Rail Research UK

The universities' centre for railway systems research

Decision Support System for Dynamic Re-Scheduling of Trains Under Disturbance

Prepared for The Railway Safety and Standards Board

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Report: RRUK/B1/1

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Summary

The ultimate goal of this project is to improve, by means of “re-scheduling”, the overall performance of the railway network, which is subject to various disruptions, some of them inevitable. With the consequent reduction in the time the railway spends working off its normal schedule, which has historically been associated with slightly increased risk of accident, the overall safety of the operation will be improved.

The project is to be conducted jointly by the Railway Research Centre, School of Engineering, University of Birmingham and the Transportation Research Group, Department of Civil and Environmental Engineering, University of Southampton. This necessitates careful planning of how the work is divided into work packages to be pursued individually, and this has been discussed in the meeting between the two Universities.

Early work has focussed on the understanding of “re-scheduling”, which is the main topic of this project, because of the similarity with “scheduling” (or “timetabling”). A combined literature survey and study of current practice has thus been undertaken.

1. Introduction

1.1 Outline and Project Objectives

The ultimate goal of this project is to improve, by means of "re-scheduling", the overall performance of railway network, which is subject to various disruptions, some of them inevitable. The project objectives are as follows:

- To review existing approaches to the management of disruptions to railway operations.
- To devise and assess revised methods of, and strategies for, disruption management, by the dynamic re-scheduling and re-routing of train movements.
- To compare and evaluate the alternative strategies for and methods of recovery from disruptive incidents, in order to determine the most promising way(s) forward.
- To investigate different levels of detailed modelling for multi-train performance to support the strategy evaluation.
- To develop a facility to provide real-time decision support to railway control centre operators to assist with responding to disturbances such as delays, failed trains, etc.

1.2 Background

Railways, especially when operating near their theoretical capacity, are particularly vulnerable to disruption by human behaviour or engineering failures that lead to delays to or even cancellation of services. It is clearly necessary to respond to this kind of disruptive incidents in such a way as to minimise the resulting problems.

Without intelligent regulation of the consequences of such disruptive incidents, the consequential effects on passenger and freight services can be much greater than necessary. Traditionally, such regulation is provided by the control centre dispatchers. While concentrating the control function in smaller numbers of control centres provides an improved overview of the 'big picture', this very concentration, in conjunction with increasing traffic, potentially results in overload of the control centre staff when things do go wrong. Whilst part of the answer may be in improved information presentation to the operators, it is equally certain that providing automatically generated "best guess" strategies for operator approval should assist in alleviating their task-load.

Some example implementations of limited systems already exist; however, the details of how things are dealt with within the systems are mostly confidential, and in most cases no publications of accuracy or quality of representation are available.

It is expected that the needs for such systems, and the extended application to wider part of the rail network, are growing stronger every now and then.

1.3 Structure of the report

- In Section 2, the overview of the initial approach to the project is presented.
- In Section 3, the definition of "re-scheduling" to be dealt with in this project is discussed.
- Section 4 shows the digest of the literature survey that has been carried out so far.

- Based on the results, a meeting was held at the University of Southampton on 6th June 2003. It is reviewed in Section 5.
- The relevance to safety of this project is discussed in Section 6.
- Descriptions of future works and concluding remarks are in Sections 7 and 8.
- A more detailed background note of the project and the minutes of the meeting in Southampton are included as Appendices 1 and 2.

2. Initial Approach to the Project

The project is to be conducted jointly by the Railway Research Centre, School of Engineering, University of Birmingham and the Transportation Research Group, Department of Civil and Environmental Engineering, University of Southampton. This necessitates careful planning of how the work is divided into work packages to be pursued individually, and this has been discussed in the meeting between the two Universities.

Early work has focussed on the understanding of "re-scheduling", which is the main topic of this project, because of the similarity with "scheduling" (or "timetabling"). A combined literature survey and study of current practice has thus been undertaken.

3. Defining "Re-scheduling"

3.1 Scheduling and Re-scheduling

In Project B1, the objective will be re-scheduling when train services are disrupted, and the operators in charge are forced to alter the existing running schedule during operating hours, and in real time.

The scheduling of normal operation is, therefore, strictly outside of the scope of Project B1. The following are the example cases that are considered out-of-scope as well, because the operators can "schedule" a timetable beforehand and run services accordingly.

(1) Disruption due to the pre-planned engineering work that occupies certain sections of the track
(2) The long-term closure of certain parts of the network, whatever the cause

However, apart from the fact that re-scheduling should be done in a limited amount of time and whilst an existing timetable is in operation, there are many techniques that could be used in both scheduling and re-scheduling; therefore, a literature survey of previous works on scheduling is as necessary as that on re-scheduling.

3.2 The types of recovery operations

The recovery operations when the services are disrupted can be categorised into one of the following:

(1) Catch-up operations (the delayed trains utilise buffer time)
(2) Extended or shortened dwell times
(3) Re-allocation of train paths
(4) Preparing reserve trainsets and crews to operate relief trains
(5) Changes to stopping patterns
(6) Re-routing
(7) Cancellation or part-cancellation of services

4. Digest of preliminary literature survey

4.1 List of papers obtained so far

(1) Goverde, R. M. P., The max-plus algebra approach to railway timetable design, *Computers in Railways VI (Proc. COMPRAIL 98)*, pp. 339-350, 1998.
(2) Middelkoop, D., *et al.*, Train network simulator for support of network wide planning of infrastructure and timetables, *Computers in Railways VII (Proc. COMPRAIL 2000)*, pp. 267-276, 2000.
(3) Soto y Koelemeijer, G., *et al.*: PETER, a performance evaluator for railway timetables, *Computers in Railways VII (Proc. COMPRAIL 2000)*, pp. 405-414, 2000.
(4) Murata, S., *et al.*: An optimal traffic regulation method for metro type railways based on passenger oriented traffic evaluation, *Computers in Railways VI (Proc. COMPRAIL 98)*, pp. 573-583, 1998.
(5) Goodman, C. J., *et al.*: Metro traffic regulation from the passenger perspective, *Proc. Instn. Mech. Engrs.*, vol. 215, Part F, pp. 137-147, 2001.
(6) Yeung, T. H., *et al.*: Railway junction conflict resolution by local search method, *Computers in Railways (Proc. COMPRAIL 2000)*, pp. 769-778, 2000.
(7) Ho, T. K., *et al.*: Railway junction traffic control by heuristic methods, *IEE Proc. – Electr. Power Appl.,* vol. 148, pp. 77-84, 2001.
(8) Isaai, M. T., *et al.*: Hybrid Applications of Constraint Satisfaction and Meta-Heuristics to Railway Timetabling: A Comparative Study, *IEEE Trans. Syst., Man, Cybern. C,* vol. 31, pp. 87-95, 2001.
(9) Isaai, M. T., *et al.*: Predictive and Reactive Approaches to the Train-Scheduling Problem: A Knowledge Management Perspective, *IEEE Trans. Syst., Man, Cybern. C,* vol. 31, pp. 476-484, 2001.
(10) Isaai, M. T., *et al.*: An Object-Oriented, Constraint-Based Heuristic for a Class of Passenger-Train Scheduling Problems, *IEEE Trans. Syst., Man, Cybern. C,* vol. 30, pp. 12-21, 2000.
(11) Chang, C.S, *et al.*: Online rescheduling of mass rapid transit systems: fuzzy expert system approach, *IEE Proc. – Electr. Power Appl.*, Vol. 143, No. 4, pp. 307 – 316, 1996.
(12) Goncalves, R., *et al.*: Improving Railway Crew Scheduling Quality: A Hybrid Approach, *19th Int'l Coference of the North American Fuzzy Information Processing Society*, pp. 378-382, 2000.
(13) Carey, M.: Optimizing Scheduled Times, Allowing for Behavioral Response, *Transpn. Res.-B*, Vol. 32, pp. 329-342, 1998.
(14) Carey, M.: Ex ante heuristic measures of schedule reliability, *Transpn. Res.-B*, Vol. 33, pp. 473-494, 1999.

A more extensive list, compiled by a final-year student, is available, which will be distributed together with this report. However, not all of the papers listed herewith are either read or obtained, and we believe most of them are of relatively low relevance to the Project B1.

4.2 Brief descriptions of the selected papers (refer to Appendix 1 for fuller details)

4.2.1 Netherland's "PETER" simulation program

(1) Documents: (1), (2), (3)
(2) Concept: Evaluation of interconnectivity. Cycle time constant throughout the network

4.2.2 Satoru Murata's considerations of passenger inconvenience

(1) Documents: (4), (5)
(2) Concept: Minimisation of passenger inconvenience and energy consumption in a single-line metro-type railway

4.2.3 Mark Ho's conflict resolution

(1) Documents: (6), (7)
(2) Concept: Let trains on two converging route pass through the converging point as quickly as possible

4.2.4 Single track railway re-scheduling

(1) Documents: (8), (9), (10)
(2) Concept: Minimisation of the sum of weighted waiting times. Model based on Iran's railway network, mostly single-track.

4.2.5 Fuzzy expert system for metro trains

(1) Document: (11)
(2) Concept: Using fuzzy rules based on the assumption specific to metro systems. Model based on Hong Kong MTR, metro trains with "all-stopping" scheduling pattern

4.2.6 Brazillian crew scheduling tool

(1) Document: (12)
(2) Concept: "Hybrid approach" – search strategies, mathematical programming and fuzzy rule base

4.2.7 Schedule reliability

(1) Documents: (13), (14)
(2) Assessment of the reliability of railway schedule.

5. Summary of the Meeting at Southampton University

The meeting opened with each group describing their previous experience and outlining their particular interests in the project. John Armstrong (TRG, Southampton) tabled two documents relevant to the project, one of which was entitled "The Disruption of Railway Operations: Background" which he had prepared as part of his Engineering Doctorate work. It was felt that this contained many useful pointers to the work necessary for the project.

The meeting then went on to clarify the overall objectives of the project, and determine the allocation of resources and tasks. An agreement was made that the overall aim of Project B1 and following work should be to develop a comprehensive model, capable of simulating normal and disrupted railway operations, and responses to the disruption. The model should be capable of demonstrating the effectiveness of alternative responses in reducing delay. It was agreed that this work is to be done in done in close collaboration by carefully constructing a set of parallel work-packages with continuous review of the linkages.

Basingstoke was suggested as a suitable location for a case study of disruptive incidents and possible responses.

It was agreed that a full-time RF in Birmingham would work on the project, with 2 x 0.5 RA roles on both Birmingham and Southampton, thus providing continuity over the duration of the project, each of them working on one of the two work packages as described below:

1. Investigation and identification of operator needs
2. Progression of simulation.

6. Relevance to Safety

Trains are, or at least should be, scheduled in such a way that no safety issues will be raised when running according to the schedule. Therefore, generally speaking, the risk will increase when train services are disrupted – in fact, experience shows that serious accidents often take place under disrupted conditions. The facility we aim to develop to provide real-time decision support for line controllers should assist re-scheduling so that the risks associated with operating under disrupted conditions can be minimised.

7. Further Work Required

The next meeting will take place in late July. After that, the collaborative work will be pursued at both Birmingham and Southampton Universities as explained in the Appendix 6.2, and with regular progress meetings, other technical meetings, especially between the RF and RA's, will take place as and when necessary.

8. Conclusions

As is documented in this report, the Project B1 has successfully started up, with overall objectives, allocation of resources and tasks, and immediate future work of all parties involved defined in the first meeting. The project will now focus on establishing the operators' needs and current operational or scheduling practices, and on developing and maintaining the simulation software model to be used in the later stage of the research.

Appendices (attached)

1. Project B1: Report 1 (Ryo Takagi)

2. Minutes of the Meeting at Southampton University

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Appendix 1
Project B1: Report 1

Ryo Takagi, 06/06/03

1. Introduction

In this report, the definition of "re-scheduling" is discussed. The list of previous publications is attached.

2. Scheduling and Re-scheduling

This project aims at "re-scheduling". In the broadest sense, re-scheduling can be a topic which covers "scheduling" within it. However, in Project B1, the objective will be the re-scheduling when the train services are disrupted, and the operators in charge are forced to alter the existing running schedule during the operating hours, and in real time.

The scheduling of normal operation is, therefore, strictly outside of the scope of Project B1. The following are the example cases that are considered out-of-scope as well, because the operators can "schedule" a timetable beforehand and run services accordingly.

(1) Disruption due to the pre-planned engineering work that occupies certain sections of the track
(2) The long-term closure of certain parts of the network, whatever the cause

However, apart from the fact that re-scheduling should be done in a limited amount of time and whilst an existing timetable is in operation, there are many techniques that could be used in both scheduling and re-scheduling; therefore, a literature survey of previous works on scheduling is as necessary as that on re-scheduling.

3. The types of recovery operations

The recovery operations when the services are disrupted can be categorised into one of the following:

(1) Catch-up operations (the delayed trains utilise buffer time)
- Effectively a "no action" strategy
- Normally only 1~5% of minimum start-to-stop run time is given as buffer time
- On metro trains, "no action" leads to "bunching"

(2) Extended or shortened dwell times
- Shortening: effectively the same as 3(1), with more significance
- Extension: to maintain or create connections between trains / to avoid concentration of passengers to a particular train

(3) Re-allocation of train paths
- Alterations of platform at a large station
- Overtaking of a slower train by a faster one
- Order (or priority) change at a junction

(4) Preparing reserve trainsets and crews to operate relief trains

(5) Changes to stopping patterns

- Increasing stops: let "express" trains serve local stations to avoid large disbenefit because of the long absence of local trains / create connections between trains
- Decreasing stops: increase catch-up capability by station skipping (metro trains: 1 min. / stop, high-speed trains: 3~5 mins. / stop). Problem in passenger guidance.

(6) Re-routing
(7) Cancellation or part-cancellation of services

4. Case studies

4.1 Disruption on King's Norton – Selly Oak – Birmingham Line

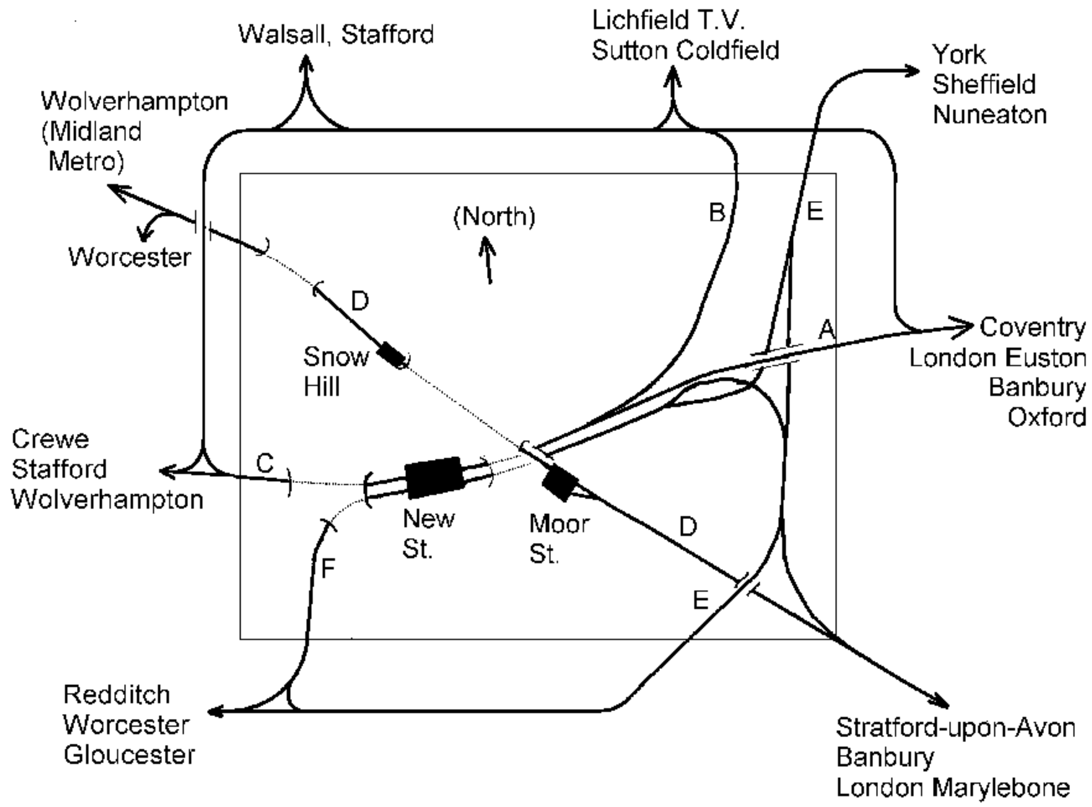

Figure 1. Map of the rail network around central Birmingham.

4.1.1 Description

(1) An "up" (Birmingham-bound) train becomes stationary at University station of Birmingham West Suburban Line (route F in the map, blockage point marked by X). Expected to become movable again X minutes later. The train is one of Class 323 running as Cross City Line services.
(2) Cross City Line trains bound for Lichfield TV, Alphaline(?) service from Bristol or Cardiff to New Street (with scheduled stop at University), and Virgin CrossCountry to Sheffield through New Street and Tamworth, are behind the train.

4.1.2 Strategies

(1) When X is small:
  a. Following trains simply come nearer to the delayed train
  b. Re-arrangement of platform usages at New Street might be necessary
(2) When X is medium:
  a. Re-route train(s) to Moseley Line (route E) – Virgin CrossCountry trains become reverted (in terms of car order) if they travel onwards from New Street

4.1.3 Necessary cost evaluation function

(1) Congestion (including the action criteria of passengers)
(2) Travel time, or the difference of it. Especially when re-routing.
(3) Train path re-allocation at New Street Station
(4) Train order becoming reverse at New Street Station or beyond when re-routed to Moseley Line.
(5) Stations becoming unserved when re-routed.

4.1.4 Problems

(1) How to consider the precision of predicted X
  a. Probability of difference between actual and predicted X
  b. The delay after the action is taken – re-routing: almost regardless of X, following: almost proportional to X when X exceeds certain amount
(2) Consideration at scheduling level … route as many trains on the Moseley Line as possible, etc.

5. Case study 2 … Disruption on Rugby – Coventry – Birmingham Line

5.1.1 Description

(1) Central Trains all-stopping service from Coventry to Wolverhampton through Birmingham New Street delayed by Y minutes between Coventry and Birmingham International.
(2) Following train: Virgin Trains express to Wolverhampton, stopping at Birmingham International, Birmingham New Street, Sandwell & Dudley and Wolverhampton.
(3) No re-routing possible – both trains use electric traction, most lines around Birmingham are not electrified.

5.1.2 Strategies

(1) When Y is small:
  a. Following train simply comes nearer to the delayed train
  b. Re-arrangement of platform usages at New Street might be necessary
(2) When Y is medium:
  a. Central's train to let Virgin's train overtake it at Birmingham International. This strategy would reduce the delay of Virgin's service seen at the arrival at Birmingham New Street when $Y > V – C – D – M$, where V and C are the scheduled departure times of Virgin's train and Central's one, respectively, at Birmingham International, D the difference of travel time of Central's and Virgin's trains between Birmingham International and Birmingham New Street, and M the minimum headway between a departing train and a subsequent arriving train.

5.1.3 Necessary cost evaluation function

(1) Congestion (including the action criteria of passengers)
(2) Travel time, or the difference of it
(3) Train path re-allocation at New Street Station

5.1.4 Problems

(1) How to consider the precision of predicted Y
   a. Probability of difference between actual and predicted Y
   b. The delay after the action is taken – order changing: Virgin's delay improved but Central's delay will be worsened

(2) Congestion
   a. If passengers can change from Central's train to Virgin's at Birmingham International and such an order-change takes place, most passengers try to use Virgin's service, possibly resulting in overcrowding.

6. Literature survey

There are many papers related to the topic. However, few papers actually describe in detail the mathematical background of the works they have done.

6.1 List of papers obtained so far

(1) Goverde, R. M. P., The max-plus algebra approach to railway timetable design, *Computers in Railways VI (Proc. COMPRAIL 98)*, pp. 339-350, 1998.
(2) Middelkoop, D., *et al.*, Train network simulator for support of network wide planning of infrastructure and timetables, *Computers in Railways VII (Proc. COMPRAIL 2000)*, pp. 267-276, 2000.
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(11) Chang, C.S, *et al.*: Online rescheduling of mass rapid transit systems: fuzzy expert system approach, *IEE Proc. – Electr. Power Appl.*, Vol. 143, No. 4, pp. 307 – 316, 1996.

(12) Goncalves, R., *et al.*: Improving Railway Crew Scheduling Quality: A Hybrid Approach, *19th Int'l Coference of the North American Fuzzy Information Processing Society*, pp. 378-382, 2000.
(13) Carey, M.: Optimizing Scheduled Times, Allowing for Behavioral Response, *Transpn. Res.-B*, Vol. 32, pp. 329-342, 1998.
(14) Carey, M.: Ex ante heuristic measures of schedule reliability, *Transpn. Res.-B*, Vol. 33, pp. 473-494, 1999.

A more extensive list, compiled by a final-year student, is available, which will be distributed together with this report. However, not all of the papers listed herewith are either read or obtained, and we believe most of them are of relatively low relevance to the Project B1.

6.2 The brief descriptions of the selected papers

6.2.1 Netherland's "PETER" simulation program

(1) Documents: (1), (2), (3)
(2) Concept
  A. Evaluation of interconnectivity, subsystem of SIMONE, rail network planning
  B. Cycle time constant throughout the network
  C. Mathematical trick: max-plus algebra
(3) Precedence graph: transition from route to route
  A. Timed Petri net used to express the graph

6.2.2 Satoru Murata's considerations of passenger inconvenience

(1) Documents: (4), (5)
(2) Concept – minimisation of passenger inconvenience and energy consumption in a single-line metro-type railway
(3) Passenger inconvenience: the sum of all the passengers' experiences that are "worse than expectations"
(4) Constraints
  A. Minimum start-to-stop running time
  B. Minimum departure-to-arrival interval
  C. Minimum dwelling time at platform
(5) Evaluation function: weighted sum of passenger inconvenience and energy consumption of trains.
(6) Optimisation algorithm: gradient projection. Some tricks included.

6.2.3 Mark Ho's conflict resolution

(1) Documents: (6), (7)
(2) Concept --- let trains on two converging route pass through the converging point as quickly as possible.
(3) Optimisation algorithms: Dynamic programing (1997), Genetic algorithm (2000)
(4) Important point: optimised results are sometimes even better than the current practice of FCFS (first come, first served).
(5) Reduction of calculation time: lookup table of run time of trains in a signal block

6.2.4 Single track railway re-scheduling

(1) Documents: (8), (9), (10)
(2) The model: Based on Iran's railway network, mostly single-track.
(3) Constraints
  A. Running time constant between stations

B. Dwell time more than scheduled
C. One block section between adjacent stations
D. Time interval between arrival of a train and subsequent departure of another train running in the opposite direction larger than the safety limit
E. Time interval between the arrivals of two trains in opposite direction larger than the safety limit

(4) Evaluation functions
A. Sum of weighted waiting times
B. Average of unit waiting time (unit waiting time = ratio of waiting time to minimum travel time of the train between certain stations)
C. Maximum ratio of waiting time to journey time

(5) Solution methods
A. Constraint satisfaction – Constraint-Based Heuristic (CBH)
B. HeuSA = CBH + Simulated Annealing
C. HeuTS = CBH + Tabu Search
D. Comparison of 2 and 3

(6) Miscellaneous tip
A. Isaai's PhD thesis available (not yet obtained).

6.2.5 C S Chang – fuzzy expert system for metro trains

(1) Document: (11)
(2) The model: Based on Hong Kong MTR, metro trains with "all-stopping" scheduling pattern.
(3) Using fuzzy rules based on the assumption specific to metro systems.

6.2.6 Brazillian crew scheduling tool

(1) Document: (12)
(2) "Hybrid approach" – search strategies, mathematical programming and fuzzy rule base

6.2.7 Schedule reliability

(1) Documents: (13), (14)
(2) Assessment of the reliability of railway schedule.

7. The fact-finding tours

We believe some fact-finding tours to find the existing scheduling, re-scheduling and line controlling practices in the rail industry is necessary at some point.
In TICO project, which the research group in Birmingham have undertaken during 2001 – 2002, a fact-finding tour to Japan and Hong Kong was performed. A report of these visits is available under the title "The Report of the Fact-finding Tour: Japan and Hong Kong, 5 – 19 April".

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Appendix 2
RRUK Project B1 Meeting No 1: Minutes

Date: 6 June 2003

Venue: Room 10017, Faraday Building, University of Southampton

Present: Colin J. Goodman and Ryo Takagi (Power and Control Group, University of Birmingham = P&CG), Mike McDonald, Julian Eyre and John Armstrong (Transportation Research Group, University of Southampton = TRG)

Discussion:

Introductions were made and interim documents distributed.

CJG and MMcD agreed that the meeting should seek to clarify the overall objectives of the project, and determine the allocation of resources and tasks.

MMcD then described the nature of TRG's work and experience and explained JE's and JA's roles, and Arup's involvement via JA's EngD.

CJG and MMcD agreed that the overall aim of Project B1 and following work should be to develop a comprehensive model, capable of simulating normal and disrupted railway operations, and responses to the latter. The model should be capable of demonstrating the effectiveness of alternative responses in reducing delay. The issue was raised of JA's and Arup's roles in this, and also of the potential involvement of Atkins via CJG. It was discussed whether work should be conducted in parallel on complementary tasks or in full, interactive collaboration. The former course was agreed to be preferable.

MMcD suggested Basingstoke as a suitable location for a case study of disruptive incidents and possible responses; noted that the simulation of operations should be reasonably straightforward, and that finding suitable optimisation criteria and techniques would be the difficult part.

It was agreed that RT would work as a full-time RF on the project, with JA and a recruit in Birmingham fulfilling the 2 x 0.5 RA roles, thus providing continuity over the duration of the project.

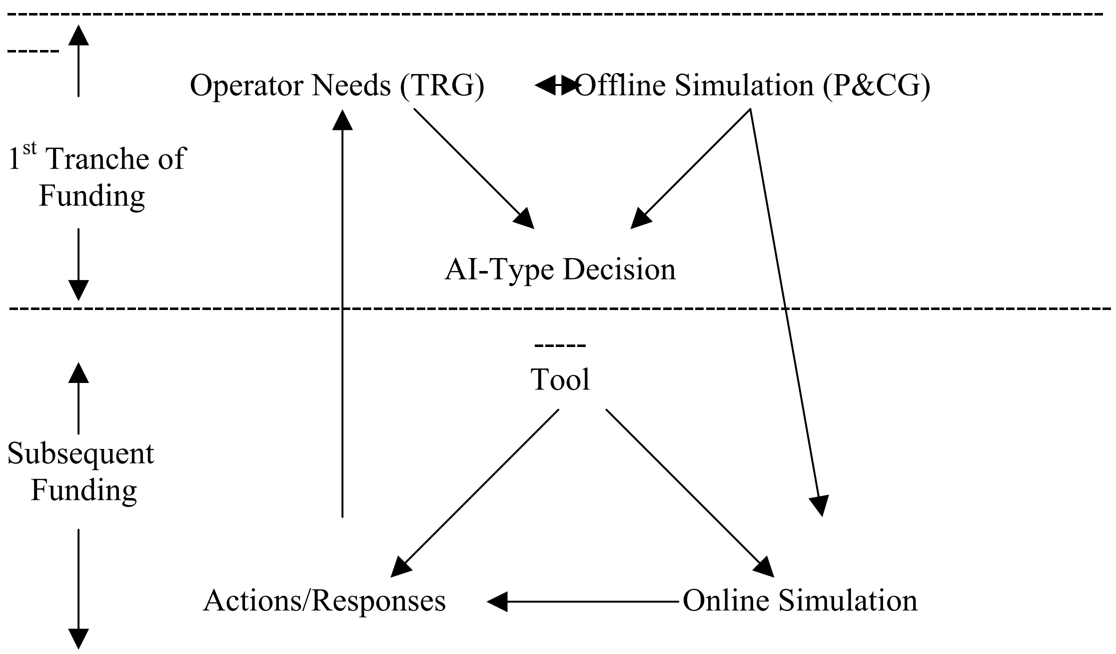
It was agreed that JA would concentrate on the Basingstoke (or other) case study, examining current responses to incidents, their good and bad aspects, and possible improvements. Otherwise, the project should be divided into two work packages:

1. Operator Needs. Assessment of current practice, using TRG's experience in Urban Traffic Control. This should feed into the modelling process as the project moves forward. Multiple sites/countries/examples should be considered. TRG to lead.

2. Progression of Simulation. May focus on a single location. P&CG to lead

It was further agreed that a short initial note should be prepared on the work packages by their respective leaders, describing the nature and scope of each.

The following approximate model of the project was proposed by MMcD and agreed:



Next Meeting: Late July 2003

Agreed Actions:

Draft Minutes	JA
Update Original Project Specification	CJG
Note 1	JA, MMcD
Note 2	RT, CJG

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