29-41.

Falkner, J.C. & Ryan, D.M. (1992). EXPRESS: set partitioning for bus crew scheduling in Christchurch. In M. Desrochers & J.M.Rousseau (Eds.), *Computer-Aided Transport Scheduling* (pp. 359-378). Berlin: Springer-Verlag.

Ferber, J. (1999). *Multi-agent systems: An introduction to distributed artificial intelligence*. London: Addison-Wesley.

Fores, S., Proll, L., & Wren, A. (2000). Experiences with a flexible driver scheduler. *CASPT2000 -- the 8th international conference on computer-aided transit scheduling.* Berlin..

Fores, S., Proll, L. & Wren, A. (2001). Experiences with a flexible driver scheduler. In S.Voß & J.R.Daduna(Eds.), *Computer-Aided Scheduling of Public Transport* (pp. 137-152). Berlin: Springer-Verlag.

Forsyth, P. & Wren, A. (1997). *An ant system for driver scheduling. Technical Report 97.25*, University of Leeds: School of Computing.

Freling, R., Huisman, D. & Wagelmans, A.P.M. (2001). Applying an integrated approach to vehicle and crew scheduling in practice. In S. Voß & J.R. Daduna (Eds.), *Computer-Aided Scheduling of Public Transport, Lecture Notes in Economics and Mathematical Systems* (pp. 73-90). Berlin: Springer.

Freling, R., Huisman, D. & Wagelmans, A.P.M. (2003). Models and algorithms for integration of vehicle and crew scheduling. *Journal of Scheduling, 6*, 63-85

Goldberg, D.E. (1989). *Genetic Algorithms in Search, Optimization and Machine Leaning*. Addison-Wesley.

Haase, K. & Friberg, C. (1999). An exact branch and cut algorithm for the vehicle and crew scheduling. In N.H.M. Wilson (Ed.), *Computer-Aided Transit Scheduling. Lecture Notes in Economics and Mathematical Systems* (pp. 63-80). Berlin: Springer.

Hoffstadt, J. (1981). Computerized vehicle and driver scheduling for the Hamburger Hochbahn Aktiengesellschaft. In A.Wren(Ed.), *Computer Scheduling of Public Transport* (pp. 35-52). North-Holland.

Huisman, D. & Wagelmans, A.P.M. (2004). *A solution approach for dynamic vehicle and crew scheduling. Report EI2004-02.* Erasmus University Rotterdam: Econometric Institute. (accepted for *European Journal of Operational Research* on October 22, 2004).

Kwan, R.S.K., Wren, A. & Kwan, A.S.K. (2000). Hybrid genetic algorithms for scheduling bus and train drivers. *Proceedings of IEEE Congress on Evolutionary Computation*, 285-292.

Kwan, A. S. K., Parker, M. E., Kwan, R. S. K., Fores, S., Proll, L., & Wren, A. (2004). *Recent advances in TRACS.* Leeds: Leeds University.

Lessard, R., Rousseau, J.M. & Dupuis, D. (1981). HASTUS I: a mathematical programming approach to the bus driver scheduling problem. In A.Wren(Ed.), *Computer Scheduling of Public Transport*, (pp.255-267). North-Holland.

Li, J., & Kwan, R. S. K. (2003). A fuzzy genetic algorithm for driver scheduling. *European Journal of Operational Research, 147(2)*, 334-344.

London Transport Users Committee. (2001). *All aboard?*. London: LTUC.

Meilton, M. (2000). Selecting and implementing a computer aided scheduling system for a large bus company. *CASPT2000 -- the 8th international conference on computer-aided transit scheduling.* Berlin.

Nwana, H. S., Lee, L. C. & Jennings, N. R. (1996). Coordination in software agent systems. *The British Telecom Technical Journal, 14 (4)*, 79-88.

Oliveira, E., Fischer, K. & Stepankova, O. (1998). Multi-agent systems: which research for which applications. *Robotics and Autonomous Systems, 7*, 91-106.

Parker, M.E. & Smith, B.M. (1981). Two approaches to computer crew scheduling. In A. Wren(Ed.), *Proceedings of the Second International Workshop on Computer-Aided Scheduling of Public Transport*(pp. 193-222). North-Holland.

Rzevski, G. (2002). *Multi-agent systems and distributed intelligence-MADIRA paper 021.* Retrieved December 15, 2003, from http://www.brunel.ac.uk/research/madira.

Shen, W., Norrie, D. H. & Barthes, J. P. A. (2001). *Multi-agent systems for concurrent intelligent design and manufacturing.* London: Taylor & Francis.

Shen, Y. & Kwan, R.S.K. (2001). Tabu search for driver scheduling. In S.Voß & J.R.Daduna(Eds.), *Computer-Aided Scheduling of Public Transport* (pp. 121-135). Berlin: Springer-Verlag.

Weiss, G. (1999). *Multi-agent systems: A modern approach to distributed artificial intelligence.* Cambridge: The MIT Press.

Willers, W.P., Proll, L.G. & Wren, A. (1995). A dual strategy for solving the linear programming relaxation of a driver scheduling system. *Annals of Operations Research,58*, 519-531.

Wooldridge, M. J. (2002). *An introduction to multiagent systems.* Chichester: J. Wiley.

Wren, A., Smith, B.M. & Miller, A.J. (1985). Complementary approaches to crew scheduling. In J.M. Rousseau(Ed.), *Proceedings of the Third International Workshop on Computer-Aided Scheduling of Public Transport* (pp. 263-278). North-Holland.

Wren, A. & Rousseau, J.M. (1995). Bus driver scheduling – an overview. In J.R. Daduna, I.Branco & J.M.P. Paixao(Eds.), *Computer-Aided Scheduling of Public Transport* (pp. 173-187). Berlin: Springer-Verlag.

Wren, Anthony. (2004). *Scheduling Vehicles and their Drivers – Forty Years' Experience: Report number 2004.03.* Leeds: Leeds University.

Wren, A., & Wren, D. O. (1995). A genetic algorithm for public transport driver scheduling. *Journal of the Operational Research Society, 22(1),* 101-110.

Wren, A., Fores, S., Kwan, A., Kwan, R., Parker, M., & Proll, L. (2003). A flexible system for scheduling drivers. *Journal of Scheduling, 6(5),* 437-455.