The Requirements for a Dynamic Bus Crew Scheduling System

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Abstract. Bus crew scheduling problem is a complex problem because of the large number of variables that are needed to be considered for optimisation, such as complexity of allocating crew shifts; rising costs of crew; and unpredictability of traffic and crew availability. There is a number of existing scheduling systems that are able to produce optimal or near optimal schedules. However, to maintain such optimality in day-to-day operations, such scheduling systems need to extend their capabilities by enabling crew re-assignment, a feature that is not currently available in most automated scheduling systems. This paper looks at the unpredictability problem more closely and investigates how bus companies currently manage their schedules. The information is elicited from literature and interviews from three bus companies in London, UK. Consequently, this paper proposes a set of requirements for a dynamic crew scheduling system that is able to perform crew re-assignment in real time given the occurrence of unpredictable events such as lateness for duty, sick on-duty, or crew absenteeism without prior notice. The proposed approach aims to dynamically maintain optimality throughout day-to-day operations.

1 Introduction

One of the major operational problems faced by bus operators is crew scheduling. Crew scheduling problem is hard to manage due to its complexity, especially when it involves a large number of crews to drive the scheduled buses. In addition, bus operators have to work in accordance with certain driving rules and any existing agreements with Trade Unions (TU) with the objectives of minimising the total shift and operational cost.

There are two main reasons why a crew schedule is immensely important. First, crew expenditure involves a large portion of a bus's operational costs. According to Meilton (2000), the cost of crew 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 rather than 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.

Generally, the main aim for developing any bus crew schedule is to achieve optimum and dynamic schedules. Optimum schedules mean that resultant schedules should minimise the operation cost, whilst dynamic scheduling means that such optimality it maintained throughout the scheduled duration. However, the main obstacle for keeping such optimality throughout day-to-day operation is unpredictable events such as, late crew, sick while-on-duty, or absenteeism without prior notice. Bus service usually operates in an unpredictability environment, especially in high-frequency routes of a busy city. Whenever an unpredictable event occurs, it affects operations, may be even for other routes as well.

In the UK, causes of unpredictable events are categorised into four categories, which are traffic, staff, mechanical and others (Copley et al. 2003). In London, London Bus Services Limited produces a performance report on a quarterly basis and the latest report of the Year 2005 (www.tfl.gov.uk/buses) stated that 2.3% scheduled-kilometres were lost due to the mechanical faults (0.5%), staff problems (0.2%), traffic occurrences (1.3%) and others (0.3%). Reasons for this phenomenon are the cancellation of the bus service due to either: not enough crew, no suitable vehicle is available, mechanical breakdown and traffic congestion. Other reasons include: demonstrations and road closures associated with the visit of foreign leaders, roadwork and increased loadings.

Usually bus operators are not penalised if the scheduled-kilometres are lost due to traffic instances but they will be penalised if it is related to mechanical or staff problems (London Transport Users Committee, 2001). Given that smooth running of vehicles and staff is the responsibility of the bus operators, this shows that bus operators should/need to manage their vehicles and staff properly so that no service disruption will occur, otherwise they will be penalised.

Existing systems such as, TRACS (Kwan et al., 2004; Fores et al., 2002), HASTUS (Rousseau and Blais, 1985), and IMPACS (Wren et al., 1985) are known to be efficient in producing optimal or near optimal original schedules. However, to maintain such optimality during day-to-day operations (dynamic reassignment), crew scheduling systems should extend their capabilities to enabling crew reassignment. This means, if any of the crew becomes unavailable, the crew schedule should remain the same, only their duty will be assigned to other available crew without rules violation. This extended capability does not necessarily need to be developed as a stand-alone scheduling system, rather it might be added to an existing system. Note that the issue here is not to develop new scheduler for producing optimal crew schedules, but merely to assist supervisor in managing crew reassignment in everyday operation, whilst maintaining the original schedule.

This paper has been organised as follows: Section 2 presents interviews from three bus companies in London concerning unpredictable events, and how they manage them. Section 3 offers the interview analysis and the difference between rescheduling and reassignment. Section 4 proposes a requirement for a dynamic bus crew scheduling system. Section 5 concludes the discussion and suggests further research in the matter.

2 Interviews

There are evidences of the unpredictability problem as discussed in previous section in literature. However, there is no literature that discusses how a typical bus company manages the resource (crew) whenever unpredictable events occur that may disrupt the schedule, particularly crew schedule. Therefore, the aim of this section is to acquire knowledge based on practical experiences of bus companies in managing the unpredictable events. Below are the objectives in detail:

1. To identify the types of unpredictable events that are likely to occur and affect its everyday operations.
2. To understand how a typical bus company manages unpredictable events that are related to everyday schedules.
3. To gain awareness of tools or software that assists them in managing and controlling the unpredictable events.
4. To investigate the possibility of using technology to help in managing the unpredictable events concerning crew schedule.

2.1 Background of the companies

Due to confidentiality reason, the name Company A, Company B and Company C are used to refer to the companies being reported. These companies operate in a regulated environment under contract to Transport for London (TFL), with contracts being usually awarded for 5 or 7 years via a rolling tendering programme.

Company A consists of two subsidiaries companies in London. They operate over 1300 buses, employ over 3900 staff, and operate from nine garages. Company A provides nearly 15% of the London market, and account for approximately 260 million bus journeys annually on about 100 day and night routes. One of the subsidiaries runs 600 buses in southeast and central London from four garages. Another operates a fleet of 700 vehicles in southwest and central London from fives garages.

Company B operates a fleet of over 650 buses on 60 routes within Central and South West London and neighbouring Surrey. The company employs over 2,000 people of whom 1,600 are drivers. The company operates from six garages.

Company C employ about 4200 staff and operate around 1300 buses. Company C operates bus services on behalf of London Buses from ten bus garages. Company C also operate the London City Airport shuttle bus services and have a small coach subsidiary, East London Coaches, who operate a series of day trips within the UK and on the continent as well as providing vehicles for private hire.

2.2 Describing the interviews

According to the objective one concerning the types of unpredictable events that are likely to occur and what effect it has on everyday operation, there are number of problems caused by crew, traffic and vehicle. Traffic is the most problematic. No one can predict and control. According to Company C, Friday is usually the most unpredictable day because Friday is the last working day. In addition, sometimes the road might be closed due to security alerts, demonstrations, or accident. Finally, motorists who use bus lanes and park near the bus stop also add to traffic problem.

Some of the unpredictable problems that are related to crew are; crew not coming without prior notice, sick while in duty and comes late. Vehicle breakdown either on the road or in the garage are also other causes of delay.

According to objective two on how a typical bus company manages unpredictable events related to everyday schedules, the problem is managed by supervisors at the garages. A supervisor is usually responsible for making sure that the bus service operates smoothly. The supervisor will carry out appropriate adjustments or changes to the existing schedules. There are no standard procedures in dealing with such problems and it is solely based on the supervisor's experiences.

It is widely agreed that there is no absolute solution for traffic problems. When a problem occurs, the bus will be late and will not run according to the schedule. That is why the times schedule takes account of the recovery time concerning traffics timing. However, if something like this occurs then it will be solved on case by case basis. For example, if there is a closed route due to accident or security alert or etc. then the driver has to change route. While doing this, a few stops might be omitted from the bus route.

If, on the other hand, a crew comes late for a duty, then the duty will be given to another crew, who might be available at that time. When the original crew becomes available, they will be assigned to an alternative duty. If a driver does not come, then the duty will be assigned to a spare (standby) crew. Company A has a policy that the numbers of spare drivers is at least 20% of the whole staff. Other companies did not mention any specific figures. If a crew is sick-on-duty, which happens often (according to company A), then they have to change at depot or the nearest relief point or stop. The spare crew will take over the remaining duty.

If a bus has problem then it will be substituted with any available bus at that time. If a bus breaks down in the middle of the journey then the bus has

to stop at the nearest stop, and then contact the supervisor. A replacement bus will be sent from the nearest depot. In Company A, the policy for keeping spare busses is at least 20% from the whole buses. Other companies did not mention any specific figures.

There are tools such as radio, AVL (Automatic Vehicle Locator) and GPS (Global Positioning System) that assist in managing and controlling the unpredictable events. These tools are only helping them in locating busses and communicating with crews. However, there are no tools that assist the supervisor to adjust the disrupted schedule. Any adjustment or reassignment is usually done manually. Currently used scheduling packages are not offering this feature. The systems are only able to do complete rescheduling.

Regarding the need for using a technology to help in managing unpredictable events concerning crew schedule the answer is an emphatic yes. All of the respondents agree that it is a good idea to have a dynamic system that is able or help to re-schedule the disrupted day or week, without the need to run a complete reschedule.

3 Interview Analysis

A number of lessons could be drawn from these interviews. For example, all companies have more or less similar codes of operation. Crew schedules produced by schedulers are mostly based on scheduling packages such as Trapeze (Company B), IMPACS (Company A) and CAP GEMINI (Company C). The common objective of all of these scheduling packages is to achieve an optimal schedule. Once a schedule is produced then it is up to the supervisors at the garage to manage the schedule manually.

The supervisor has various responsibilities. The main responsibility is to make sure all the buses run on time based on the predetermined schedule. The bus company has to comply with the schedule that has been agreed upon with the TFL. If the company does not perform well, the contract will be suspended. Other than this responsibility, the supervisor has to manage the schedules (times, crew and ROTA), manage the crews, and the busses in everyday operation. These responsibilities are immensely hard especially when dealing with unpredictable events.

All companies agree that unpredictable or unforeseen event is likely to occur everyday and every time. As Company C claimed, there is no such a day as a same day, and Friday is probably the most likely day that such unforeseen events happen. There is no standard solution. They have to manage the problem case-by-case.

The role of a supervisor in dealing with unpredictable events is illustrated in Figure 1.The supervisor has times schedules, crew schedules, and ROTA schedules. The times schedules show planned movement for each bus, times against location, while crew schedule show the activity for every duty from sign-in to sign-off. ROTA schedules show which person is assigned to what

duty in a week. Then, the supervisor has to manage resources i.e. crews and busses. When a certain unpredictable event occurs the supervisor must perform appropriate adjustments to the schedule or change resource allocation. Times and crew schedule will remain the same only re-allocation or reassignment is done to cover the schedule. For instance, if a bus is broken down then a spare bus will be allocated to cover the remaining schedule. Similarly, if a crew is not coming, then their duty will be assigned to a spare crew. Supervisors in charge at the garage tend to manually reallocate or reassign. This practice is the same in all companies.

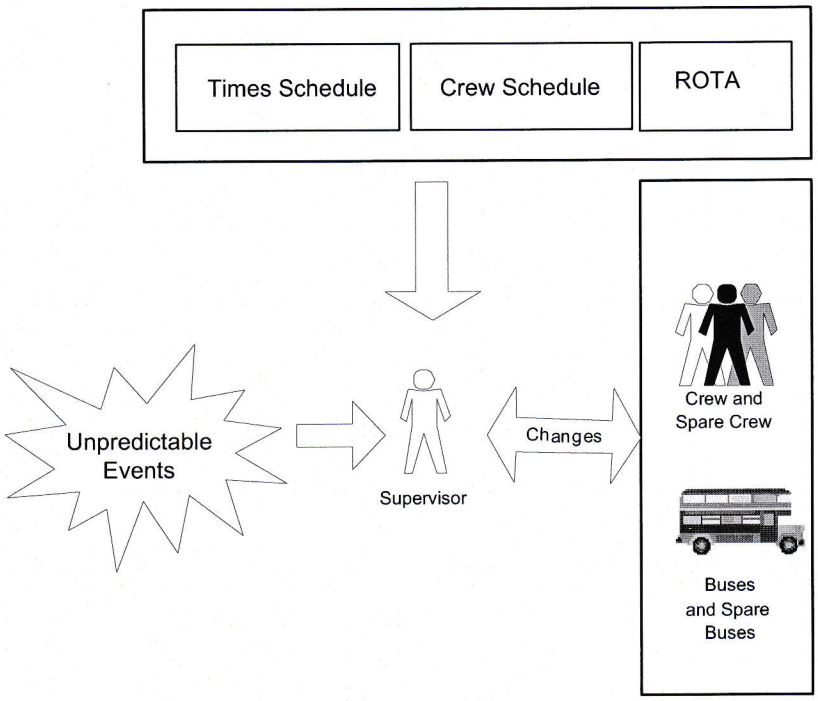

Fig. 1. Supervisor manage the unpredictable events in everyday operation

Although there are some management tools, for example, Automatic Vehicle Location (AVL), still the supervisor has to manage busses and crews properly to make sure all the bus run on predetermined schedule. AVL is an automatic tool that is able to pinpoint the location of a vehicle in operation. According to Company C, AVL can give you the location but not the reason. For example, if Bus A is 15 minutes late, the AVL screen will show its exact

lactation, but the supervisor will not know the reason of such delay. He has to contact the crew by radio to know the reason.

Also existing crew scheduling systems do not support the reassignment process. It is good to have optimal schedules but when unpredictable problems occur the schedule is not optimal anymore. Thus, a crew scheduling system that supports the process of reassignment is needed to help supervisors in dealing with day-to-day crew operational problems.

Two issues have been discussed in this section; the nature unpredictable events and the role of supervisor in managing such events. From the first issue it can be shown that crew is one of the sources of unpredictable events and has a substantial effect to the crew schedule, thus everyday operation. On the second issue, we realise that supervisors play a major role in managing unpredictable events and crew reassignment is a way of dealing with such events.

3.1 Rescheduling versus Reassignment

In this research, we propose to use crew reassignment because of complexity associate with rescheduling, and practicality. The term crew rescheduling here means whenever there is disruption, the current crew schedule will be rescheduled. Whilst, reassignment means, if any of the crew members is unavailable the crew schedule will remain the same, however, the duty of the missing member will be assigned to another available member. The complexity associate with rescheduling could be understood from the constraints (i.e. driving hour rules) of crew itself. When trying to conduct any rescheduling activities, schedulers need to consider the cost and time issues, such as number of available members, driving hours left for each one, and their location of every crew. With such added constraints it becomes very difficult for the system to find an optimal schedule. Huisman (2004) has proposed a crew rescheduling approach whenever a bus is late. One of the assumptions posed by Huisman (2004) is availability of unlimited crew members, however, this is hardly to be realistic. In real situations, it is not practical to reschedule the whole crew whenever a problem occurred. Because this may change driving hours, break timings, and assigned route. Usually a sudden change to the crew schedule is not acceptable to the crew members because it may disrupt their other aspects of their lives (Wren et. al., 2003), and probably will put member under stress (Company B). In addition, crew might have to drive the bus in other routes, which are not familiar to them. In a nutshell, schedule change should be avoided or minimized.

From the aforementioned discussions, it is argued that currently, rescheduling is not suitable for real time applications because crew members might not accept a sudden change. It may be more suitable for planning future events when the crew members are ready to accept sudden change. In this research, reassignment method will be used to tackle the problem of unavailability of

crew members in real time. The following section will presents requirement statement for the propose system.

4 The Requirement Statement for a Dynamic Bus Crew Scheduling System

The objective of the intended system is system is to assist supervisor to do reassign crew for everyday operations in order to cope with unpredictable events such as crew arrival late for duty, sickness, or absenteeism without prior notice. The proposed system aims to maintain crew schedule optimality throughout. Optimal in the sense of minimizing the use of spare crew and dynamic in providing quick solutions to supervisors in dealing with the such events. To fulfil this objective, the system should have the functional requirements as below:

Function 1: Interface with the existing system
Objective: This function is needed to acquire crew schedules and duty assignment that were generated by the existing crew scheduling system.
User: Supervisor
Description: The system should be able to connect with the existing crew scheduling system. User can view duty assignment and predetermined crew schedules, which includes; duty number, route number, garage name, number of spell, sign-in times, start driving times, etc.

Function 2: Storing real time information
Objective: To ensure that the system captures the status of the crew and the crew schedules, because when the system need to do reassignment the current status of every crews and crew schedules need to be known.
User: Supervisor
Description: The system should be able to store real-time information concerning crew and duty schedules. Such information includes; sign-in times, start driving times, finish driving time, start break time, finish break time, current status of crew, sign-off time, total driving time, etc.

Function 3: Reassignment whenever needed
Objective: To reassign crews in case unavailable crews.
User: Supervisor
Description: The system should be able to reassign crews in real time whenever is needed without violating the EC Driving Hour Rules such as those rules concerning break and daily driving hours. Continuous driving hours should not exceed four and half, and total daily driving time should not exceed ten hours. The break should be at least forty-five minutes.

Regarding "Function 3", the proposed reassignment should be similar to the currently practiced manual reassignment as discussed in the previous section. Reassignment should cover four events:

1. **Crew comes late for duty:**The system should be able to assign their duty to available crew at garage. The available crew could be crew that have signed-in but has not started driving, crew that is on a break, or crew which have finished their duty but not signed-off yet. The system should choose a crew who has the lowest driving hours and the duty time needed should not exceed daily driving limit. The chosen crew's original duty may be given to the late-crew.
2. **Absent-without-prior notice:**Normally, a duty consists of two spells. The system should be able to divide the duty into the predetermined spell. Then the system should assign each spell to an available crew at garage. The available crew could be one that has finished their duty but not signed-off yet. The system should choose a crew with the lowest driving hours whilst the duty time needed should not exceed daily driving limit. If there is no match then a spare crew will be used to cover the duty.
3. **Sick-on-duty:**The system should be able to assign their remaining duty to available crew at garage. The available crew could be a crew that is on a break, or a crew that has finished their duty but has not yet signed-off. The system should choose a crew who has the lowest driving hours and the duty time needed should not exceed daily driving limit, and not clash with crew duty. If there is no match then spare crew will be used to cover the duty.
4. **Unavailable part of the duty:**Sometimes a crew might not be available on part of the duty because of some unforeseen reasons. The system should be able to assign his unavailable duty to available crew at garage. The decision mechanism should be same as in (1), (2) and (3).

5 Conclusions

This paper has described the nature of unpredictable events during everyday operations based on the practical experiences of three bus companies in London. It has shown that unpredictable or unforeseen events are likely to take place most of the time. Existing crew scheduling systems are not capable of coping with this problem because the objective of such systems is solely to achieve an optimal schedule. Once a crew schedule is produced then it is manually manage by supervisors at garage.

The task of a supervisor proved to be very difficult. They have to manage resources i.e. crews and busses. When a certain unpredictable event occurs the supervisor must perform appropriate adjustments to the schedule or change resource allocation. A dynamic crew scheduling system that supports the process of reassignment is needed to help a supervisor in dealing with day-to-day operational problem.

The research found that rescheduling is not suitable for a real time because crew members still cannot accept a sudden change. It may be suitable for a plan change or in the future when crew members ready to accept a sudden change. The research considered reassignment method to tackle the problem of unavailability of crew members in real time.

This paper presents a set of requirements for a dynamic bus crew scheduling system that is able to reassign crew for everyday operations when dealing with unpredictable events. The proposed system aims to maintain optimality throughout everyday operations by minimizing the use of spare crew and dynamically providing quick solutions to supervisors while dealing with such events in real time.

For the next step the research aims to implement the proposed system using multi agent concept. Multi-agent systems (MAS) are particularly good in handling changes that inevitably occur during bus operation. Crew reassignment is done by negotiations amongst agents representing resources and demands in a so-called virtual market. Agents negotiate the best matches that are the minimum-cost allocations of crews to duties, which satisfy, as far as possible, the specific requirements of each duty and every crew member. This approach although quite novel and not yet tried in the area of bus crew scheduling, has been tested and evaluated on other scheduling problems such as manufacturing (Jia et al., 2004), logistic management (Karageorgos et al.,2003) and meeting scheduling (Lee and Pan, 2004).

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