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NEW STRATEGIES FOR DEVELOPMENT OF RAIL TRANSPORT

INFORMATION TECHNOLOGY APPLICATIONS

European Train Control System (ETCS), European Integrated Radio Enhanced Network (EIRENE), and the future European Rail Traffic management System (ERTMS)

Abstract

Although the requirements of high-speed and interoperability with existing sophisticated cab signalling systems may be specific to Western Europe, the ETCS and EIRENE specifications could be of great interest for Asian Railways. While adopting the new technologies, it will be necessary to direct its induction in accordance with business requirements. For this, EU-UIC has a core ERTMS users group, who evaluate the technology from the cost and business requirement viewpoints.

The new EU-Directive on the interoperability of the high-speed rail network

For more than five years, the European Union has been pressing forward with the project relating to the provision of a high-speed railway network. The major technical operating problem has been to overcome the present multiplicity of signalling and train control systems. This issue thus has a major bearing on the new Directive for the interoperability of railway traffic, issued in July 1996. A further objective of the EU is the opening up of markets for procurement in the public sector, which would include railway signalling. The railways are particularly interested in the use of modern technologies with a view to improving the productivity, reliability and attractiveness of railway transport. This includes the use of radio links for the continuous transmission of information between the ground and the train.

The new interoperability directive stipulates that in future all parameters for installations and vehicles that constitute a precondition for unrestricted movement within the networks are to be technically harmonized. It further determines future acceptance procedures for the different components of a railway system together with test methods to establish the ability to operate any critical parts of the systems. These new regulations pave the way for the opening up of procurement markets: Approval certificates once granted in a European country have to be recognized by all the remaining member states.

The new directive is accompanied by the Technical Specifications for Interoperability (TSI) and general European specifications and standards. A company was formed for the specific purpose of drafting the TSI. The "Association Européenne pour l'Interoperabilité Ferroviaire" (AEIF), comprises representatives from industry and from the railways (through the UIC). The elaboration of a TSI for the areas infrastructure, energy, signalling/train control, rolling stock and maintenance is in full progress. There is a draft document available on signalling and train control, which stipulates that infrastructure systems used to date, can continue to be used by new vehicles. However, for future renewal measures or new network extensions, it will be obligatory to apply new technologies.

The specification work for ETCS, a new train control system, by UIC/ERRI

A vast volume of work on the first phase of the ETCS Specifications was completed by the end of 2000. The UIC financed most of the project through its European member railways and had the complex undertaking supervised by a select committee. In the course of the project duration of more than five years, the EU Commission developed an increasing interest in the resulting comprehensive set of specifications and secured its own rights of use by contributing financially. Today the following specifications are available:

- Functional Requirements Specification (FRS) with summary;
- System Requirements Specification (SRS) with summary;
- Sub-System Requirements Specification (SSRS) for Eurobalise, ETCS radio interface and ETCS CAB;
- Requirements for Safety, Environment, Reliability, etc.

Particular attention was given to the work on displays and operating modes. A computer-controlled simulator is available for demonstrations and modelling of the numerous functions.

The clarifications of the ERRI A 200 Working Party have shown not only that ETCS is useful and necessary for high speeds, but that within the framework of a standard system structure for train control with standard components it can also cater for the needs of the national networks including regional lines carrying little traffic. As regards the ETCS concept the following rough distinction may be made between three levels.

- Level 1 is a train protection system for use in combination with conventional external signals. It serves essentially to improve safety and may also constitute a prerequisite for the single manning of cabs.

- Level 2 is a train control system which may replace external signals and which is therefore suitable for high - speed traffic. As far as the technical aspect is concerned the ETCS fixed equipment in this form is superimposed upon conventional signal box equipment.
- Level 3 differs from level 2 in that the function of train location and train integrity detection is effected using on - board equipment, which will lead to a significant simplification of the current fixed equipment.

Between these levels there is a certain degree of interoperability in that a vehicle fitted with level 3 equipment is capable of operating on networks equipped with level 2 and level 1 fixed equipment, and a vehicle with level 2 equipment is capable of operating on level 1 network.

The integration of ETCS into existing structures is easiest and fastest with level 1. Conversely, level 3 will entail major design modifications to the associated systems, particularly as far as the fixed equipment is concerned.

From a technical point of view, there are three basic requirements:

- Cost - effective application of ETCS to all future railway lines and stations (three levels of application);
- Flexible use of balises, loops and radio for data transmission between train and ground;
- Possibility of operating on installations with existing infrastructure systems make the ETCS system highly complex.

With regard to interoperability, it is necessary not only to specify the functions of ETCS, but also a number of further aspects in a uniform manner:

- the definition of various operating modes;
- the ETCS language;
- procedures in connection with data transmission over various transmission systems;
- the functional modularity of the system;
- administrative functions for data processing.

At present there is no other specification in existence anywhere that deals so extensively and in such depth with the subject of system integration.

Testing of prototype Eurobalises and development of ETCS loops

The success of European cooperation has been most obvious to date in furnishing EUROBALISES. In tough negotiations, all those involved managed to agree on the concept of what is known as a magnetic balise with the following features:

- 27 MHz for energizing the balises;

- 4 MHz carrier frequency for the ground - train link;
- 27 MHz carrier frequency for the link with the ground;
- 565 Kbytes/sec data transmission (in both directions);

The companies produced detailed specifications accordingly. Four companies replied to a call for tenders for the supply of prototypes launched last year. They provided a variety of products, which could be tested for interoperability in a laboratory and for reliability on a test track.

For the first time in railway history, it is now possible to buy interoperable balise products from at least 4 different suppliers.

Regarding the ETCS - loop, one of the signalling companies presented an innovative idea, which seems to meet with general approval. For in-line data transmission this uses a leakage cable that can be fitted in the rail groove. A return cable in the center of the track is no longer necessary with this concept. This solution has the big advantage that the vehicles can usually use the same antenna transmission device as that used for EUROBALISE. The beginning and the end of a loop section are indicated using passive EUROBALISE.

Specification work for a new digital train radio system EIRENE (European Integrated Radio Enhanced Network)

The present train radio systems based on a standard defined 25 years ago are no longer capable of meeting future requirements. In 1992, therefore, the UIC embarked on feasibility studies for a future system. In 1993 they took the fundamental decision in favour of using the GSM Standard prepared by ETSI (GSM = Global System for Mobile Communications) which has in the meantime been increasingly used on public networks in the 900 MHz frequency range.

It may be assumed from this that in future both service and passenger-oriented communication requirements in the speech and data traffic area will be effected using the same radio system; an important application will be for ETCS.

Studies have shown that in certain respects the GSM Standard needs to be adapted to specific railway requirements (e.g. Operating at 500 km/h, group calls, short build-up times for connections). It was arranged for this work to be undertaken at ETSI and that it should more or less be completed by the end of 1995. In tough negotiations with the frequency allocating authority, CEPT, a satisfactory solution covering the allocation of a dedicated frequency range for the railways in the 900 MHz band also emerged.

The ERTMS Project

This project, which is supported financially by the EU, is to test the applicability of ETCS and EIRENE on the three railways that already use cab signalling systems for high-speed lines. These are DB AG (Germany), SNCF (France) and FS SpA (Italy). The interaction of ETCS with such systems that are intended to remain in use for many years to come represents a major challenge and is to be tested on the basis of direct cooperation between the specialists from the respective railways. A joint project management team has been created to this end in the form of a European economic interest group, otherwise known as the ERTMS Users Group. This team of about fifteen people has meanwhile started work in a Brussels office. The ERTMS Users Group's counterpart is a consortium of European signal manufacturers known as EUROSIG in the same composition as that adopted for the previous research programmes.

A further important participant in the overall project is the MORANE consortium, which aims to furnish a new digital radio system based on the EIRENE Specification. Also involved in the project are RENFE, the Spanish railways, together with the state-run infrastructure company CEDEX, since the aim is to test the components of the future ERTM/ETCS on-board equipment on the existing high-speed line between Madrid and Seville. The EU Commission has these activities embedded in a rigidly structured project. A comprehensive master plan was established to this end together with a timescale to cover the principal activities. With an estimated overall cost of approx. 430 million ECU, this project has become the biggest rail transport project.

INFORMATION TECHNOLOGY

Comparison of West European and North American Railways

Introduction :

The increasing demand in the Railway Industry to improve the quality and to reduce the costs have resulted into a increasing appeal to the application Information Technology (IT). IT is generally considered to be a key success factor for the railway industry.

The railway business processes could be split up into internal processes and those requiring interaction or co-operation with other railways. Another division might be between processes which are critical core competencies and lead to competitive strength versus non-critical competencies.

Both European and North American railways consider reliable and high quality information in all stages of the transport process as critical for success. This presentation will concentrate on the current status of the application of IT to international or interline rail-traffic, not to the internal processes of a railway.

Comparison between the North American and West European railway collaboration in the application of IT shows that the North American railroads have a lead of a number of years over Western Europe. Reasons are for example the earlier deregulation, the stronger competition, the more IT Oriented management and also the easier climate for co-operation in North America.

In Europe, international IT co-operation is primarily based on consensus between the railways, in general

within the framework of the UIC. Because all West European Railways are in different stages of development, their vision of the transport business in general and the application of IT in particular differs significantly. This makes the consensus process extremely difficult, which results in slow progress and sub-optimal solutions.

In North America, at least the class one railroads are all more or less in the same phase of development. Their vision of the transport business and the application of IT seems to be rather consistent. New IT projects are only undertaken if at least the few major North American railroads agree. The Association of North American railroads (AAR) and notably its IT subsidiary Rail Inc play a key role in the development and operation of North American IT systems.

Key IT-applications in Western Europe

Basically, two kinds of international IT applications might be distinguished here: passenger applications and freight applications.

2.1 Passenger applications

Up to now, in the area of international passenger transport no supranational railway distribution systems exist in Western Europe. Each railway has its own domestic sales systems which sometimes encompass reservation functions. The functionality of the different systems however varies per railway according to its commercial policy. Not infrequently, the booking func-

tions on behalf of smaller railways are hosted by reservation-systems of larger railways. The data exchange between the various reservation-systems is governed by UIC standards (leaflet 918) and supported by Hermes, the railways proprietary data communication network. Unfortunately, leaflet 918 covers only the "highest common factor" of the different systems, which is not always sufficient.

Nowadays, interconnectivity of railway distribution systems is a key issue for the UIC. The DB and the SNCF, the two most important players in this area, have agreed to harmonise new function in the future. Another important factor will be the global distribution systems (GDS) of the airlines. A number of railways have connected their systems to one or more airline GDS's to enhance their sales. UIC projects have been started to improve information exchange between railway distribution systems and access to and the quality of information on international products.

2.2 Freight applications

Probably driven by requirements of the market, the freight sector of the West European railways has been much more active in the international electronic exchange of data (EDI) than the passenger sector. The implementation of the Hermes data network, more than 10 years ago, gave an impetus to the electronic exchange of freight transport data. Since that time, a dozen so called Hermes functions have been designed and implemented. The most applied functions are "the pre-announcement" and the "wagon trace". Hermes functions are small applications, integrated into the national freight information systems. Due to the national differences and the lack of strong commitments, the quality of the international data is not always satisfactory.

Therefore, at the end of the last decade, more centrally controlled applications like Docimel and HIPPS were proposed. The Docimel project, which aimed to replace the paper consignment note by electronic data exchange, was started in 1987 and was abandoned in 1992. Technically, it was based upon a distributed architecture with a central "server" and national "clients". All relevant events were to be stored centrally and distributed to concerned "clients". Supply of information to final customers however, always remained the responsibility of the associated railway.

Together with the deliverables (a full set of functional and technical specifications), the conclusion came that the Docimel-objective, the European-wide disappearance of paper consignment notes, was too ambitious and not feasible. Out of the Docimel project, a sub set of functions was extracted, and baptised "Orfeus". Orfeus does not aim to replace all the paperwork. Today, the central "server" is in operation, together with six railways (SJ, DSB, DB, SBB, FS and NS). For the moment, the paper consignment note is still used in parallel. Agreements are set up to cover the legal aspects of EDI applications. In the future, more participants are expected to join, and new functions are planned for container traffic and customs.

The HIPPS project was set up as an independent project in 1989. The purpose of HIPPS is planning and monitoring of freight transport. Basically, HIPPS is divided into four stages. The first stage offers timetable information

for international transport. The second phase is designed to provide information on the actual forwarding schedule whilst the third phase involves the tracking of a wagon. Finally, the last phase deals with measures in case of delays or other deviations from the forwarding schedule.

The first HIPPS phase has been in operation since late 1995. Next stages will follow in the coming years. Like Docimel/Orfeus, the architecture of the HIPPS system is distributed. The central HIPPS "server", installed in Frankfurt, connects the participating "client" railways via the Hermes network and distributes relevant information to all railways concerned.

Recently, problems have arisen with respect to confidentiality. Due to the changing, more competitive position of the West European railways, the transparency of information is at issue. This might significantly influence the design of the HIPPS system and delay the implementation of forthcoming functions.

It can be seen that in spite of the increasing effort and attention, progress in the realisation of key IT applications for freight transport is not sufficient to meet the requirements of the business. Data quality is still a major problem and the chosen architecture, which is based on national information systems, seems to be inadequate.

Key IT-applications in North America

Most key IT applications on behalf of the North American railroad have been developed and are operated by Rail Inc, a subsidiary of the AAR. With the exception of AMTRAK, the North American rail business is entirely freight. This explains why all key developments of Rail Inc are freight applications. The following systems are being developed and/or in operation :

Interline settlement system

The objective of the Interline Settlement System (ISS) is to "handle the error free settlement of freight revenue (\$ 18 billion per year) on behalf of the North American railroad Industry".

The system is based upon a central information system in Washington which collects and issues interline revenue waybills. Edition of waybills is supported by a number of Industry Reference Files . The system has been in operation since 1993 and since October 1996 has been handling virtually the complete range of interline settlements for the railroads.

Rate EDI Network

The Rate EDI Network (REN) aims the "electronic communication of price information seamlessly among participating railroads". The REN system replaces the old manual price inquiry system. It contributes to the accuracy of the billing and the price information and reduces the number of disputes. The main function is the capture, validation and distribution of (new) prices, generated by the railways. The system, which does not determine nor store prices, is protected with several security and verification mechanisms. The first phase of REN has been operational since 1993.

Industry Reference Files

Basically, all key information systems rely on a number of Industry Reference Files (IRF). The data in the reference files are provided by the participating railways as well as by other non-railway sources. Today, the following files are in operation:

- Centralised Station Master (CSM)
- Customer Identification Files (CIF)
- Junction Interface File (JUNC)
- Mark Register (MARK)
- Routing file (ROUTE)
- Shipment Condition File (SCF)
- Standard Transportation Commodity Code (STCC)
- Universal Machine Language Equipment Register (UMLER)

New files for "Route Approval" and "Serving Carrier/ Reciprocal Switch" (SCRS) are under development.

Interline Service Management

The mission of the Interline Service Management (ISM) system is "to develop and to foster the implementation of business processes and to support information systems which will allow interlining carriers to provide a reliable, competitive and seamless service". The benefits of ISM are:

- better communication between interline partners on the base of formal commitments, the interline service agreements.
- more efficient car handling and marshalling based on trip plans.
- an increased services level due to transport monitoring and post trip analysis.

The system is operational. 75% of the multi carrier transports are covered by ISM agreements. To date, trip-plans are exchanged between seven railways.

Industry PC Package

A standard PC software package "to give the customers a seamless view of the railways industry and to promote

the usage of electronic data interchange, while reducing customer and railroad costs". The first Phase, which covers the capture of consignment note data, E-mail and inquiry facilities, is in operation. The second phase which deals with wagon order, switch and release functions and the last phase which covers invoicing are being developed.

Apart from the IT applications, a strict Data Quality Assurance program has been set up to improve the quality of consignment, trip plan and settlement data. Obviously, AAR and Rail Inc seem to be well on the way to establish reliable information exchange on behalf of the multi carrier railway transport business in North America. Especially their attention to "seamless service" and "quality improvement" deserves attention. Rail Inc is spending annually about \$ 25 million on IT.

Conclusion

The application of Information Technology is considered to be a key success factor for both North American and European Railways. Up to now, the North American railroads, organised in the AAR/Railinc framework, seem to be quite successful in the realisation of information systems on behalf of their customers. Based on a data infrastructure like IRF, a number of key applications have been built, to support the business processes in virtually all its phases.

The West European railways are not yet in this position. In spite of significant investments and effort, the deliverables are still rather limited. This seems to be partly due to the chosen organisation based on consensus, voluntary participation, and independence. This is mainly due to significant differences in the vision of the business objectives of West European railways.

Govt of India to introduce smart cards for storing data

The government will introduce 'Smart cards' with large data storing capacity for driving licences, vehicle registration certificates and national permit for commercial vehicles to replace the present system of lengthy paper work by the end of this year.

"We plan to replace the present system with Smart cards that will store personal and vehicle information. State transport authorities would be issuing around 50 million such cards in the next two year," Ashoke Joshi, Secretary, Roads, said at the end of a seminar on 'Induction of IT in road transport sector'. The user-friendly Smart cards would cut down the cumbersome documentation procedure and be tamper proof. The cost of the new cards would only be marginally higher than the prevalent fees structure. Computerisation of regional and district transport offices has been initiated by a number of state government including Delhi, Maharashtra, Bihar, Goa, Punjab and West Bengal, and the same would be interlinked with each other with a national network soon. A data bank on licences issued, vehicle registration and road permits would be created that could be accessed from anywhere.

A Train Rescheduling Simulator Combining Pert and Knowledge-based Approach

-Dr TOMII Norio

ABSTRACT

A new simulation method of train traffic rescheduling, which combines a PERT method with a knowledge-based approach, is introduced. Calculations of train arrival/departure times are done by PERT, and rescheduling is done by a knowledge-based program in parallel with the calculations. This makes it possible to construct a practical train traffic rescheduling system which runs very fast and enables rescheduling during the process of calculating train arrival/departure times. We have developed a prototype system and examined the effectiveness of our simulation method through several experi-

1. INTRODUCTION

In order to solve complicated scheduling problems in the real world, simulation is often used. The problems which we are particularly interested in and are trying to solve by simulation are called train traffic rescheduling. This is a series of schedule modifications which are made by experts called train dispatchers in order to restore the train traffic, when it is disrupted by accidents, natural disasters, engine troubles etc. Train traffic rescheduling consists of cancellation of trains, change of train orders, change of car utilization schedule, change of assigned track and so on. This is quite an important job both from social and managerial points of view. That is, if the rescheduling is poor, a lot of people are inconvenienced, and sometimes a huge amount of money has to be refunded. Also, train traffic rescheduling is an extremely difficult job for the reasons such as:

- A quick decision-making is needed. (Trains are running!)
- A large number of trains are involved.
- Various conditions have to be taken into account, such as seriousness of the accidents, time until the troubled car is fixed, availability of extra rolling stocks, crowdedness of the trains, characteristics of the railway line (e.g.. Line for commuting or line for intercity transport), etc.

This means that train traffic rescheduling is a large size combinatorial problem which has to be solved in a short time, and which is highly site-dependent. Furthermore, sometimes not all the necessary information is kept in computers. So, it is almost impossible to solve the problem by computers only, and they are solved through man-machine collaboration. Computer programs propose a restored traffic plan simulating the movements of trains based on the current situation and the knowledge concerning the train traffic and train traffic rescheduling. Proposed plans are shown to train dispatchers, and they give some modifications so that the plans become more suitable for the current situation. These computer programs are called train traffic rescheduling simulators. During the process of simulation, modifications to restore the traffic (i.e.. Rescheduling) are done and if the modifications cause some contradictions of schedule (deadlocks), they have to be detected and removed.

As the train traffic simulation methods, two methods have been developed, namely, an event-driven simulation method and a network simulation method. Although the former is a better known simulation method, it has disadvantages that the execution speed is slow, and it is difficult to detect and remove deadlocks. The latter (Abe and Araya 1986) is a method which utilizes PERT. A train schedule is expressed by a kind of PERT network, in which nodes correspond to arrival/departure of trains and arcs correspond to constraints such as departing orders, train routes, limitations caused by facilities etc. Feasible arrival/departure times are calculated using the property that the feasible time of each node is obtained as the weight of the longest path from the start node. The network simulation method can be done with an execution time of $O(|N|+|A|)$, and this means the simulation speed is quite high. It also has an advantage that if the schedule contains a deadlock, it is detected in the simulation process. On the other hand, this method has a big disadvantage that rescheduling cannot be done in the simulation process. This is because the schedule has to be rigidly expressed by the schedule network prior to simulation, and it is impossible to calculate the feasible arrival/departure times if the network is modified in the process of calculation. (Note that traffic rescheduling corresponds to modifications of the network.)

In this paper, we propose a new simulation method called hybrid simulation method designed combining PERT method and knowledge-based approach (Hayashi et al. 1994), (Cheng et al. 1994). One of the basic ideas is to modify the PERT network in the PERT calculation process consulting the knowledge base so that train rescheduling can be conducted concurrently with the simulation process.

Some of the issues which arise when this approach is used are:

- How to decide the timing of invoking the knowledge base?
- When the knowledge base has decided that the given schedule has to be modified, how the result is reflected on the PERT part.
- When there appears an inconsistency be-

tween the decisions by the knowledge base and the current PERT network, how it can be settled?

We settled these issues by introducing a concept called order interchangeable node sets to express groups of nodes whose mutual orders are likely to be changed and by enhancing train schedule PERT network adding this concept. This method has advantages that the simulation speed is high and that rescheduling can be done during the simulation process. Also, deadlocks are not only detected but can be removed. Rescheduling is done consulting a knowledge base, and simulation systems tailored to each site are easily obtained.

In section 2, we explain requirements of train traffic rescheduling and in section 3, we describe the details of our hybrid simulation method. In section 4, we prove the effectiveness of our simulation method by showing the results of the experiments which we did on our prototype system.

2. REQUIREMENTS FOR TRAIN TRAFFIC RESCHEDULING SIMULATORS

Train traffic rescheduling simulators have to satisfy the following requirements: - Execution speed must be high. Trains are running and quick decisions are needed. Also, simulation is usually repeated several times until a desirable restored schedule is obtained. - Traffic rescheduling has to be done in parallel with the calculation of feasible train arrival/departure times. In train traffic rescheduling, simulation consists of two tasks: one is to calculate feasible times of each train arrival/departure. Since train traffic has to be carried out under the physical and logical constraints (some of them are shown in Table 1), once there are delays or changes of the schedule, trains are not always able to arrive or depart on time, thus feasible times of train arrivals/departures have to be calculated. The other task is to reschedule the traffic so that it is restored. These two tasks have to be done concurrently, because in order to reschedule the traffic, feasible times of train arrival and departure are needed, and the rescheduling may affect the feasible times of trains afterwards. - Simulators have to be able to detect and resolve deadlocks. A deadlock means a contradiction in a schedule; thus if there are deadlocks in the schedule, it is impossible to get the feasible times of train arrival/departure by simulation unless the deadlocks are resolved. - Simulators have to be intelligent enough to make necessary changes in the original schedule so that the traffic is restored. When the delay is rather small, only changes of train orders are done. In case there happens a relatively large delay, other methods such as cancellation of trains, change of car utilization plans etc. are used. But it is quite difficult for computers to employ these methods because usually effectiveness of these methods strongly depends on the situation about which computers do not have all the information. Thus, usually, only changes of train orders are done by computers. There are two types of changes of train orders. One is called a crossover conflict decision. A phenomenon called a crossover happens in such a situation where two trains, an arriving train (Train 1) and a departing train (Train 2) are involved, and equipments such as a railway crossing point which are to be shared by both trains exist on each of their routes as illustrated in Figure 1.

In such a case, there is a dependency between the arrival time of the arriving train (Train 1) and the departure

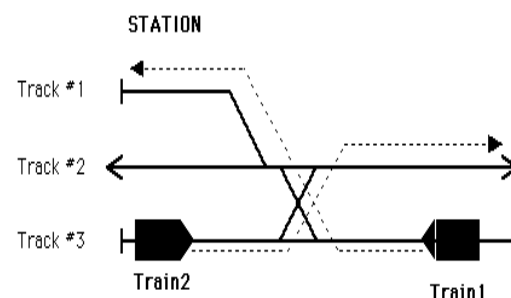
time of the departing train (Train 2). When Train 1 arrives at the station, Train 2 can depart at the same time as the arrival time of Train 1. On the other hand, when the event of the departure of Train 2 comes first, several minutes are needed between Train 2 departure and Train 1 arrival. This chronological dependency is called a crossover conflict. Deciding train orders considering crossover conflicts is extremely important, since if the decision is poor, a lot of arriving trains are kept waiting near the station, which throws the whole traffic schedule into a mess. Also, there are a great number of occasions where crossover conflicts must be considered. So, to make the decision by a computer is quite helpful to train dispatchers. There is the second type of changes of train orders, namely change of departing train orders (we call this departing order decision). This is typically done when a slow (usually local) train is going to be caught up by another (usually one or more express) train. In order to get a more reasonable schedule, the departing order of these trains should be changed so that the express trains depart first, and they can run without any obstacle ahead. Departing order decisions have also to be done so many times that to make this decision by computer is quite helpful too.

3 HYBRID SIMULATION METHOD

3.1 An Outline of the Hybrid Simulation Method

We propose here a new approach to train traffic simulation called a hybrid simulation method. Basic ideas of our method are as follows: - Order interchangeable node sets We introduce a concept called order interchangeable node sets to enhance the train schedule network. An order interchangeable node set means a set of nodes whose order of execution has possibility of change. - Knowledge base An execution order among the nodes in each order interchangeable node set is decided by consulting a knowledge base. Thus, it is easy to install site-specific knowledge and it is also simple to add and modify the knowledge. - Deadlock Although the original train schedule usually does not contain deadlocks, there may appear deadlocks when the schedule is changed for the purpose of traffic rescheduling. In our hybrid simulation method, not only existence of deadlocks is detected but they are resolved if found any in parallel with the calculation process. This method preserves the advantage of the PERT network method that simulation can be done at a

Figure 1



high speed. It has other advantages, which the network simulation method does not have, that it is possible to reschedule the traffic in the simulation process, and that if there appear deadlocks, they can be resolved. Formerly, a train schedule network with order interchangeable node sets is a network $GO=(N, A, O)$, where N is a set of nodes, A is a set of arcs and O is a set of order interchangeable node sets. N is a set of nodes, and $n \in N$ corresponds to a departure or an arrival of each train, and $A \subseteq N \times N$ is a set of arcs which correspond to constraints concerning the schedule and the facility limitations as described below. An arc from Node x to Node y indicates that the event expressed by Node x has to occur after the event of Node y . The weight of the arc expresses the minimal time interval between the event x and the event y . There are several types of arcs, such as minimum running time arcs (the weights express the minimum running time of trains between stations), minimum departure-departure interval time arcs (the weights express the minimum time interval between two departing trains), minimum arrival-arrival interval time arcs (the weights express the minimum time interval between two arriving trains), maximum capacity between stations arcs (the weights express the maximum number of trains which can simultaneously exist between stations), track arcs which express the track usage orders of stations. As for an imaginary node, there exists a start node. Weights of arcs from the start node to each arrival/departure node express the scheduled time of arrival/departure. O is a set of order interchangeable node sets $O \subseteq N \times N$. This means that the order among the nodes in an order interchangeable node set may be changed during the simulation process.

3.2 How to Find Order Interchangeable Node Sets

The simulator decides whether the execution order among the nodes of order interchangeable node sets should be changed or not, when it encounters a node which is contained in some order interchangeable node set. This decision is done by consulting the knowledge base. Since this is rather a time-consuming process, it is indispensable to register necessary and the least number of node sets as order interchangeable node sets. Order interchangeable node sets for crossover conflicts are obtained using the following properties. [Properties] 1. A crossover conflict happens for an arriving train and a departing train whose routes share some facility (such as railway crossing points). 2. Crossover conflict never happens for trains which use the same track. 3. A crossover conflict happens in events which occur consecutively. These properties can be rephrased in terms of graph theory as crossover conflicts do not happen between two nodes n_1 and n_2 such that there exists a path from n_1 to n_2 or from n_2 to n_1 . Order interchangeable node sets for departing order decision are found as a set which consists of a local train and express trains which are overtaking and which are likely to overtake the local train. Figure 2 shows an example of a train schedule, and in Figure 3, a train schedule network with node order interchangeable sets created from the schedule of Figure 2 is depicted. Nodes connected by dotted lines are order interchangeable node sets.

3.3 Simulation Method

Simulation on the train schedule network with order interchangeable node sets GO is done following the procedure described below: 1. Topological Ordering To topologically order the nodes in GO . Topological ordering means to give a number $num(n)$ to each node $n \in N$ so that $num(x) < num(y)$ when there exists an arc (x,y) (Aho et al. 1974). 2. To calculate feasible arrival/departure time of each node Calculation proceeds as follows: (a) To pick up a node n which has the smallest topological number among the nodes whose time is not yet calculated. (b) To calculate the weight of the longest path from the start node to n . (c) If there exists an order interchangeable node set (OINS) which contains n , and the times of the other elements of the OINS are already calculated, the knowledge-based part decides the mutual order of the nodes in the OINS. (d) In case the decided order is different from the current schedule, the network and OINSs are maintained so that they are compatible with the modified schedule. (e) To set a range of reordering as from Top_1 to Top_2 , where Top_1 is the smallest topological order value and Top_2 is the largest topological order value among the nodes which were modified. To cancel the calculated times for the nodes whose topological orders are between Top_1 and Top_2 . To topologically reorder those nodes. Go back to 2-(a). 3.4 Knowledge Base The knowledge base of our prototype system contains heuristic rules acquired from train dispatchers. Currently, we have installed approximately 30 rules in total. 3.5 Results of the Experiments 3.5.1 Execution times We have implemented our prototype system on an engineering workstation (SUN Sparc Station 10) using C and Ral (Ral 1991), and conducted several experiments. In Table 2, we show the results of our experiments. We picked up a train which starts around 9 o'clock (this is one of the times

Figure 2

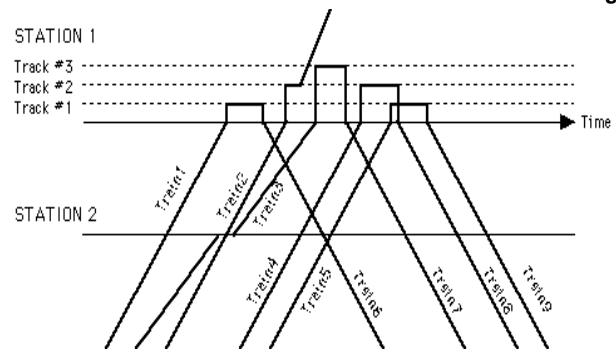
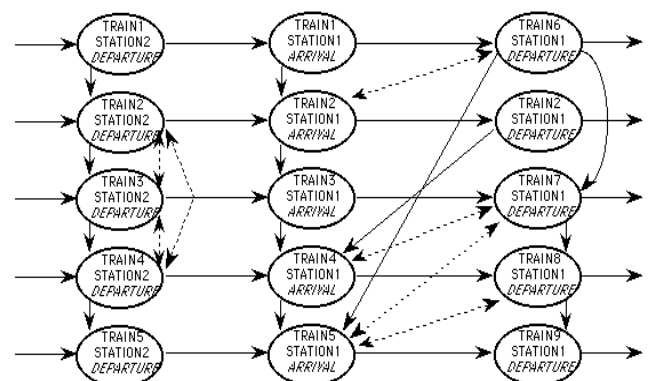


Figure 3



when train traffic is the most crowded), and caused it to delay. We performed 6 experiments changing the time of the delay. The total number of the trains and stations in the schedule we used are 690 and 36 respectively. We carried out a simulation in the time range of 6 hours (6 o'clock to 12 o'clock), and the numbers of the nodes and the arcs transformed from this schedule are 5,155 and 14,497 respectively. (This schedule is as dense as Tokaido-Sanyo Shinkansen Bullet Train Line.) Table 2 shows the delay of the first delayed train, execution time, the number of rule invocations for crossover decision and departing order decision. Table 2: Results of execution times case delay crossover rule departing rule execution time 1 0 min 0 times 0 times 0.74 sec 2 5 min 22 times 0 times 1.15 sec 3 10 min 21 times 10 times 3.15 sec 4 15 min 23 times 10 times 4.28 sec 5 20 min 24 times 17 times 6.20 sec 6 30 min 22 times 13 times 6.73 sec The execution time of the conventional network simulation method (i.e. Network simulation method without order interchangeable node sets) was 0.51 seconds irrelevant of the time of delays (Note that the conventional method does not have an ability to modify the schedule during the process of simulation. So, the value of delays does not affect execution times). Simulation times for our hybrid simulation method are from 0.2 to 6.2 seconds longer than the conventional network method, but there seems to be no problems in these execution times in constructing a practical train traffic simulator. 3.5.2 Traffic rescheduling results In Figure 4, we show how the traffic is restored in the cases of Table 2. This graph depicts the sums of the delay times of all the train arrivals and departures. The results of the conventional network simulation method are also shown. From this graph, we can say that the sums of the delays in our method are smaller than those in the conventional network simulation method, and that our method is effective in restoring the train traffic.

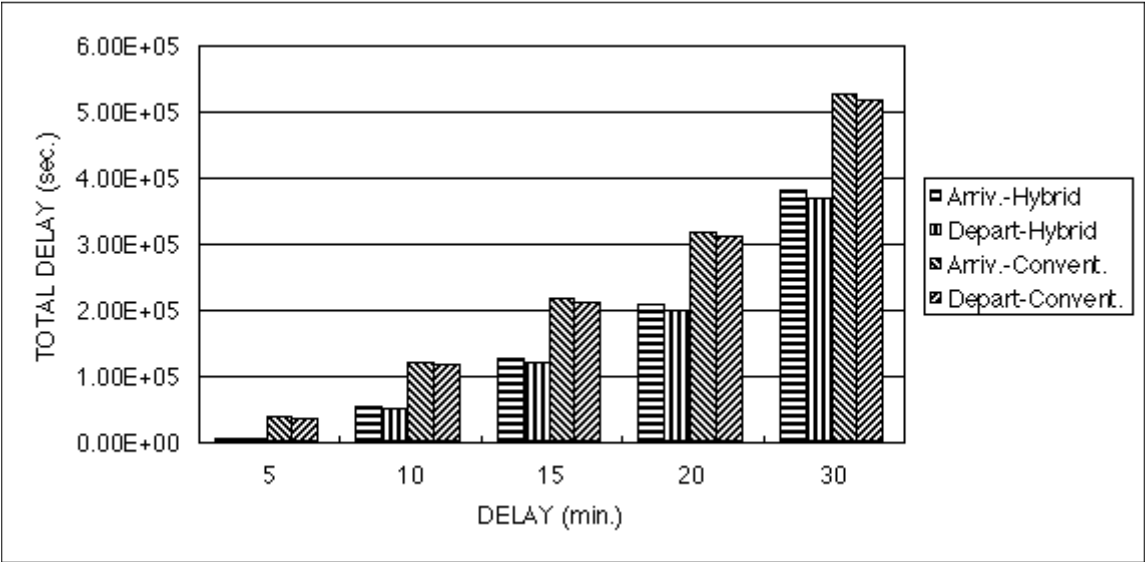
4. Conclusions

We have introduced an idea to express a train schedule by a PERT network with order interchangeable node sets. We have also developed a new train traffic simulation method called hybrid simulation using this network and a knowledge base for change of train orders. We believe that ours is an effective simulation method combining a mathematical programming method and a knowledge-based method, and this approach is quite useful to develop a practical expert system.

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Figure 4



Development of a train performance computation system on an engineering workstation

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Abstract

We have developed a train performance computation system on an engineering workstation. The system, called SPEEDY, produces a train performance diagram following users' indications concerning train operation conditions.

SPEEDY has desirable functions, excellent man machine interface and a high processing speed. We will describe the configuration and characteristics of SPEEDY, then evaluate the system by comparing the results with those made by human experts.

CTRAM Update

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