Integrated Dynamic Vehicle and Crew Scheduling Using Multi-Agent System

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ABSTRACT

Vehicle and 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. This article proposes a Multi-Agent System (MAS) approach to solve integrated dynamic vehicle and crew scheduling problems. MAS are 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 integrated and dynamic vehicle and crew scheduling by using the concept of MAS.

Keywords: Vehicle Scheduling, Crew Scheduling, Integrated Scheduling, Multi-Agent System.

INTRODUCTION

Vehicle and crew scheduling is another area where integration is important. The need is largest in regional scenarios, which often have fewer relief points for drivers, such that long vehicle rotations can either not be covered with legal duties at all or only at very high cost. In such scenarios the powerful optimization tools of sequential scheduling are inappropriate. Rather, the vehicle and the crew scheduling steps must be synchronized to produce acceptable results, i.e., an integrated vehicle and crew scheduling method is indispensable. In urban scenarios integrated approach also has potentials as well. The current planning systems provide only limited support for integrated vehicle and crew scheduling. There are frameworks for manual integrated scheduling that allow to work on vehicles and duties simultaneously, rule out infeasibilities, make suggestions for concatenations, etc. Without integrated optimization tools, however, the planner must still build vehicle schedules by hand, anticipating the effects on crew scheduling by skill and experience.

Although in the early eighties several researchers recognized the need to integrate vehicle and crew scheduling for an urban mass transit system, most of the algorithms published in the literature still follow the sequential approach where vehicles are scheduled before, and independently of, crews. Algorithms incorporated in commercially successful computer packages use this sequential approach as well, while sometimes integration is dealt with at the user level [1]. In the operations research literature, only a few publications address a simultaneous approach to vehicle and crew scheduling. None of those publications makes a comparison between simultaneous and sequential scheduling. Hence, they do not provide any indication of the benefit of a simultaneous approach.

The first article on the integrated vehicle and crew scheduling problem was published in 1983 by Ball, Bodin, and Dial [2]. They describe the problem at the Baltimore Metropolitan Transit Authority and develop a mathematical model for it. However, they propose to solve this model by decomposing it into its vehicle and crew scheduling parts, i.e., the model is integrated, but the solution method is sequential.

The complete integration of vehicle and crew scheduling was first investigated in a series of publications by Freling and co-authors [3][4][5]. They propose a combined vehicle and crew scheduling model and solve it by integer programming methods. Computational results on several problems from the Rotterdam public transit company RET with up to 300 timetabled trips, and from Connexxion, the largest bus company in the Netherlands, with up to 653 timetabled trips are reported.

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 vehicle and 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 defines the vehicle and crew scheduling problem and unpredictable events problem. Section 4 provides the overview of MAS approach to vehicle and crew scheduling and describes the proposed framework. In section 5, the conclusions and suggestions for further research are dealt with.

OPERATIONAL PLANNING OVERVIEW IN A BUS OPERATOR

There are four major operational planning in a bus company. There are; timetabling, vehicle 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 [4][5][6]). In this research, the researcher treats them as a simultaneous 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 vehicle scheduling. Vehicle 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, vehicle and crew scheduling problem will be described.

VEHICLE AND CREW SCHEDULING PROBLEM

The definition vehicle and crew scheduling problem (VCSP) is the following: given a set of service requirements or trips within a fixed planning horizon, find a minimum cost schedule for the vehicles and the crews, such that both the vehicle and the crew schedules are feasible and mutually compatible. Each trip has fixed starting and ending times, and the travelling times between all pairs of locations are known. A vehicle schedule is feasible if (1) each trip is assigned to a vehicle, and (2) each vehicle performs a feasible sequence of trips, where a sequence of trips is feasible if it is feasible for a vehicle to execute each pair of consecutive trips in the sequence. From a vehicle schedule it follows which trips have to be performed by the same vehicle and this defines so-called vehicle blocks. The blocks are subdivided at relief points, defined by location and time, where and when a change of driver may occur. A task is defined by two consecutive relief points and represents the minimum portion of work that can be assigned to a crew. These tasks have to be assigned to crew members. The tasks that are assigned to the same crew member define a crew duty. Together the duties constitute a crew schedule. In particular, each duty must satisfy several complicating constraints corresponding to work load regulations for crews. Typical examples of such constraints are maximum working time without a break, minimum break duration, maximum total working time, and maximum duration. The cost of a duty is usually a combination of fixed costs such as wages, and variable costs such as overtime payment.

UNPREDICTABLE EVENTS PROBLEM

In a daily operation, a 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. In the UK, the occurrence of unpredictable events are categorised into four, which are traffic, staff, mechanical and others [7]. 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.

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.

MULTI-AGENT SYSTEM (MAS) APPROACH TO INTEGRATED VEHICLE AND 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 [8]. 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 [9].

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 [8]. 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 [10][11][12][13][14]. 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 vehicle and crew scheduling system based on MAS paradigm as shown in Figure 1. 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 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 vehicle scheduling and crew scheduling. Between them is the proposed system, which is MAS, scheduling system.

The proposed MAS 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 ensures 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.

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 vehicle and crew scheduling, 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 [15], 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.

CONCLUSIONS

This paper has described the integrated vehicle and crew scheduling problem, and then review the current approaches. 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 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

[1] Darby-Dowman, K., Jachnik, J.K., Lewis, R.L., & Mitra, G. 1988. Integrated Decision Support Systems for Urban Transport Scheduling: Discussion of Implementation and Experience. Pages 226–239 of: Daduna, J.R., & Wren, A. (eds), Computer-Aided Transit Scheduling: Proceedings of the Fourth International Workshop. Springer Verlag, Berlin.

[2] M. O. Ball, L. Bodin, and R. Dial, A matching based heuristic for scheduling mass transit crews and vehicles, Transportation Science 17 (1983), 4–31.

[3] R. Freling, Models and techniques for integrating vehicle and crew scheduling, Ph.D. thesis, Erasmus University Rotterdam, Amsterdam, 1997.

[4] R. Freling, D. Huisman, and A. P. M. Wagelmans, Models and algorithms for integration of vehicle and crew scheduling, Tech. Report EI2000-10/A, Econometric Institute, Erasmus University Rotterdam, 2000.

[5] R. Freling, D. Huisman, and A. P. M. Wagelmans, Applying an integrated approach to vehicle and crew scheduling in practice, Computer-Aided Scheduling of Public Transport (Vo and J. R. Daduna, eds.), Lecture Notes in Economics and Mathematical Systems, no. 505, Springer Verlag, Berlin, 2001, pp. 73–90.

[6] 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.

[7] 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.

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

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

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

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

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

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

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

[15] Smith, R.G., (1980), The Contract Net Protocol: High-Level Communication and Control in a Distributed Problem Solver. IEEE Trans. Computers, vol.C-29, no.12, pp.1104-1113.