Advanced decision support: improving control room effectiveness

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Abstract

The effectiveness of a control room relies heavily on the expertise of the staff working under difficult and stressful conditions. The increased workload, that arises as complex situations unfold, adversely affects the quality of decision-making leading to reduced effectiveness. Significant benefits and improvements in performance can be achieved from deployment of advanced decision support systems (DSS) to aid control staff in carrying out their duties. A DSS is designed to co-operate with the staff’s own decision-making and assist them in detailed implementation of their chosen strategies. The potential of DSS will be illustrated through a prototype system designed to aid Metro line-control staff recover normal service following an incident, e.g. broken down train. The system is designed to assist line-control staff in the detailed implementation of their chosen recovery strategy and provide specific support for crew and train resource management. Further, through forward simulation, the system is able to monitor and anticipate short- and longer-term performance issues and propose refinements to the chosen strategy. The DSS employs an agent-based framework. This is particularly suited to rail lone-control operations, where continuous co-operation and negotiation between control centre, depots and crew managers is essential to achieve effective and efficient service recovery. In our implementation, the agents are structured in layers that address distinct functional areas. A user presentation layer for anticipating users’ interests and requirements and aid negotiation between other users; a service layer for planning, provision and prediction of rail services; and a resource layer for monitoring, negotiating and managing resources. Advanced decision support has the capability to reduce the problem of information overload and increase control room effectiveness. Increased control effectiveness will, through improved responses to events, allow the resources under control, whether that is road or rail, to be used more effectively.

Keywords: real time, knowledge based, decision support system, agent, knowledge acquisition, JACK.
1 Introduction

1.1 Metro-line control room overview

The workload for Metro line-control staff in the control room is generated primarily by exception handling. When the railway is running smoothly, even at peak services, the control room staff have minimal residual work. However, staff become extremely busy during, and for a considerable time after, an incident. Major incidents can arise from many causes, including:

- Equipment, signals, train and track failure
- Accidents and weather
- Lack of available staff and staff error
- Fire alarms and security alerts
- Passenger loading, and
- Body on line.

Other minor disruptions to planned railway operations can be the result of trains being out of sequence at branches, or unscheduled physical needs relief of drivers. Although there are a wide variety of potential causes, such as the individual failure of a large number of items of equipment, the number of consequences is relatively limited and include:

- Missed headway (i.e. gap in service)
- A queue of trains particularly behind a gap in service
- Partial line closure such as non-stop operation or blockage in one direction
- A complete line blockage where a station may be closed, and
- Passenger build-up on platforms and trains.

The overall effect is that service is degraded and crews and trains tend to drift out of place and time with respect to the normal schedule. Beyond the “technical” consequences of the incident, there are the strategic consequences related to the operation railway. These include:

- Reduced passenger service (e.g. failure to transport passengers or provide a regular service)
- Missing of performance targets, with potential consequential revenue loss (e.g. government subsidies are often dependent on meeting contractually agreed levels of service)
- Increased staff stress, increasing potential for additional mistakes or failing to meet safety, legal or regulatory requirements.

1.2 Workload estimates

The approximate distribution of this workload has, through task analysis obtained by ourselves from observing Line Controllers at work, been estimated to be as shown in Table 1.
Table 1: Workload estimates.

<table>
<thead>
<tr>
<th>Line Controller Task</th>
<th>Workload %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive report</td>
<td>15%</td>
</tr>
<tr>
<td>Make strategy decisions</td>
<td>10%</td>
</tr>
<tr>
<td>Make detailed decisions</td>
<td>60%</td>
</tr>
<tr>
<td>Respond to queries</td>
<td>10%</td>
</tr>
<tr>
<td>Anticipating longer term constraints</td>
<td>5%</td>
</tr>
</tbody>
</table>

This shows that the Line-controller’s detailed decision making is by far the largest of these tasks, and is primarily related to resource management issues, in particular effective crewing decisions.

1.3 Skill types applicable to Line Control

Further results from the task analysis we carried out provided the information for the following table, which identifies the key skills and, types of decision for those tasks performed by the line controller.

Table 2: Key skills.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Key skills</th>
<th>Type of decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive reports</td>
<td>Verbal, visualisation</td>
<td>Verbal common sense and knowledge</td>
</tr>
<tr>
<td>Determine consequences</td>
<td>Railway knowledge and common sense</td>
<td>Verbal common sense and knowledge</td>
</tr>
<tr>
<td>Select strategy</td>
<td>Common sense</td>
<td>Verbal common sense and knowledge</td>
</tr>
<tr>
<td>Trade off performance versus resource</td>
<td>Visualisation and attention to detail</td>
<td>Detail scheduling and temporal reasoning</td>
</tr>
<tr>
<td>Implement actions</td>
<td>Attention to detail</td>
<td>Detail scheduling and temporal reasoning</td>
</tr>
<tr>
<td>Anticipation</td>
<td>Temporal reasoning and scheduling</td>
<td>Detail scheduling and temporal reasoning</td>
</tr>
</tbody>
</table>

1.4 Knowledge, experience and standard operating procedures

The knowledge used to run the railway system, and in particular service recovery, is based on both operating procedures, determined and mandated for legal, safety or operational purposes, and the direct experience (heuristic knowledge) of the staff involved running the railway.

For example, the evacuation of a station and running of trains during a bomb alert must adhere to certain agreed procedures. This ensures that all parties concerned (railway staff and emergency services) have a common understanding of the actions that are being carried out to achieve the evacuation goal. The strategy for service recovery after a broken down train, although constrained by the line’s physical topology, will also be guided by the experience of the line
controller and recognised tactics (such as stepping back of drivers in loop-back scenarios) to maximise traffic flow. The overall decisions making process for the line controller can be described as follows. Procedural knowledge is also used to drive the decision making process.

- **Match strategy** – using libraries of both long term and short term strategies and the current assessment the most appropriate overall strategies are presented to the line controller.
- **Detailed plan** – after the strategy has been selected, it is transformed into a detailed workable plan consistent with the current situations, constraints and desired objectives.
- **Implement action** – once the detailed plan has been identified and approved, the system co-ordinates the various instructions to staff and passengers, and control systems required to implement the selected plan and satisfy the agreed strategy.

1.5 **Context**

The following context diagram shows the external entities that need to be considered when carrying out the line control activity. The scope is large, with many actors. Some of these actors are human while others are physical or legacy computer based systems that support current activities.

![Context diagram of Line Control activity.](image)

**Figure 1: Context of Line Control activity.**

The Line Control activity encompasses many activities including: Monitoring status of rail operations, including trains, drivers, and platforms; Controlling of...
signals; Informing passenger; Decision-making; and Supervision. To provide effective decision support in assisting the line-controller with service recovery the decision support system:

- Relates to the line controller’s decision-making strategies.
- Assists in the detailed implementation of the recovery strategy.
- Provide specific support for crew management functions by anticipating crewing schedule problems and proposing solutions.
- Monitors and anticipates the performance of the railway using metrics perceived by regulatory authorities and passengers, and also propose solutions that would lead to improvements.

Our experience in developing decision support systems has focused on the goal of keeping the controller in the decision loop at all times. This is required when the final responsibility of any action will reside with the controller. It also provides more effective graceful degradation when unforeseen situations arise, because the system ensures that the controller has a better understanding of how the situation arose. This is of particular benefit in legacy systems, where it is impracticable to replace the entire infrastructure to support autonomous computer based decisions.

2 Application architecture

2.1 Agent based architecture

The system is implemented as an agent based system, where each agent has an internal structure based on the Beliefs Desires and Intentions (BDI) paradigm. Agents have a common internal structure that is characterised by the following diagram (Figure 2).

Each agent has a set of beliefs, or models, implemented as databases of facts that define the agents understanding of its environment, together with interfaces providing the inputs and outputs (sensors and effectors) for the system. Depending on the functionality of the agent optional modules provide additional capability to the agent including: situation awareness and prediction; plan generation, execution and evaluation. Agents within the application are structured and characterised in three distinct layers.

- **User presentation layer agents** - The presentation agents are directly responsible for supporting the interaction between the human operators involved in running the railway. In particular, the main focus of attention for this prototype is the interaction with the line controller, which is targeted toward their decision-making activities. More details of the actual interface mechanisms employed are provided in section 5, below. Presentation agents also support interfaces with crew, line depot and station managers, drivers, emergency services and maintenance staff. For example, the driver presentation agent would handle driver instructions, monitoring their
location and activity, and manage the information required by and requested from the driver.

- **Service layer agents** – Agents at this layer are responsible for determining the overall strategies that should be considered by the operator. This requires appropriate line model based on a situation awareness of the current state of the railway, staff and passengers. Situation awareness also extends to include projections or anticipations of the future state of the system, through forward simulation. Agents at this level would also make requests to the resource layer to allocate/reserve resources necessary to carry out particular strategies or tactics.

- **Resource layer agents** – These agents interface with railway resources (e.g. crew and train scheduling, and station announcements), and provides for the control of rail specific resources. For example, although core line control activities at the service layer would decide that certain announcements or classes of passenger announcements should be made, the resource layer agents would be directly responsible for making individual announcements, which have to be co-ordinated with specific events such as train arrivals.

Figure 2: Generic agent architecture.

### 3 System integration

One of the main challenges in developing a DSS is that the system will be to interface with other legacy systems, integrating with existing infrastructure without requiring the wholesale replacement of existing systems. For the metro-line domain the DSS will have to interface with the signalling computer and other resources to obtain information on the location of trains, spare stock and make changes to railway operation; and to the crew rostering computer for information on constraints pertaining to specific crew, such as normal meal
breaks, shift durations and detraining information. Agent based systems provide a natural mechanism for integrating with legacy systems through encapsulation. For example:

- Initiate file transfers between agent and the legacy system – copying train timetable or daily crew rosters
- HTML, mobile and applet clients – text/page drivers or other off duty staff to help support incident recovery; and HTML rendered pages for summary reports to managers
- Direct API calls, providing interface where a permanent connection is maintained with third party and legacy systems – access to databases, signalling computer (subject to safety interlocking)
- Instructions by phone/radio/announcements – inform or instruct crew, other staff and passengers.

4 Operator interfaces

Crucial to the effective operation of a decision support system is an ability to communicate effectively with the operators of the system. Although a number of different interfaces are expected the key interface used to advise the operator and through which the operator can control various actions is the operator console.

The operator console provides the central interaction point between the DSS and the operator, enabling the operator to view advice and recommendations suggested by the DSS and subsequently accepting or rejecting the advice. Progress checks can be made on actions already accepted by the operator. The operator console component provides the focus of interaction between the DSS and operator, providing new information from the DSS as well as updates to the progress of tasks currently being executed by the DSS. There are a number of specific requirements for the component:

- Alerting the operator to new messages from the DSS.
- Enable the operator to accept, reject and suspend DSS advice and recommendations.
- Display the current processing status of the DSS for the advice and recommendations accepted by the operator
- Read-only display of information; operators cannot input information.

4.1 DSS messages

The operator console displays information it receives from the DSS, and force specific constraints upon the information passed from the DSS to the operator console, Figure 3. There are two basic message types that are required to support the operator console. First, ‘recommendation’ messages contain the details of the recommended actions/advice that is to be displayed by the console. Second, ‘status update’ messages contain updates of the status for the actions, plans, tasks and activities that comprise DSS recommended actions. These messages are now discussed in more detail.
- **Recommendation Messages** - Recommendation messages provide the information displayed by the operator console when advice or recommendations are generated by the DSS.
- **Status Update Messages** - The operator console requires the DSS to send status update messages so that it can update the status of the various actions, plans, tasks and activities within the recommendation messages when they are displayed to the operator.

![Figure 3: Overview of operator console display layout.](image)

The operator console provides a type of ‘drill-down’ view of the DSS advice and processing status.

- **Message List display** - This is the primary display through which the DSS interacts with the Operator, and is always visible and displays messages that are available from the DSS. Each message has an associated set of exclusive recommended actions that could be performed. A brief summary of the action is provided to the operator, along with reasons why this action has been recommended. Each action has a button to allow the operator to accept or cancel the action. The operator can select an action to show further details in other windows within the display. The first stage in this process involves the display of the plans required to perform the action. This display is now described.
- **Plan List display** - The display shows the complete list of plans that are required to perform the specified action selected within the main message list display. These plans are a high-level breakdown of the activities that must be undertaken, and correspond with the notion of plans to be executed by agent(s) within the DSS.
• **Task Schedule display** - The task schedule display shows a Gantt-style breakdown of the tasks associated with a specific plan that has been selected within the plan list display, providing a simple representation of task execution that can contain both sequential and parallel tasks. The display shows a basic temporal ordering of tasks in a clear concise way.

### 4.2 Message status

There are a number of different states that are used within status update messages, which are summarised in 3. In the operator console, there is a text description of the status of a recommended action, whilst in the plan list display, task schedule display, and task details display there are coloured icons to represent the status of a particular plan, task or activity. When all activities, tasks and plans have completed for an action, the action status is marked as Completed, and then the message is removed from the message list. Figure 4 provides an example display of a DSS message.

<table>
<thead>
<tr>
<th>Status</th>
<th>Action</th>
<th>Plan</th>
<th>Task</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended</strong> - Recommendation by the DSS waiting for operator response</td>
<td>y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accepted</strong>    - Operator has accepted the recommendation but the action has yet to be performed</td>
<td>y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rejected</strong>    - Operator has rejected the recommendation</td>
<td>y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cancelled</strong>   - Operator has cancelled the recommendation</td>
<td>y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pending</strong>     - Waiting for execution to commence</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td><strong>Running</strong>     - Being executed by the DSS</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td><strong>Suspended</strong>   - Execution is currently suspended</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td><strong>Completed</strong>   - Execution has completed</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
</tbody>
</table>

### 5 Conclusion

The prototype application has provided us with a tool to examine the various risks that will exist in developing an operational system. These include: technical risks involving the complexity of scheduling activities, such as crew, and the usability of the MMI in a real-time context; engineering risks such as the provision of necessary infrastructure to provide useful functionality; and user acceptance risks involving sufficient trust buy staff in using the new tools. Some
of these risks can be addressed by using appropriate appraisal criteria to assess performance, including:

- The quality of problem ‘anticipation’ by the system.
- The quality of responses generated by the system.
- The clarity of the line controller’s perception of the system situation.
- The measure of reduction in control room workload during service recovery.
- The effectiveness of railway operation as measured by performance metrics.
- The speed of recovery as perceived by passengers and rail staff.

Figure 4: Example operator console display layout.

Although our main direction for this prototype has been metro line service recovery, the work has been based on experiences and techniques derived from developing large-scale military Airborne Early Warning applications. We believe that these techniques are also applicable to other domains such as:

- Road traffic management, although not as constrained as a rail system, there is a close relationship between rail and motorway networks where there are infrequent access points.
- Power distribution control, where there is a need to timely bring on-line of extra generating capability during periods of high demand, or provide support for recovery after power outages due to faults or unexpected high load demands.
- North sea helicopter fleet operations, where services are often stopped due to adverse weather conditions, and where helicopter and pilot availability is
constrained by CAA regulations. With delays of up to several days, costs to operators and the oil industry can be extensive, and need to be managed.

- Telecommunications management, where equipment failure can cause loss of bandwidth and services that have to be restored using alternative routing

The framework used is *JACK agents*, from Agent Oriented Software. JACK is an agent-based environment for building commercial multi-agent systems. JACK supports the required agent-oriented concepts of: agents, capabilities, events, plans, knowledge models, resource and concurrency management, supporting the BDI programming model used in the development of the application.