Design and Testing of a Railroad Dispatching Simulator using Data-Link Technology

by

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ABSTRACT

Prior research has established the need for a more efficient communication environment than the radio environment in the railroad industry and particularly for the dispatching task. Data-link technology has been introduced successfully in the aviation world and greatly improved the communication environment. The objective of this research was to examine the primary consequences as well as the side effects of the use of data-link as an alternative communication channel for dispatchers. Human-in-the-loop experiments were run on the MIT/Volpe National Transportation System Center dispatching simulator. The primary goal was to see whether the introduction of a data-link system improved the dispatching environment in terms of safety, communication efficiency and productivity. Secondary goals included trying to understand how the introduction of data-link technology would affect the dispatcher's task and strategies.

Two data-link systems were designed and tested: a directed system with no broadcasting capacity and a broadcast system. Both were found to be highly efficient communication tools if used in addition to the radio. The results of this experiment suggested that an ideal communication environment for dispatchers should include a radio/data-link combination, where the radio would be used for simple or urgent transmissions and the data-link system for more complex safety-critical messages. In terms of safety measure, both data-link environments clearly proved superior to the current radio environment by itself. Safety of maintenance workers was equally greatly improved by both data-link systems. Train safety however, was improved only when using the data-link broadcast system. No increase in measured dispatching productivity (trains and track maintenance) was observed with data-link. In addition to communication times and railroad safety, data-link seemed to improve the overall situation awareness.

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 The railroad environment today

Rail traffic has increased drastically in recent years. This is mainly due to three reasons:

- First, railroad companies have been trying to acquire a larger portion of the exponentially increasing transportation market [Railroad Facts, 1996 Edition].
- Second, massive abandonment of several non-profitable track-segments has shifted the traffic towards the remaining lines, hence increasing congestion.
- Third, a recent increase in governmental investments in railroad transportation has led to improved safety and performance and has increased consumer confidence [Surface Transportation Research Funding, Federal Role, and Emerging Issues, US GAO, 1996].

To satisfy the traffic increase, railroads have increased the number of trains per hour by investing in new equipment, personnel and technology. Investments in equipment and personnel are relatively easy to undertake because they don't imply any modification in the company's know-how. Investments in new technologies, however, can lead to fundamental changes in the work environment. The effects of these changes are often neglected during the investment decision process as well as during the implementation of the technology in itself [Parasuraman, 1997].

Investment in equipment

During the major mergers of the 70's, investments in equipment stagnated due to numerous cuts in the fleets [Allen, 1993]. Afterwards, the evolution of equipment investment steadily decreased with interruptions each time car tonnage increased and new types of cars were designed [Railroad Facts, 1996 Edition]. Usually, equipment investments consist of replacing old equipment. With equipment getting always better in terms of lifetime and reliability, the number of locomotives and cars bought steadily decreased until the end of the 80's.

However, recent increases in traffic clearly led to an increase in equipment investments. Between 1992 and 1995, more than 800 new locomotives were bought! [Railroad Facts, 1996 Edition]

Investments in personnel

Along with the investment in equipment, railroads had to invest in personnel. A peculiarity of this kind of investment is that managers are reluctant to realize them. They try to avoid them as long as possible using new technology and distributing the workload more evenly. Periods of improvement in fleet management follow hiring periods and vice versa.

Investments in new technology

New technology is always considered a good way to solve problems. Often one thinks that problems are solved because the methods to solve them are new, but one forgets that new methods create new problems. Railroads are no exception to the rule.

The fundamental constraint for a railroad is the track network. Once the fleet and crews are large enough to absorb the demand, the track network becomes the limitation. Why? The number of trains per hour on a track depends on the type of track and on the safety rules. Hence, the number of trains per hour a track can sustain is the bottleneck. This number is called the line capacity. Research has shown that for each track there is a line capacity limit and that if the line capacity exceeds 80% of that limit, recovery from any mistake is very difficult [Martland, 1995].

The line capacity is obtained if you divide the number of trains that can fit on the track by the time needed to complete the ride. For example, if the ride between Boston and New York City takes 4 hours and 6 trains can fit on the track at the same time, the line capacity is 1.5 trains per hour. One can easily see that train speed and separation are the critical elements in the equation. If you increase speed, the line capacity increases, if you decrease train separation, the line capacity increases. Following this rule, railroads have been pushing their networks to the limits by investing in faster trains and new technologies that allow them to significantly reduce train separation without reducing overall safety. Centralized Traffic Control is one of them.

Conclusion

The benefits from the use of new technologies are obvious to railroads. The drawbacks embedded in the new technologies are mainly human factors related. These changes have had a huge impact on the methods used by railroads to run and control trains. In all railroads departments, tremendous restructuring has taken place. Maintenance Of Way (MOW) people have had to electrify the track, to learn to deal with new repairs and to cope with more repairs due to the increased track usage. Train engineers have had to get used to the new locomotives, to learn how to shift safely between the typical "out of the window" signals and the in-cab signals for higher speed trains. And finally, dispatchers have had to learn how to use the new interface, how to handle more trains and more working crews, how to combine high speed and lower speed trains.

The main consequence of all these changes is the enormous need for communication between all these participants. The amount and the quality of the information exchanged between all the participants soon became a problem. The radio, until now considered as the only efficient and safe communication channel for communication in the field, has become over crowded. Some pieces of information have been lost or are no longer available. As the main player in the information processing and flow, the dispatcher became our focus. How does he get the information? On what "channel"? How does he select the information that is interesting to him? How does he transmit the information? Is this task easy? Is it his main task? Is proper handling of the information a safety-critical issue?

To answer all these questions we decided to analyze the communication environment of the dispatcher using two approaches in parallel. The first element was a Cognitive Task Analysis (CTA) and the second element was an information flow analysis. A CTA is an analysis of the cognitive demands on a complex task [Potter, Roth and Woods, 1997]. It was performed to try and understand the strategy that dispatchers have developed to complete their task. The information flow analysis was performed to put all the elements together to successfully complete our goal: design a data-link system that would offload the radio channel but would keep the safety critical features of the current radio environment. We wanted to integrate into the design of a new environment the most salient strategies previously developed to perform the dispatching task.

1.2 The existing communications environment of the dispatcher

1.2.1 A general look at communication

The first question to ask is, what is considered as communication? The definition in the Webster Dictionary reads: communication

1 : an act or instance of transmitting

2 a : information communicated **b :** a verbal or written message

3 a : a process by which information is exchanged between individuals through a common system of symbols, signs, or behavior <the function of pheromones in insect *communication*>; *also* : exchange of information **b :** personal rapport <a lack of *communication* between old and young persons>

4 *plural* **a :** a system (as of telephones) for communicating **b :** a system of routes for moving troops, supplies, and vehicles **c :** personnel engaged in communicating

5 *plural but singular or plural in construction* **a :** a technique for expressing ideas effectively (as in speech) **b :** the technology of the transmission of information (as by print or telecommunication)

Communication is one of the most difficult tasks in human life. Making sure we are understood is something humans have been obsessed with since the beginning of life. The reason why it is so difficult is because each individual is fundamentally different. This first and essential characteristic is the biggest issue and even with the invention of signs and symbols to communicate, replaced later by languages, it is still the biggest issue. In the railroad environment as everywhere else communication is an essential part of the job. The techniques used by railroads to deal with this issue are interesting, but also are old and overcome by the multiple demands placed upon them. Some say the twenty-first century will be the revolution of the information century; why not prepare for that century and see how railroads could benefit from this revolution?

1.2.2 The dispatcher's task

Train dispatchers are responsible for managing track use, ensuring that trains are routed safely and efficiently, and ensuring the safety of the maintenance of way (MOW) personnel working on and around the track [Devoe, 1974]. These are complex tasks that require integrating multiple sources of information (train position, MOW requests and weather), projecting in the future and balancing demands.

To analyze the dispatcher's complex task, in the light of communication, we performed a CTA and an information flow analysis. The goals of this CTA were to identify which factors contribute to performance difficulty, to uncover knowledge and skills that experts (in our case dispatchers) have developed to cope with task demands, and to specify ways to improve individual and team cognitive performance through various methods (training, better user interface…). In our case, the CTA was aimed particularly at understanding how data-link, can affect human performance. The information flow analysis was an attempt to categorize the types of information dispatchers currently process, as well as their way to process it, in order to design a data-link system that would fit their needs and not confuse them. For more details about the CTA see [Roth and Malsch, 1999].

Dispatching is a demanding task. It combines two main elements: routing and communication. The routing is relatively automatic once dispatchers are used to the schedule and to the routing interface. It seems to be a background task: routing decisions appear to be almost a subset of the communication task, nothing more than a set of outputs from the communication task at a given time and a set of inputs to the communication task sometimes later. The main task is in fact the communication task if one allows communication to include more than just communication between humans (e.g. setting a switch is a "communication" task with the track network).

Successful performance of the routing task depends on the ability of the dispatchers to monitor train movement beyond their territory, anticipate delays, balance multiple demands placed on track use and make rapid decisions. This requires monitoring train positions and delays. Finally, traffic over the radio places particularly high attention demands. Answering requests, determining the current state of railroad operations (delays, speed restrictions, and track outages), informing railroad entities of the current state of operations, coordinating with other railroad "supervisors" (e.g. train masters and yard master) are all part of the communication task the dispatcher faces to stay informed and in control.

All these elements combine into three types of demands:

- The attention demand associated with monitoring the radio channel and responding to radio requests.
- The demand on memory, associated with the need to keep track of many more elements than the ones actually displayed on the routing or communication interface.
- The demand on track usage, associated with the physical assignment of track to trains, MOW or rescue teams.

1.2.3 The dispatcher's strategies

Dispatchers have developed several strategies to smooth the way for the trains to pass through their territory, satisfy the multiple demands on track usage, "listen for" information and finally "back up" their memories. Awareness of dispatcher strategies is important for designers of new aiding technologies. First, strategies often signal problems in the current dispatching environment that dispatchers are compensating for, and may suggest ideas for new aids. Second, when introducing new technologies, designers need to be careful not to inadvertently create conditions that prevent the dispatchers from utilizing their strategies, especially if there is no replacement strategy.

The first strategy consists of off loading the memory requirements. A great amount of factual information needs to be taken into account when making routing or dispatch decisions. Some of this information can be found in the rule books (such as the NORAC rule book), in the schedules, in various memos and updates. All that information does not need to be memorized, but quick location of the information should be ensured. Therefore dispatchers have developed techniques to extract key pieces of information in a more readily accessible form. One example of this information compiling activity is the "Cheat Sheet", a piece of paper summarizing the most relevant information in the schedule. A blank "Cheat Sheet" is used every day, with the daily information each dispatcher prefers. Another example is the Desk Book, a clipboard including formal memos, speed bulletins, scheduled track outages or informal notes by dispatchers themselves. Both tools provided the dispatcher with a convenient way of keeping track of changes and updates.

The second strategy is to anticipate and plan ahead. This includes a lot of team effort from the dispatchers on abutting territories, but also from the people in the field. The first step is to develop a "game plan", to work out meets and passes depending on train schedules and priorities for each shift and territory ahead of time. Dispatchers usually summarize parts of this game plan in the cheat sheets. The second step involves situation awareness during the shift. Dispatchers maintain a big picture of railroad operations. They monitor activity beyond their territory. When they have a wall panel overview, as is the case in the South Station dispatching center of Amtrak in Boston, they monitor where trains are on the railroad even before they enter their territory. The third step is to think ahead, i.e. ask adjoining dispatchers about changes in the usual routing, alert them about changes and work to maximize efficiency. This includes planning for contingencies such as engine failures and late or unscheduled trains. The final step is taking advantage of the party line feature of the radio and planning accordingly. Dispatchers listen for information on the radio channel, which is not directly addressed to them but provides important clues to potential delays, to problems or needs for assistance. Typically dispatchers listen for "train out of station" messages, equipment problems (when a train engineer is talking to the mechanical department), other dispatchers commitments that might have an impact on their territories, and finally listen for mistakes.

The third strategy is proactive behavior. Dispatchers tend to take advantage of the windows of opportunities they have or create for track usage. If they have foul time they can give away, dispatchers will call up MOW crew and not necessarily wait for the MOW crew to call. In the same spirit, they will, if they have time, call train engineers before the train is scheduled to leave the station to give them the speed bulletin for the ride.

The fourth and final strategy we could identify is the dispatcher's tendency to level the workload. They tend to shift the work to lower workload periods by pre-naming the trains, clearing routes in anticipation of needs and giving provisional authority (giving track away until further notice). Other methods include reducing as much as possible the amount of communication (especially for work crews) and performing multiple tasks in parallel (e.g. clearing a route for a train and answering the radio for a MOW person).

1.2.4 Needs

The suggested improvements

After the CTA and the information flow analysis, we isolated some of the issues we have identified in the dispatching activities and we proposed some improvements. Here are some of the suggested improvements:

- Enhanced information display (real time train positioning, real time delay update)
- Shift paper resources to electronic media (track charts, street maps overlaid over track charts, desk book, rules book)
- Planning and scheduling aid for weekly or monthly operation (mainly for management)
- Shifting the radio communications to other media (Transmitting messages and authorization forms over electronic media, providing a call-back capability)

Some of the above are very easy to implement. Others are more difficult and would require more investigation and research work. For details see CTA report [Roth and Malsch 1999].

The radio issue

There was a clear consensus amongst all interviewed persons that the radio is now overloaded. Furthermore, there was a clear indication that radio is not well suited for some of the communication tasks. For example, long dialogues intended to convey detailed information, such as exact location, should be conducted on a more private channel. Dispatchers would almost certainly benefit from some visual graphics to provide a common frame of reference and avoid any misunderstanding.

Therefore, we took a special look at various ways to shift some of the radio communication to another media. Cellular phone and fax seem like a very short-term solution. Digital Data-link technology seems like a good alternative in terms of technological feasibility as well as financial feasibility. It definitely provides a vehicle for taking information that is now passed over the radio and transferring it over the data lines instead (Ditmeyer and Smith, 1993). However, the results of the CTA showed that the party line feature of the radio provides a very useful information tool for dispatchers to be aware of the state of operations, anticipate situations and act proactively. These essential elements of the dispatchers' strategies should be preserved in some way.

There are other issues to be aware of when designing a replacement for the radio:

- Auditory vs. visual communication – auditory communication (radio) provides a parallel channel with respect to the visual track layout, i.e. one can perform a routing task on the track layout while answering the radio. "Visual communication", e.g. data-link would not provide this feature. Auditory is hard to ignore but more ephemeral. It can be quickly forgotten. Visual may not be attended.
- Open vs. private – an open channel (public broadcast) makes for better situation awareness as long as it is not too congested (it then becomes an annoyance), a private channel makes for quick communications. See [Midkiff and Hansman, 1993], [Pritchett and Hansman, 1994] for work in the aviation world.
- Real time vs. offset time – radio is a real time communication, there is no need to worry about the acknowledgement.
- Natural language vs. symbols or graphics.

All these issues have to evaluated and taken into account when considering shifting some radio communication to other media. Radio will obviously not disappear but some communications would certainly benefit the whole system if on another media.

1.3 Data-link communication and the dispatcher

Data-link is a very broad notion. It applies to hardware as well as to software in the field of digital communication and information transmission. However, be it hardware or software, data-link's essential goal is the use of digital technology to communicate information from a central to a vehicle and vice-versa.

The recent boom of data-link technology is due to the fact that that storage and processing combine with communication in a highly efficient way thanks to tremendous advances in the computer industry. It is in fact very easy to find successful examples of implementation of data-link: wireless telephony, flooding telecommunication markets, is probably the most obvious example. Others can be found in the transportation field. In the aviation industry, first with the computer systems for booking and reservation, but then also with the data-link communication systems applied to flight control (flight computer, air traffic control system, Traffic Alert and Collision Avoidance System-TCAS- and other electronic devices). In the ground transportation world, data-link is the basis for the famous ground tracking system implemented by many shipping companies (e.g. UPS, FedEx).

1.3.1 The benefits of data-link so far

Data-link has improved transmission of raw data as well as meaningful information. Data could be compared to the letters of the alphabet and information to individual words, actually carrying interesting meaning. The current data-link technologies improved the sheer data transmission rate. Transmission rates have increased in all communication fields and more "space" is available for data. Information processing technologies also made enormous progress. Alerting systems (such as TCAS, or Group Proximity Warning Systems, GPWS, in the aviation world) are becoming more and more reliable thanks to improved understanding and modeling of information processing but also thanks to the increase amount of raw data available.

As mentioned previously, by looking at the railroad industry and particularly at the dispatcher's task in the railroad family, we noticed that most inefficiencies are due to the relatively difficult data transmission.

In most other fields in which data-link has been introduced, this technology was the source of immense gains in terms of safety, efficiency and productivity. In the railroad industry, the problem is clearly a communication problem and data-link has proved to be a good solution to this type of problem. We hope that data-link will achieve in our field the same sort of results as in the more modern younger brother: the aviation industry. Given that the dispatcher seemed to be the key element for communication in the railroad control environment, we investigated the benefits and drawbacks of the implementation of data-link in the dispatcher's working environment. First we delimited the domain we were considering when talking about data-link.

1.3.2 A first look at data-link for railroads: benefits and drawbacks

The two main benefits to railroad industry if data-link were implemented are more real time data available and improved information in terms of quantity, reliability and quality [Vanderhorst, 1990]. Using the experience gathered in the aviation world, we will describe, in the following paragraph what we think are some of the possible benefits of data-link. As usual the world is not perfect and therefore data-link also has drawbacks.

A new way of transmitting old data

Data-link creates in many cases alternative communication channels. These new channels have advantages and drawbacks specific to the quantity of information, type of information and quality needed. Therefore, data-link often doesn't replace totally the old data transmission channels but reorganizes the ancient data flows.

In the case of railroads and especially in the case of the dispatching task, data-link might help reduce the congestion level on the radio environment by creating new communication channels: written message systems but also teleconference abilities or even remote control.

Real time information

Real time information is important for everybody on the railroad, be it the dispatcher himself, the engineer, the MOW crews, the train master, the chief dispatcher, the yard controller... Real time transmission makes the processing of the data easier and more meaningful. The contribution of real time information can be understood when one observes the current dispatching environment and the current data flows and information flows. At the Amtrak South Station dispatching center, the CETC supposedly provides delays for each train. However the update frequency of the delay is so low that dispatchers do not trust the overhead or wall display of the territory and their delay information. The current CETC is not a real-time system and therefore much of the data is never transformed into usable information. Current data-link technologies could help the dispatcher do his work more efficiently.

Additional information

Additional information is always useful. Note that we are using the term information not data! Increasing the amount of data however, might lead to confusion. This is a typical problem encountered every time data-link as been implemented, be it in the aviation industry or other sectors of the transportation industry. In order to use new technology in an efficient way, one has to make sure that data-link is going to provide additional data that can be turned into useful information. By analyzing the dispatcher's task, our goal was to spot the missing information he most needs. In one sentence, any piece of information available to the dispatcher only through his memory should also be provided to him otherwise. The following are some examples: exact positioning of trains, exact positioning of MOW crew's on the track, exact speed, real time grade crossing state, real time track state, update list of emergency phone number, map of the surroundings of the track.

Data analysis

The improved computer power and speed available creates previously unheard of opportunities. Any portable computer is as fast and powerful as the best desktop computer in its category roughly five years ago for the same price. Processing speed and "intelligence" is now commonly available. Displays are getting more and more efficient and the need for special computers to handle high quality graphics is progressively disappearing. New hardware has made data analysis more easily available; new software has increased data analysis' quality and accuracy. In the aviation industry, this can be seen with the famous and controversial TCAS system, a computer system used as a decision aid and alerting system for air traffic control. Inputs are primarily speed and position, outputs are degree of danger and corrective action to be undertaken.

In the railroad case, if you assume that data-link provides you with the additional information mentioned above, many computer systems can be imagined to improve safety, efficiency and productivity. The grade crossing is an easy example: a camera with a reasonably frequent update could be shown to the train engineer or to the dispatcher. If the image shows a potential obstruction the engineer or the dispatcher could take appropriate action by triggering the brake. The system could even do the analysis itself and automatically slow down the train. Another example is the state of the engine monitoring: an intelligent monitoring and investigation system could check the state of the engine in real time and report to the mechanical department in case of danger of a serious failure. A conflict probe with a proximity sensor, involving not only trains, as is the case currently in the CETC system, but also involving MOW crews and eventually other temporary elements, would certainly benefit the overall operations.

More specifically in the dispatcher's case, one of the most important elements in the dispatching decision process is the "time to reach" a specific point. A system that would evaluate this time instead of the dispatcher would certainly be very helpful for routing decisions. A conflict probe as mentioned previously will certainly make the dispatcher more aware of the potential collisions occurring in his territory.

Information display

Data-link can also considerably improve the way information is "explained" to the final recipient. Displays can be improved by adding information but also by completely changing the display type.

In the dispatching case, we know that the display of the blocks in the current CETC technology is limited by the field signals. If railroads switched to in-cab signals and precise real-time positioning, the display of the system-state would be completely different. Another example can be found with the string diagrams, currently used only for planning but rarely for routing except in Japan [Igarashi, 1995], [Sano, 1998]. String diagrams do not allow for a good representation of how to solve meets and passes. They are a two dimensional tool representing distance to the target and time but not position on a set or parallel tracks. This third interesting information is the crucial piece of information for solving meets and passes. By allowing three-dimensional display or other "smart" solutions, data-link can rehabilitate string diagrams.

The drawbacks

As one can see, data-link has the potential of drastically improving the quality of information provided to each individual on the railroad system. One of the reasons for this quality improvement is the widely available information. This is also an important drawback for a very well known reason: information equals power. And in the railroad industry, power has to be in safe hands. If MOW people have the possibility of monitoring the track network and the movements of trains, they might decide to work on some part of the track on their own, without asking the dispatcher for foul time as is necessary in the current environment. This would lead to a possible safety hazard and is something railroads will have to prevent.

1.3.3 Creating a safe, efficient and productive messaging system

We decided to simulate and test a railroad environment to evaluate data-with respect to safety, efficiency and productivity, as well as reduction of the congestion on the radio channel.

1.3.3.1 Data-link to improve the dispatcher's communication environment

Given the results of the dispatching cognitive task analysis, we were determined to focus on improving the dispatcher's communication environment. Therefore the primary use of data-link for us will be as a creator of replacement communication channels to alleviate the communication demand placed on the radio channel. From all the new types of channels available, we focused on the written message channel.

The first reason is the cost. Railroads are currently not willing to invest in highly expensive equipment if the returns on investment are not concrete and significant. Equipping all the grade crossing or even better all the possibly dangerous location with a monitoring camera and have the pictures automatically processed into a useful information or an appropriate action is very expensive and might not lead to a tremendous increase in traffic.

The second reason is reliability of the data-link technology. This raises the issue of human and computer supervisory abilities [Sheridan, 1992]. Designing a system that is reliable and improving performance over the human can be very difficult depending on the level of complexity of the task. Also making sure that the "system-human" pair is fail-safe can introduce limitation in the computer system's performance.

The third reason is the urgency of the need that we meet. As mentioned above, the high increase in traffic as well as the productivity requirements led to an immensely congested radio channel. The need to get some of the data or information transmission off the radio channel is urgent and any alternative channel should be considered seriously, be it as simple as the fax or the cellular phone.

The fourth reason is the high inertia of the railroad industry. Historically, the railroad industry has not been very open to change. Therefore, satisfying an urgent need might be a good way to introduce new technology slowly.

Finally, starting slowly with the implementation of data-link is a way to ensure that the changes accompanying the introduction of a new technology are taken care of. Starting with a new communication channel most people are already familiar with under the form of electronic mail should allow us to understand more thoroughly the shift in behavior all the entities on the railroad will have to deal with.

1.3.3.2 Our design

We designed a written messaging system as an alternative solution to the current radio communication environment. This messaging system would be used in addition to the current radio channel for the standard information transmissions such as bulletins, trespasser or other hazard alerts, state of the engine reports, position reports or track outage scheduling. To make the use of this messaging system more easily and, because it was demanded by dispatchers, we used preprogrammed messages for as many messages as possible including the previously listed tasks. The first step of the design process was to evaluate the advantages and drawbacks of the current system. After acknowledging the superior transmission speed of the radio environment with respect to a classical written messaging system with keyboard entry, and bypassing the issue preprogramming messages, we faced the next challenge when dealing with situation awareness. This led us to design two different messaging systems. The first one allows only "one to one" communications, the second one allows "one to N" communications. Both have advantages and drawbacks. These will be discussed later.

1.4 Research Goals

1.4.1 An overview of our experiment

The ultimate goal is to have an accurate idea of the influence on the dispatching environment of data-link technology when used to create an alternative communication channel for the current radio channel. To achieve this, we designed two different data-link messaging environments and benchmarked them against the current radio environment. The design of this benchmarking experiment allows for testing of two main effects of the introduction of data-link messaging systems. First, it will evaluate the level of improvement in terms of safety, efficiency and productivity achieved with this new environment. Second, it will determine what kind of attention allocation changes are likely to occur.

1.4.2 The testing method

To evaluate safety, efficiency and productivity we use various techniques including an open-question questionnaire, various omission measurements, an evaluation of various communication times and a train-MOW schedule compliance measurement. To get an idea of the change in the attention allocation pattern we use a closed-question questionnaire as well as a debriefing session with open questions.

1.4.3 The expected results

We expect to show that the data-link messaging systems increase the safety, efficiency and productivity of the environment if compared to the current radio environment. After a quick overview of the dispatching task, it seems that the introduction of data-link should be beneficial in terms of efficiency and productivity. We also hope to get reliable information on a possible attention-allocation shift. Introducing another visual communication mode in the dispatcher's environment might cause dispatchers to split their visual attention between the messaging system and the routing system, thus reducing their ability to perform multiple tasks at the same time.

2 Methodology

2.1 Overview

2.1.1 Our main question: do we improve communication using data-link?

For our experiment the fundamental question was "do we improve the communication environment of the dispatcher when using data-link in addition to the usual radio channel?" In order to answer this question we designed two different data-link environments, implemented them on a dispatching simulator and benchmarked them against the best simulation of the current environment we could create. Also for research purposes we kept the environments separate, i.e. no experiment combined data-link technology and the radio environment. This is naturally a very strong restriction imposed on our results, but this was chosen in order to make the results clear-cut. In a real world implementation of data-link one would combine the benefits of both environments and just sort the information according to the channel used for transmission.

2.1.2 The simulator

Santanu Basu and the MIT Human Machine System Lab have programmed the dispatching simulator we used. It is composed of two main elements: the dispatching desk and the experimenter desk. The dispatching desk simulates the dispatcher's task in the railroad environment and recreates the dispatcher's two fundamental activities: routing and transmitting information. The experimenter desk simulates the outside world by having the experimenter complete the code's actions (e.g. simulation of the trains or the triggering of hazards during the experiment), play-acting various entities of the railroad, i.e. the train engineers, the MOW crews, the yard-master… For details see [Basu, 1999].

2.1.3 Two main questions

The benchmarking procedure focuses on two main questions. First, what are the areas of improvement and second, what is the effect of data-link on the attention allocation pattern and on the dispatcher's game plan. To answer the first question, we use various measures of safety of operations, measures of the efficiency of the communication environment as well as measures of the overall improvement in productivity. Answering the second question will be somewhat more judgmental because the attention measure is based on the subject's feelings [Endsley, 1993]. These methods will be discussed in further details later.

2.2 The simulator description

2.2.1 General description of the simulator

The simulator is divided into two distinct parts: the subject's side, i.e. the dispatching side and the experimenter's side, i.e. the outside world's side.

2.2.1.1 The dispatcher's side

The dispatching part is composed of two main elements reflecting the two main activities of the dispatcher: the routing simulator and the message communication console.

The routing simulator is a replica of the CETC routing system of the Amtrak Dispatching Center in South Station Boston. It simulates the routing activity and therefore also simulates trains on an imaginary track network. Simulated train dynamics are based on the dynamic analysis of a real train (the French Train à Grande Vitesse, TGV) [Lanzilotta, 1996].

The message-communication console is the data-link version of the radio handset. Depending on the set of independent variables for each experiment, the handset or the message console will handle the communication task of the dispatcher. As mentioned previously, in real life, the message console (i.e. data-link communication) would only partly handle the communication load during dispatching operations, such as work scheduling.

From the dispatcher's point of view, the simulator recreates three different types of environments depending on the independent variables set for each experiment (see below). Therefore the simulator will not always be used with all pieces of hardware, software or interface listed below. In each set of independent variables however, the two main elements are present: the routing simulator (always consisting of two screens displaying the track) and the communication tool (message console or radio). Interaction with the simulator's different parts will be described later.

2.2.1.2 The Experimenter's side

The experimenter's side of the simulator is the element that recreates the "outside world" with which the dispatcher is constantly interacting. This outside world consists of all other entities of the railroad environment: other dispatchers, MOW crews, train engineers in the controlled territory or outside of the controlled territory, yard masters… The experimenter will have to play-act all these entities with the help of an underlying computer code. Details of the simulator are found later.

2.2.2 The equipment

The entire experimental equipment comprises six PCs connected via an internal network (LAN), a set of 4 portable radios and a video camera. The experiment was video taped and most of the actions of the dispatcher will be recorded and analyzed to retrieve the desired data. Finally, the experimenter will tape his comments when monitoring the experiment using a audio tape recorder.

2.2.2.1 Hardware

The computer part of the simulator: Six PCs on an internal network (LAN)

Six PCs are distributed into two different rooms. In one room we have the subject's dispatching station consisting of 3 PCs. In the other room we have the experimenter's supervision/monitoring station also consisting of 3 PCs.

To simulate the "outside world", the 3 PCs in the subject's room (dispatcher's desk) are connected via an internal network (LAN) to the three PCs in the experimenter's room. This network connection is the equivalent of the data-link hardware whose preexistence we assumed in our experiment (satellite or terrestrial link with exact positioning and permanent connection –[Kim and Martland, 1999]). The experimenter's supervising and monitoring activity takes place using the three PC's in the second room. He controls the experiment and feeds the 'outside world" using the simulator's code. The second set of three PCs is used to control the experiment and monitor the subject's actions.

Computer configuration

The configuration of the PCs is of no importance. The only requirement was to have an average processing speed and video card. The display doesn't involve any advanced graphics and is therefore not a constraint.

The typical configuration is the following:

- Pentium Motherboard with a 400 (or 450) MHz Processor with 512k Cache
- Mid-Tower Case
- 128 MB Memory Module
- 13x Min / 32x Max IDE CD ROM
- 1.44 Floppy drive
- 10.2 GB IDE Hard drive
- 3COM Network Ready certified 10100 Network card
- nVidia 16 MB AGP Graphics accelerator
- 104 Keyboard
- Microsoft Intellimouse
- EV700 17'' Monitor with 15.9'' Viewable Screen

A set of four portable radios for the simulation of the current radio communication environment

To simulate the radio communication environment (as observed in South Station, Boston or in Pittsburgh) we use a set of 4 Motorola HT/MT1000 portable radios. The frequencies of these radios can be adjusted, as well as other features like the emission power or the scan functions.

Here again the equipment has been split for use in the two different rooms. One radio is present in the dispatcher's room and the three other radios are used in the experimenter's room to recreate the radio activity on the radio channel when simulating the current radio communication environment. Note that in the radio communication case, we used more than one experimenter to be able to simulate communications between two non-dispatcher entities of the railroad. That is why we needed more than one portable radio on the experimenter's side.

A video camera for data collection

A video camera located in the subject's room records all experiments and allows us to properly analyze the computer-recorded data. It was of crucial use in the radio communication case. On the same tape we record the experimenter's comments during the experiment, in case some additional information was needed to be able to better read the computer-collected data afterwards.

2.2.2.2 Software

As for the hardware configuration, the software is of no importance. The simulator has been programmed using the Java programming language. Therefore the only requirement is to have the ability to run Java (for more details see [Basu 1999]).

All six PCs have the same software:

- Windows 98
- Kawa 3.1.0
- Java 1.1.7

2.2.2.3 Interface

The interface of the simulator is the result of the design of three different environments: the radio environment, the data-link directed environment and the data-link prioritized environment. The radio environment case is very specific and as mentioned above is the reference for the testing of the other two environments. To simulate that environment, we used portable radios.

As described previously three PCs are in one room and the other three PCs are in another room. The two stations look relatively similar when the simulation is not running. Both rooms are furnished with a large desk on which the PCs are used.

However, when the experiment is running, both desks look fairly different. Therefore we will describe each interface individually. Also, depending on the independent variables (i.e. the environment tested), the dispatcher's interface changes quite a lot. We will describe the various environments more thoroughly in the next sections.

Note: theoretically, all six computers can run all interfaces/windows.

The dispatcher's interface

While sitting at his desk the subject has in front of him at maximum three screen depending on the tested environment (independent variables). Two of these screens are meant to display the track layout (routing simulator) and one is used for the dispatcher's message console (communication simulator). When not presented with the message console screen, the dispatcher uses a portable radio. The dispatcher interacts with the various screens using a mouse for each screen. For the message console, he uses a keyboard.

As mentioned, when the simulation is running, the dispatcher subject and the experimenter see somewhat different screens/windows. For routing, the dispatcher usually has an "active" track layout window. "Active" means that this window allows routing of trains, blocking of various track sections, clearing of routes and other actions mainly controlling equipment in the field. All possible actions are described in further detail in the next section. This window is displayed on the two screens dedicated to routing. It shows the entire territory controlled by the dispatcher. Finally, this window can also be used to input information in the system essentially interacting with the dispatcher message console window described in the next paragraph.

For communication in both data-link environments, the dispatcher uses the dispatching message console window. This window shows the message console as seen by the dispatcher with the adequate pre-programmed messages. A detailed description of the window will be given when describing the various environments. For now, it is important to know that this window receives can receive inputs from the "active" track layout, that it displays a list of received messages, a list of messages, which were sent by the dispatcher, and one message from each list. For communication in the radio environment, the dispatcher uses the portable radio. Note that in this environment the dispatcher uses only two computers.

The experimenter's interface

While sitting at his desk, the supervising experimenter always has three screens in front of him. Two of these three screens are meant to display the track layout i.e. to monitor the routing. The third one is used for the message console. He also has a set of three portable radios used only in the radio environment. The experimenter(s) interacts with the various screens using one mouse per screen. Keyboards are available for all three PCs but should be used mainly for the message console.

As explained previously, the experimenter's task is to monitor the experiment but also to play-act various railroad entities (MOW people, train engineer and yard master). Therefore he has access too much more information than needed if he would be only one of the entities or if he would only be monitoring an experiment with multiple subjects serving as different railroad entities.

The experimenter's territory display is a "passive" track layout window. "Passive" means that this window does not allow the basic dispatching activities. As for the dispatcher, it can be used to input information in the system and to interact with the experimenter message console window. However, this "passive" track layout window can be used to perform actions usually performed by the various entities represented by the experimenter. One example is the ability to halt the train or to derail it. Another example is the ability to reverse the train's direction. This window is shown on the two screens with the track layout.

In the data-link communication case, the experimenter sees a message console window, representing the message console as used by the experimenter. All pre-programmed messages are at his disposal to help him play-act all entities of the railroad such as trains, MOW crews, CETC system and mechanical department... The structure of that window is identical to the window used by the dispatcher. A list of incoming messages, a list of outgoing messages and the ability to view one message within each list. In the radio communication scenario, the experimenter(s) still uses the message console. However, it is only used to ensure identical experimental conditions for each subject. This is to say the message console feeds the experimenter with the appropriate role to play. The computer-generated messages are not sent out to the dispatcher.

General comments on the simulator's interface

As mentioned, when the simulation is running, subject and experimenter see somewhat different windows. However, the data-link system we designed and simulated has the ability to access and display any of the four previously mentioned windows on any given screen-station. The typical screens are an "active" track layout on the two left screens and the dispatching message console window on the right screen. All other entities of the railroad might have access to a "passive" track layout and their individual message console.

2.2.3 How to interact with the simulator.

In this section we will present the various ways to dispatcher interacts with the simulator. For further details on the reasons that led us to implement this kind of interaction, see the section discussing the design of the three environments. First we will present a list of the various tasks the dispatcher subject faces. Then we will describe in detail how he can perform them using the simulator.

2.2.3.1 Various tasks for dispatchers and experimenters

The following is a list of actions available to the dispatcher. To initiate each of these actions, there is a particular procedure. These actions are the main dispatching actions we could identify during the cognitive task analysis.

- Analyzing the current situation in the field
- Clearing interlockings
- Unclearing interlockings
- Blocking sections of the track
- Unblocking sections of the track
- Reading text messages
- Replying to text messages
- Creating text messages

Now consider the actions the experimenter performs:

- Analyzing the current situation in the field

- Halting trains
- Derailing or stalling trains
- Reversing trains
- Reading text messages
- Replying to text messages
- Forwarding text messages initiated by the system to automate the experiment and to ensure identical experimental conditions
- Creating text messages

All actions mentioned above can be realized using the track layout window and/or the message console.

2.2.3.2 How to perform the dispatcher's tasks

Analyzing the current situation in the field

To transmit information about the situation in the field and create a sort of remote supervising presence, railroads use a colored track display with various pieces of information. By looking at this track layout, the dispatcher usually gets a very accurate picture of the state of his territory. These track layouts come in various forms, with head panel overview or without, with redundancy or without. We used a track layout based on the observations made at the Amtrak South Station dispatching center in Boston as well as at the Conrail dispatching center in Pittsburgh.

The track layout windows all have the same conventions:

- Red sections of the track represent sections of the track occupied by trains.
- Blue sections of the track represent sections of the track protected by signals and given away for MOW work.
- Green sections of the track represent clear routes. This means that signals are set so that trains can move on freely on that section of the track. Only interlocking sections of track can turn green.
- White sections of the track represent free routes. A train can enter these sections of track if there is no signal restricting his movement on his way.

- Yellow is a color used in the data-link environment only. It is used to locate the track mentioned in the incoming message highlighted at the time, i.e. the one message in the list of received messages displayed fully.
- Stations are usually a set of parallel track with the name of the station on top. Note that some stations have the number of the track displayed on the track layout.
- Interlockings are named and the name is indicated above the interlocking between the entry representation of entry signals and the representation of exit signals.
- The number of each train is usually displayed above or below the train depending on the train's direction. Odd numbers represent outbound trains, even numbers represent inbound trains. An arrow is added on the right or on the left of the train to make the direction more easily understandable.
- Finally on the left of the train number a + or a – sign indicates if the trains is late, early or on time with respect to the schedule.

Acting on the situation in the field

To act on the situation in the field the dispatcher subject as well as the experimenter subject both use a set of buttons at the bottom of their respective track layout window. They can also use their message console.

We will start to describe the procedures the dispatcher subject's has to use to take actions and then go on to the description of the experimenter's procedures.

Clearing interlockings

To clear interlockings, the dispatcher first has to click on the "clear route" button at the bottom of the "active" track layout. Then he clicks on the entry and exit signals of the interlocking according to the route he wants the train to take. He has to make sure he clicked both, the entry signal and the exit signal. He will know that a signal has been successfully selected when the color of the signal changes from red to yellow. Once he has successfully clicked both signals, the color of the selected path through the interlocking changes to green and so does the color of the signal.

Unclearing interlockings

Usually interlockings unclear automatically after the passage of the train on the cleared path. When uncleared the route turns back to white. However, if the dispatcher clears an interlocking by mistake or if he just changes his mind, he can unclear the interlocking. First, he should click on the "unclear route" button at the bottom of his "active" track layout. Then he should click any of the two signals in order to unclear the path. The color of the previously green and selected track through the interlocking goes back to white.

Blocking and unblocking sections of the track

To block sections of the track, the dispatcher has to first click on the "block track" button at the bottom of his track layout. Then he has to click on the block he wants to give away. This process has to be repeated for each block.

To unblock sections of the track, the dispatcher has to first click on the "unblock track" button at the bottom of the screen. Then he has to click on the block he wants to take control of. This process has to be repeated for each block.

Reading text messages

To read any text message, the dispatcher, as well as the experimenter, have to highlight/select the desired message within the list of messages available to them on their message console. The message will then appear integrally at the bottom of the list of messages.

Creating or replying to text messages

To create a message, users should click on the "send" button at the bottom of their message console. A message tree will then appear (see below for details). This tree is different for each entity of the railroad and therefore different for the dispatcher subject and for the experimenter. The message tree has four layers: priority, recipient, general subject and final message. At the general subject level, all final messages about one specific subject can be found. The user is then required to choose the desired message according to his needs and to fill in the blanks. Further details are to be found in the section discussing the design of the environments.

To reply to a text message, any user of the system has to click on the "reply" button at the bottom of his message console. The same tree as in the previous case will then appear. The only difference is that the recipient field will be filled in automatically by the messaging system.

2.2.3.3 How to perform the experimenter's actions

Halting trains

Usually train halt depending on the state of the signal. Trains also halt when stopping at a station. The halt train button at the bottom of the "passive" track layout the experimenter can use is simulating the train halting for reasons not linked to the schedule or the signaling system. For example, to simulate an engineer halting the train, the experimenter has to click on the "halt train" button at the bottom of his "passive" track layout and then click on the desired train. Communication actions have to be taken separately.

If the experimenter decides to restart the train, he will use the "restart" train button in the same way than the "halt train" button.

Derailing or stalling trains

The procedure to simulate a derailed or a stalled train is identical to the halting train procedure. The only difference is that the train is usually not restarted.

Reversing trains

To simulate an engineer reversing a train, the experimenter has to click on the "reverse" button at the bottom of his "passive" track layout and then click on the train to be reversed. Here again, the appropriate communication actions have to be taken separately by the dispatcher as well as by the experimenter.

Forwarding or "modifying and forwarding" system-initiated text messages

This is a procedure we designed for experimental purposes. To forward a system-initiated message to the dispatcher, the experimenter only has to select the desired message amongst his list of system-initiated received message and to click the forward button at the bottom of his message console. The result of this forwarding action is that the dispatcher receives the computer-generated messages.

All these actions are integrated in the simulation as the result of the design decisions taken for the three environments. These decisions as well as their advantages and drawbacks will be explain in the next section.

2.3 The three environments

In this section we will describe the final design as precisely as possible. Then in a second part we will walk through the design choices and explain what led us to the final design described earlier.

2.3.1 The final design

The design of the messaging system was one of the most challenging parts of the preparation work for the experiment. As expected, the data-link case brought a lot of novelty and therefore a huge number of advantages but also some drawbacks. We will see later that some of these drawbacks literally shaped our design. One should also remember we purposefully chose not to mix the radio and the data-link environment. The dispatching simulator was mainly focused on the routing part of the dispatcher's task. This can be easily understood given that the communication part in the current environment is mainly done over the radio and that this part of the dispatcher's task would typically be play-acted in a training simulator.

2.3.1.1 The radio environment

The goal here was to replicate the current dispatching environment in the most accurate way given the experimental conditions. We based our design on observation made at the Amtrak South Station dispatching center in Boston and at the Conrail dispatching center in Pittsburgh. Both dispatching centers functioned in a similar manner [Roth and Malsch 1999].

The final design of the radio environment consists of two elements: the routing simulation and the radio communication protocol. For clarity reasons we will look at both elements from the dispatcher's perspective as well as from the experimenter's point of view.

The dispatcher's routing simulation

The routing simulation fits as closely as possible the current CETC system. The state of the territory is displayed on as many VDU as necessary, in our case to.

The color coding - The color coding is conventional, with red indicating the presence of trains, green indicating the cleared routes, blue indicating track work, and white indicating dependence on signal state for passing through.

The information display - Station and interlockings are named. Signals and tracks numbers are not displayed. Train numbers are displayed above the track if traveling outbound and below the track if traveling inbounds. Also, inbound trains have even numbers and outbound trains have odd numbers. In addition to the position of the number, an arrow is located on the left or on the right of the number to indicate the direction. Finally, a + or – sign is displayed on the left of the train number to indicate the trains status with respect to his schedule. However, this delay display only updated when passing an interlocking.

The track layout - The track consists of a terminal, Boston, with ten platforms from which four branches depart towards New York City. The four branches, respectively A, B, C and D have various lengths and different amounts of stations. For a complete overview of the track see below. Branch names and station names are indicated. Remember that the track display is not on scale. The number of blocks has been restricted to the minimum.

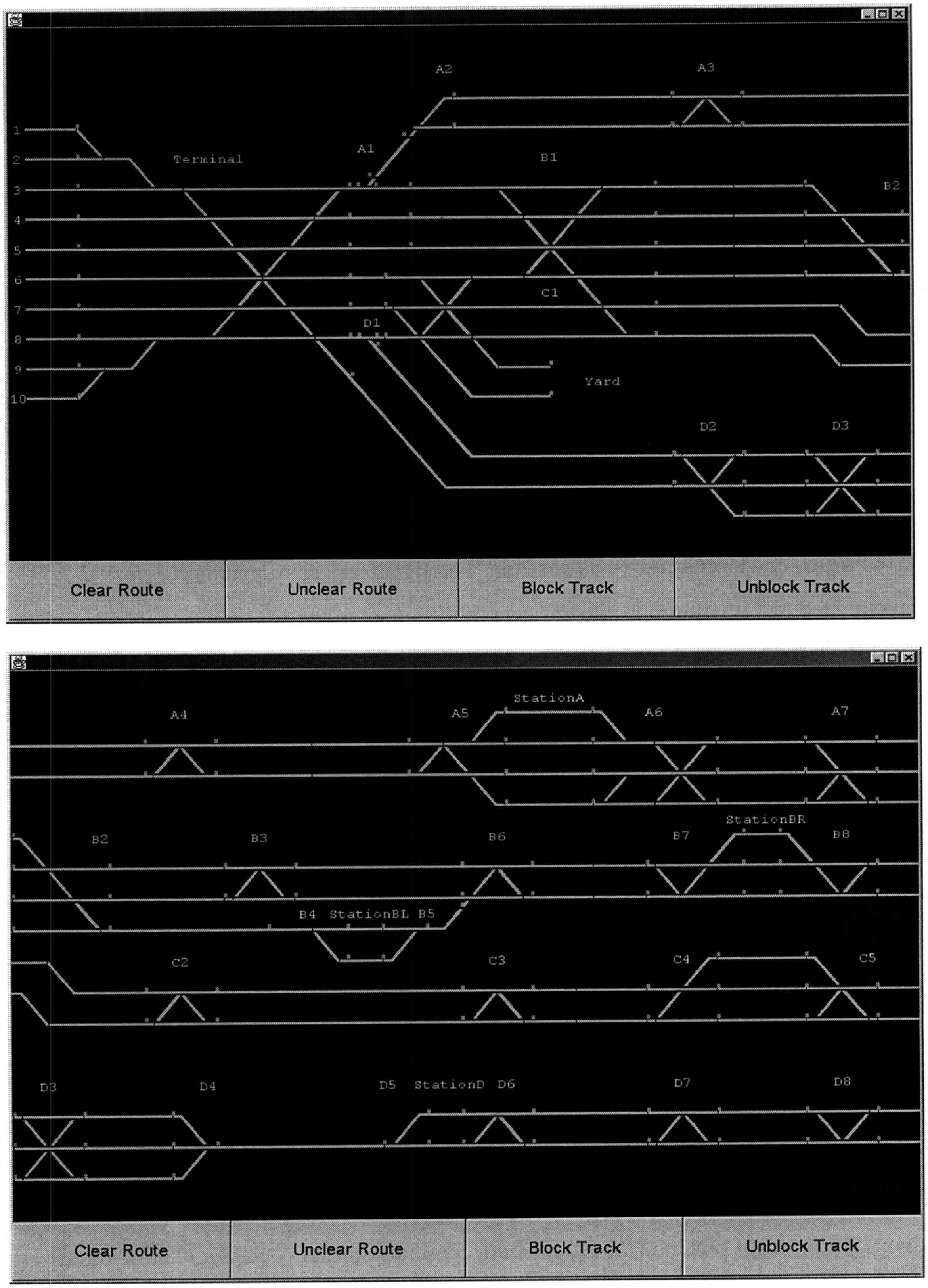

Figure 2-1: Active track layout

The naming - The naming of locations is structured as follows. First the location with respect to interlockings and stations (i.e. between two interlockings, in an interlocking or between a station and an interlocking), then the number of the track (from top to bottom at the location specified before) and finally the number of the block.

Routing activities - The main routing tasks are available using mouse-clickable buttons at the bottom of the screen: clearing and unclearing a route as well as blocking and unblocking tracks. The track unclears automatically after the train goes through. The unclearing delay typically encountered by dispatchers when correcting a mistake is not implemented. If the state of a switch is modified when a train is in the interlocking on that switch or when he is about to enter the interlocking, the switch will remain in its initial position. Hence, trains do not derail. The signal however, will turn red and the train will start the emergency braking. If his braking distance is not available he will pass by the red signal and stop has soon as possible. The signal aspect system has been implemented and it will propagate the state of the signal to the adjacent signals and trains will slow down and eventually stop if a cleared route is not available. For our experiment we use the simulator with a two-aspect signal system. However the simulator has the ability to run with up to nine aspects. About blocking and unblocking, the main difference between our system and the currently used system is the ability in our simulator to block individual parts of the track between two interlockings or within an interlocking.

The dispatcher's communication protocol

Here again the communication protocol fits the current protocol as closely as possible. As one might notice, the rules are far less complex than in the real environment but the basic structure still remains.

Calling up an entity on the railroad and transmitting a message - The following is the complete set for a message transmission in the radio environment.

- The protocol sentence for establishing communication is: "[caller identification] for [called person identification] OVER"
- The protocol answer implying that communication is established is: "[called person identification] speaking OVER"

- Then the free style part of the radio communication starts. In this part transmission has to be terminated by the work OVER. The "OVER" indicates that the speaker expects and follow-up on his transmission.
- The end of the transmission is marked by the following protocol pair: "[1st person's identification] OUT" and "[2nd person's identification] OUT"

Giving a form D - A Form D is a track use authority form issued by train dispatchers under very specific circumstances. Details can be found in the NORAC rules book. For this procedure the contact is established using the procedure mentioned in the preceding paragraph. The free style part however has to include the dictation and repeating of the form D information. Dispatcher read and writes down: "Date [date]. Dispatcher [name] is giving track [track [identification] away to [work crew name and number] between [start time] and [finish time]". The work crew (i.e. the experimenter) writes down and repeats/reads: "Date [date]. Dispatcher [name] is giving track [track [identification] away to [work crew name and number] between [start time] and [finish time]". In case of an error or if something is not repeated properly, the process has to be repeated. The form D used in our experiment can be found in the Appendix D.

Giving away foul time, blocking track for maintenance - When the dispatcher is giving away foul time he is not expected to write down any information (he might however want to do that). The transmission procedure for granting foul time is relatively similar to the procedure described for the form D case. The only difference is that the dictated and repeated text has no rigid structure.

The experimenter's role

As mentioned previously, the experimenter is an observer with respect to the routing part of the simulation. For the communication part, his role is somewhat special, as he will have to play-act a large variety of railroad agents ensuring equal treatment of all dispatcher subjects. In the next paragraph we will briefly explain how he will supervise the experiment.

The experimenter play-acts, with the help of other experimenters, various agents of the railroad. The messages to be transmitted to the dispatcher will be mainly computer generated in accordance with the dispatcher's routing decision. If the simulation is programmed to act on the presence of a trespasser during a given time span during the experiment, and if the dispatcher is routing a train through the area where the trespasser is supposed to be, the simulator will send out a message to the experimenter. The experimenter will then call up the dispatcher on the radio and pretend to be the engineer of that particular train. He will alert the dispatcher of the presence of trespasser on the track at the location he just passed. If the dispatcher routes no trains through the territory while trespasser are supposedly present there, these trespassers will go unnoticed by the dispatcher.

Finally experimenters also play-act with each other. Obviously on the railroad, communications are not always directed towards the dispatcher. To simulate these inter-entity communications, experimenters here again use a set of computer generate cues and talk amongst themselves using the three radios available in the experimenter room. Naturally experimenters are bound to the exact same communication protocol than the dispatcher.

2.3.1.2 The data-link directed (DD) environment

The data-link directed environment is a dispatching environment in which communication is realized using an email like tool: a message console with a set of pre-programmed messages, to be sent to ONE and only ONE recipient. For experimental purposes, we do not allow for radio communication when using the data-link directed environment.

The dispatcher's routing task

The routing part of the simulation stayed the same given our investigation choices.

The dispatcher's communication task

The communication part is the new concept we are testing. The fundamental element of the communication system in the data-link directed case is the message console. This message console is the only communication tool for the dispatcher with the outside world. It is also the only communication means of the outside world (i.e.

experimenter) with the dispatcher. The radio was not available during the data-link directed case experiment.

The message handling can be divided into two parts. The first part consists of the message processing, i.e. reading the message and take appropriate action. The second part consists of the message creating. Both parts will be described in the following sections.

The message processing

The message console consists of a screen with a mouse and keyboard for information input. The screen is split into four parts:

- A window with the incoming message list
- A window displaying the highlighted messages amongst the previous list
- A window listing the messages that were sent out
- A window displaying the highlighted messages amongst the list of sent-out messages

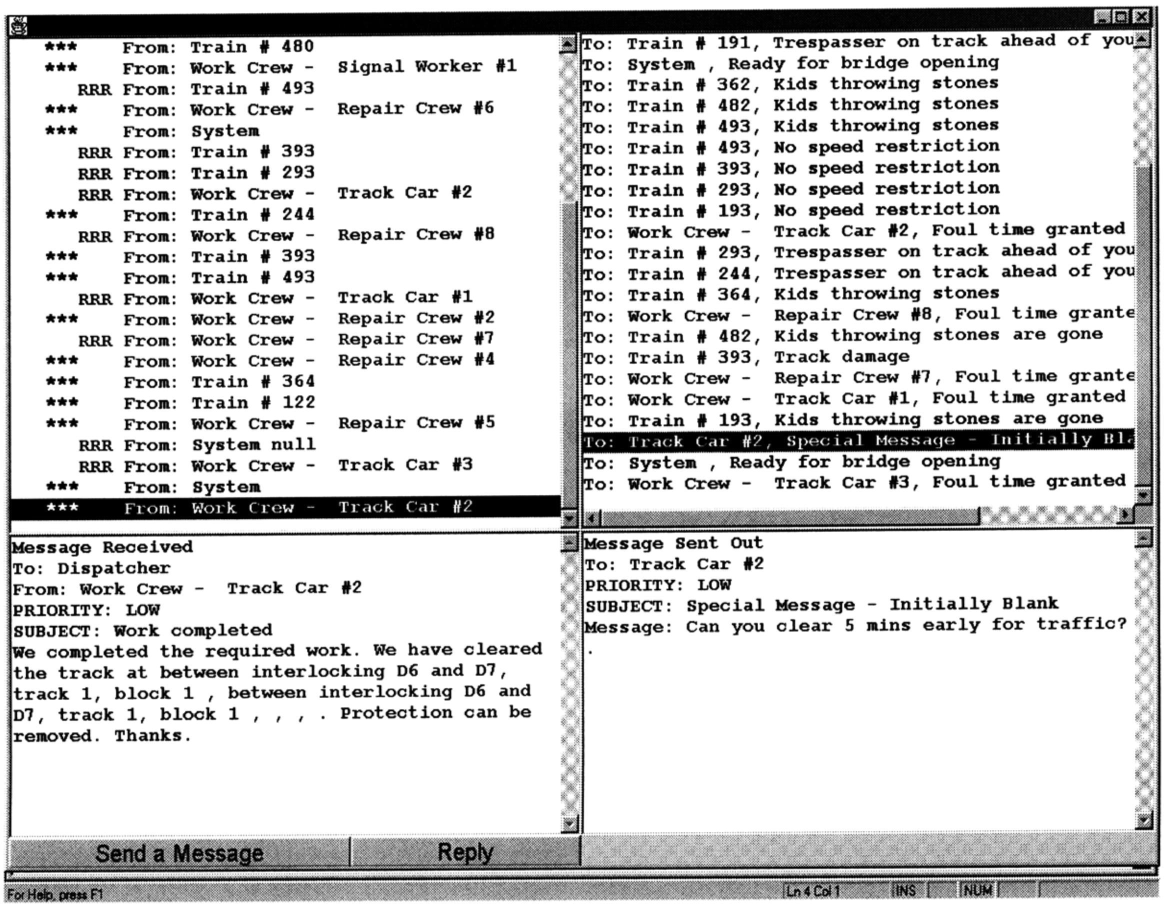

Figure 2-2: Dispatcher message console

The received-messages window - The upper left window displays the list of incoming messages. With each incoming message an additional line is added to the list specifying the sender. Messages are sorted by arrival time. As long as they have not been selected, they are preceded by a series of four question marks, to indicate that their exact content is unknown. Once they have been highlighted, they are preceded by a series of stars to indicate that they have been read (in a large sense). Finally if the dispatcher uses the reply button to answer the message, the message will be preceded by a series of "R" to indicate that the message has been replied to.

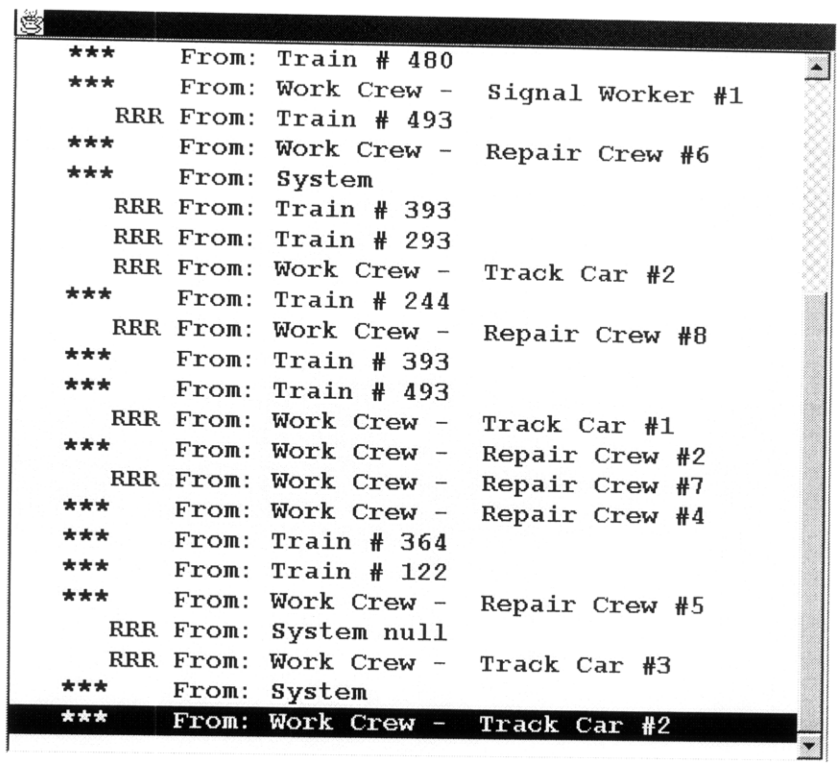

Figure 2-3: Received messages window

The full text message window for received-messages - The lower left window displays the entire message text of the message the dispatcher decided to highlight in the previously described window. Remember that if this message contains a location indication, this location is highlighted on the track layout.

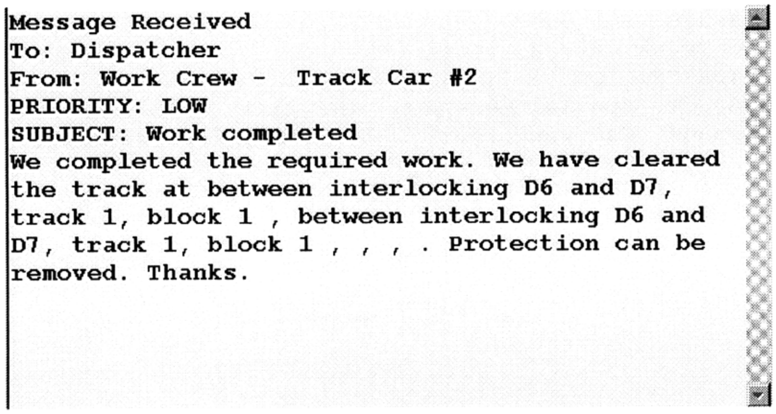

Figure 2-4: Full text message window – Received message window

The sent-out message window - The upper right window displays the list of outgoing messages. With each message sent out by the dispatcher during the experiment, another line is added to the list. The line contains in order the following information: subject of the message, priority and recipient.

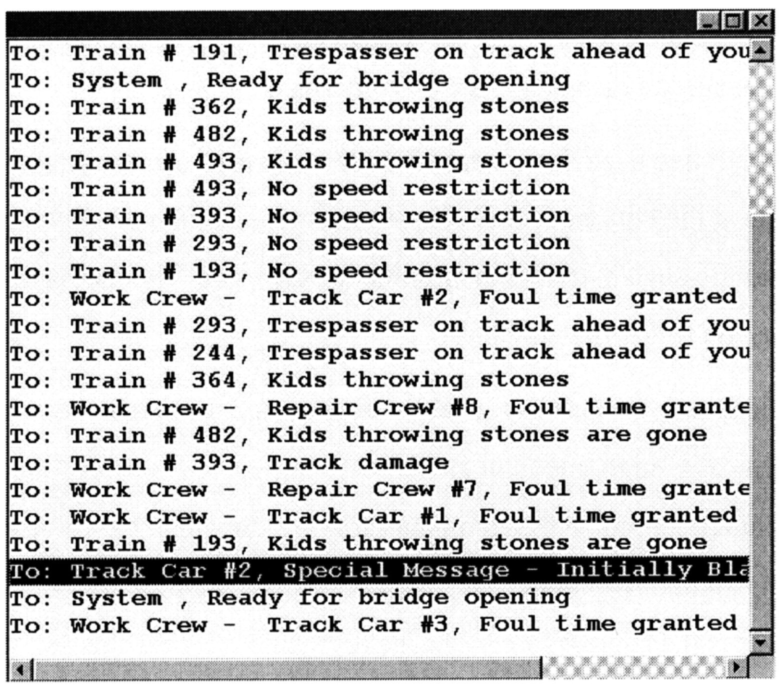

Figure 2-5: Sent-out message window

The full text message window for sent-out messages - The lower right window displays the entire message text of the message the dispatcher decided to highlight in the sent-out message window. This full text window does not have the location-highlighting feature.

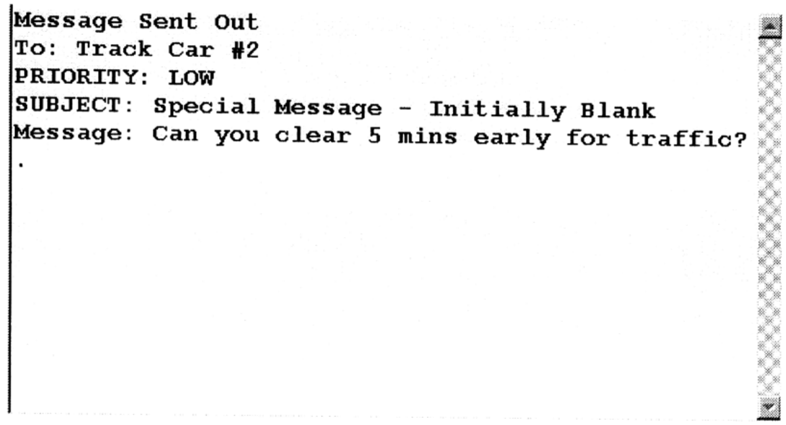

Figure 2-6: Full text message window – Sent out messages

The message creation: the dispatcher's message-tree

As mentioned above the dispatcher communicates by reading, answering or sending messages. To save time, the messages encountered most frequently have been preprogrammed. The dispatcher only has to scroll within a message tree to reach the message of his choice. In our experiment the message tree contains a small number of fundamental messages the dispatcher is expected to use.

The message-tree used for the data-link directed case can be obtained by choosing one of the options at the bottom of the received-messages window. Clicking the reply button or the send message button launches the message tree. The message tree is a four layer tree and has the following structure:

- The first indication is the priority level of the message the dispatcher wishes to compose. Typically: high, medium and low.
- The second indication, to be found on the same window than the priority level is the recipient. An example would be: "To engineer – danger warning"
- The third layer is the subject category. The dispatcher reaches this set of choices once he chose the priority level and the recipient. He then has to choose the general subject of his message. Again a typical example would be a choice between: "trespasser" and "kids throwing stones"
- The fourth and last layer in the message tree is simply a list of all the messages available in that subject category. The dispatcher sees a set of buttons with the

detailed subject of the message. By clicking one of these buttons, he launches a window with the desired message.

The whole dispatcher message tree used for the experiment in the data-link directed case can be found in Appendix A.

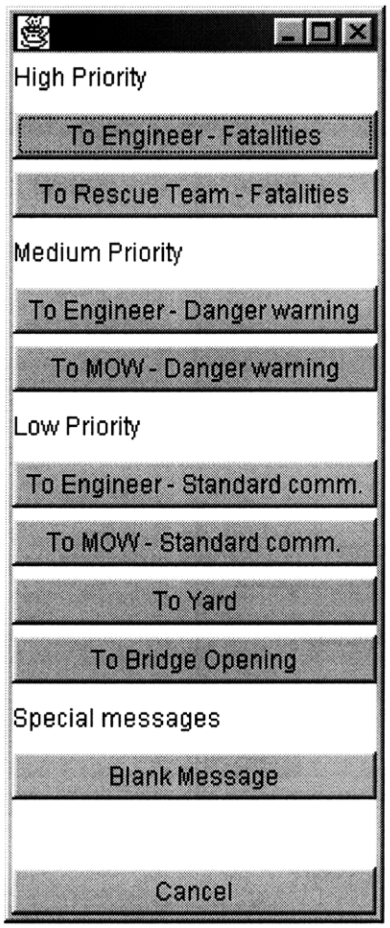

Figure 2-7: First two layers of the dispatcher message tree

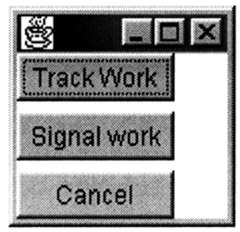

Figure 2-8: Third layer of the dispatcher message tree

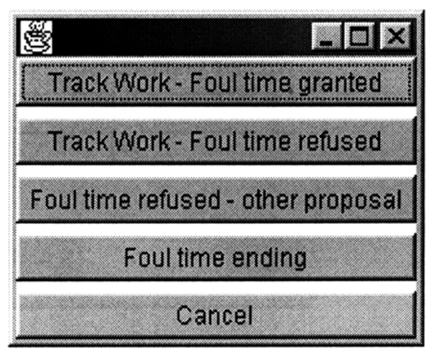

Figure 2-9: Fourth layer of the dispatching tree

To complete the message creation, the dispatcher has to fill in the blanks. In the data-link directed case he is restricted to ONE recipient, i.e. ONE value for the "To" field. Once the appropriate information has been filled in, he can send the message. Typically the dispatcher has to fill in a location field, a time field and a train number field.

To fill in the blanks the dispatcher can use the mouse or the keyboard to input information. To fill in time information, the only solution is the keyboard. To fill in location information or to fill in train number information, the dispatcher can use the mouse along with the "active" track layout. By double clicking on the location or train number field, he can select the location with other mice on other screens. Once a field has been filled in, the cursor moves to the next blank field.

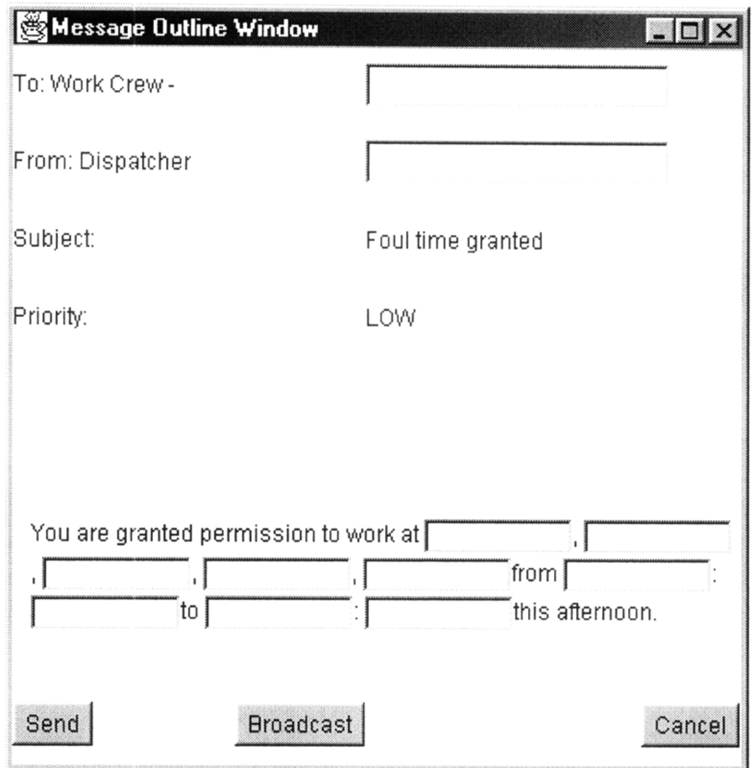

Figure 2-10: Preprogrammed message

For the experiment, we suppose that messages, once sent, are always acknowledged. No acknowledgment protocol has been implemented. This feature would have to be implemented in real data-link operations so that the dispatcher has a way of knowing that his message has been read.

The message tree used in this experiment is a small version of a more complete and detailed message tree drafted following the CTA. The more complete version can also be found in the Appendix A. Note also that the simulator can handle an indefinite number of messages in the message tree. If there is a need for new messages it is very easy to incorporate them into the existing message tree. Eventually each dispatcher could have his individual set of preprogrammed messages and his individual tree structure.

The experimenter's monitoring

The experimenter has no influence whatsoever on the routing decisions. However he is expected to monitor that trains behave the way they would with a train engineer. Typically if an engineer were given notice to stop, the experimenter would halt the train. If the train engineer is asked to reverse the train's direction, the experimenter is supposed to input the necessary information in the simulator, i.e. update the simulation. As mentioned previously, any switch or signal related action is not available to the experimenter on the dispatcher's territory.

The experimenter's play-acting task

As explained previously the experimenter's main task is to play-act various entities of the railroad. In the radio environment he was "computer-aided" in his play-acting activity. Here again this was the case. However his play-acting task is not the only one, he was expected to perform another important task: the "message routing", the essential part of the data-link directed case. As usual, to perform his part in the experimental process, the experimenter has his set of three PCs; two of them displaying an "passive" track layout and the third one displaying the experimenter message console.

As in the radio environment case, the experimenter play-acts various agents of the railroad. Most of the agents he play-acts have an "intelligence", i.e. trains, MOW crew and others are objects on their own in the simulation. They send messages to the experimenter when necessary exactly like in the radio environment setup. The only difference is the fact that all these entities are bound to communicate via text-message due to the experimental conditions (data-link directed). Hence, to play-act these entities the experimenter need only forward these computer-generated messages to their final recipient (mostly the dispatcher in our case).

In addition to the computer generated messages and when necessary, the experimenter has to create and send other messages. This is typically the case whenever the events usually triggering that message can't be easily captured and categorized by a computer. A typical example would be answering a special request from the dispatcher such as the advancement status of electrification work. In this example, the type of work is rather precise and should be mentioned in the answer. Also the appreciation of the advancement is very subjective. A computer would not be able to create a "human enough" message. Note that theoretically the dispatcher can't distinguish between a forwarded message (computer-generated) and an experimenter created message. The reason why we used computer-generated messages and why the experimenter has to forward these messages will be explained later.

<u>The experimenter's message processing</u>

As explained in the previous paragraphs, the experimenter has to forward the messages created by the computer to the dispatcher. He also has to forward the messages he receives from the dispatcher to the various railroad agents present in the simulation. The experimenter's message console window looks fairly similar to the dispatcher's version. It consists of a screen with a mouse and keyboard for information input. Here again, the screen is split into four parts:

- A window with the "to be forwarded" message list
- A window displaying the highlighted message amongst the previous list
- A window listing the created and send messages
- A window displaying the highlighted message amongst the list of created and sent-out messages

What makes the experimenter's message console fundamentally different from the dispatcher's console is the double play-acting and message "routing" role of the experimenter.

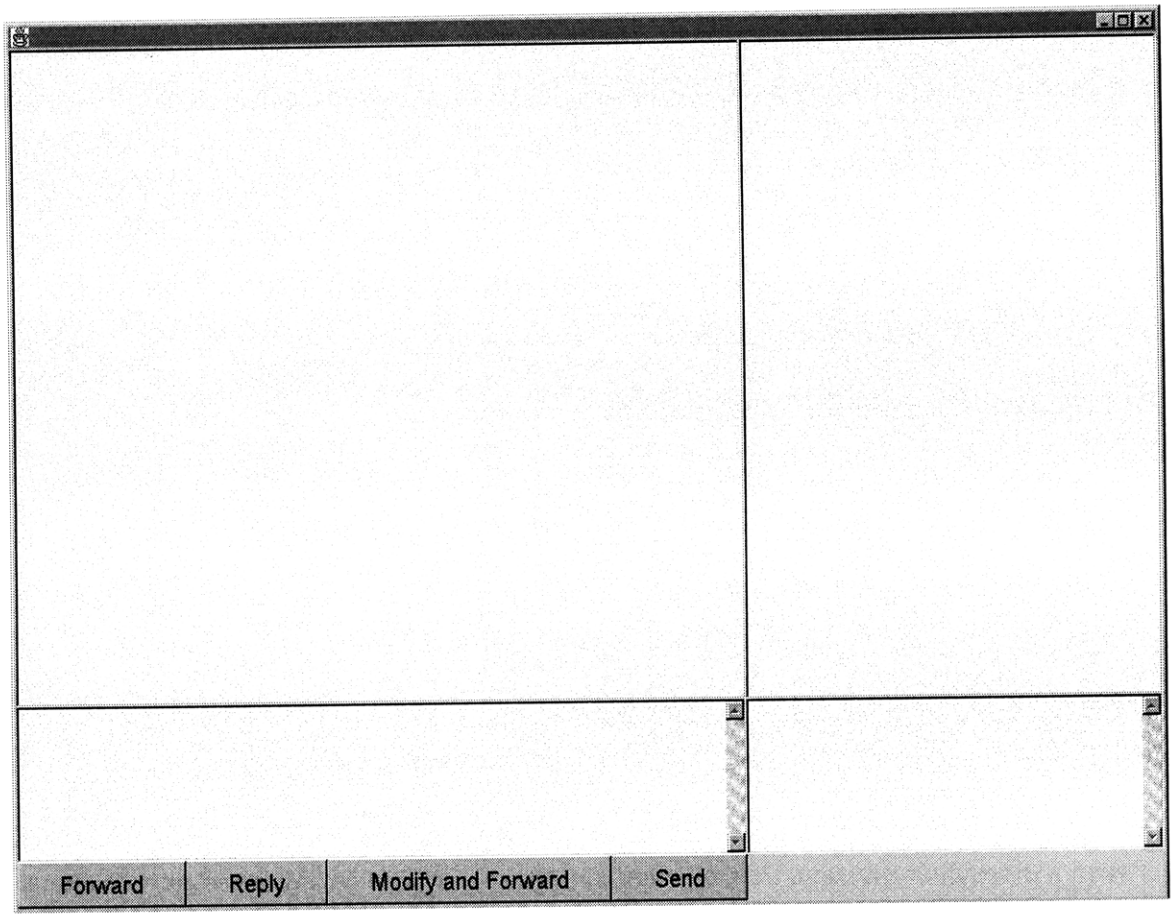

Figure 2-11: Experimenter's message console

The "to be forwarded" message window - The upper left window displays the list of messages the experimenter will forward or did forward. With each incoming message an additional line is added to the list containing, in order, the following information: subject of the message, level of priority, recipient and provenance. The messages are sorted by arrival time. As long as they have not been forwarded, messages are preceded by the following string "<unconfirmed>". Once forwarded, this string is removed.

The full text message window for forwarded messages - The lower left window displays the entire message text of the message that the experimenter decided to highlight in the previously described window. Here again this full text window does not have the location-highlighting feature.

The created and sent-out message window - The upper right window displays the list of messages created and sent out by the experimenter. With each message sent out by the experimenter during the experiment, another line is added to the list. The line contains in order the following information: subject of the message, priority and recipient.

The full text message window for created and sent-out messages - The lower right window displays the entire message text of the message the experimenter decided to highlight in the created and sent-out message window. This full text window does not have the location-highlighting feature.

The experimenter's actual message creating

To create a message, the procedure is quite similar to the procedure used by the dispatcher. The main difference is the fact that the experimenter has all trees available. Therefore we introduce an additional layer in his tree (first layer). The experimenter's message tree used for the data-link directed case is obtained by choosing one of the buttons at the bottom of the "to be forwarded" message window. Clicking this button launches the message tree. Figure 2-11 shows the first layer of the experimenter's message tree. He can choose the entity he is going to play-act. He is offered the choice between a dispatcher message tree, an engineer message tree, a MOW message tree and a "miscellaneous" message tree. After this level, trees are similar in structure to the previously described dispatcher message tree.

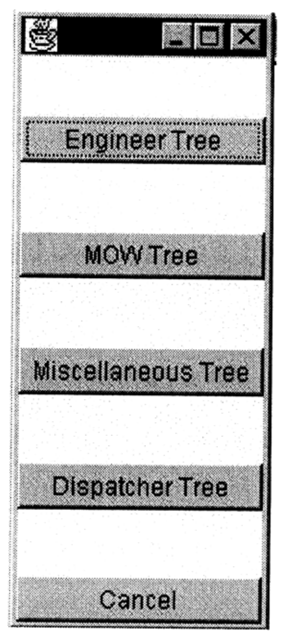

Figure 2-12: First layer – Experimental message tree

The whole experimenter message tree used for the experiment in the data-link directed case can be found in Appendix A.

To complete the message creation, the experimenter has to fill in the blanks the same way than any agent in the railroad would. Remember that, in the data-link directed case he is restricted to ONE recipient, i.e. ONE value for the "To" field. Once the appropriate information has been filled in, he can send the message. Typically the experimenter has to fill in a location field, a time field and a train number field. As usual, to fill in the blanks, the mouse or the keyboard can be used. The experimenter can use the mouse along with his "passive" track layout in the same way as the dispatcher (see above).

The experimenter's activity is the basis of the experimental procedure. As explained later, he provides "human" intelligence to the simulation experiment.

2.3.1.3 The data-link broadcast (DB) environment

The data-link broadcast case is a dispatching environment we designed in which communication is realized with an email like tool that is almost similar to the data-link directed case. The main difference is the fact that the message console in the data-link broadcast case uses pre-programmed messages that can be sent to more than ONE recipient. In fact each message is sent to a primary recipient and to a small group of railroad entities. In other words it is a ONE to ONE+G messaging system, where G is a pre-specified ensemble of railroad entities. As one can guess the general features of the system do not differ fundamentally from the data-link directed case. To avoid being too lengthy in this section, we will restrict ourselves to describing the differences between the data-link directed and the data-link broadcast environment.

The dispatcher's task

The routing task does not change. It remains the same in the all three environments. The communication part however is slightly modified. The key feature of the communication system in the data-link broadcast case is the new message console. As in the data-link directed case, the dispatcher communicates by reading, answering or sending messages. For commodity reasons, the messages encountered most frequently have been preprogrammed. The dispatcher scrolls within a message tree containing the basic set of messages, and reaches the message of his choice. Also one should remember that the message console is the only communication tool the dispatcher has available to interact with the outside world, as radio is not available during the data-link broadcast case.

As in the previous section, the dispatcher's message-handling can be divided into two parts. The first part consists of the message processing, i.e. reading the message and taking appropriate routing action. The second part consists of the message creating. The message processing is totally identical with the data-link directed case (see the description of the four windows). The message creating is slightly different, mainly because the data-link broadcast environment prompts the dispatcher for a recipient group in addition to the primary recipient he had to specify in the data-link directed case. The message tree used for the data-link broadcast case is obtained by clicking one of the buttons (send or reply) at the bottom of the received-messages window. The message tree is the same tree than the one used in the data-link directed case.

To be able to broadcast the message to more than one railroad entity in the data-link broadcast environment the dispatcher has to specify one primary recipient and a GROUP of secondary recipients. Therefore, once he reached the full text of the message in the message-tree, in addition to specifying a single recipient like in the data-link case, the dispatcher is be prompted when clicking the broadcast button to chose ONE group amongst a list available to him. In our experiment this list is relatively small (see Appendix A for the list of the groups). However the system can easily be customized and eventually, the dispatcher will not only be able to create his own preprogrammed messages and customize his message tree, but also to preset a personal list of recipient groups.

Again, for responsibility/liability allocation reasons and in order to make the dispatchers comfortable with the system, we assumed that messages are always properly acknowledged by their recipient once sent. No acknowledgment protocol has been implemented. This feature would have to be implemented in real data-link operations so that the dispatcher has a way to know that his message has been read.

The experimenter's task

Here again, the experimenter's main task is to play-act various agents of the railroad. He is still "computer-aided" in his play-acting activity and is also expected to perform the "message routing" task. This task is much larger in the data-link case because the simulator's broadcast feature was not ready at the time of the experiment. Therefore, the experimenter was the person in charge of duplicating the messages sent to the primary recipient and of sending it individually to each member of the recipient group the dispatcher had chosen. In addition to the computer generated messages and when necessary, the experimenter has to create and send other messages whenever a computer would not be able to create a "human enough" message.

So far there seems to be no difference with the data-link directed case except in volume, and for the experimenter this is true. However, for the dispatcher there is a fundamental one: forwarded and experimenter created messages are broadcast. In the data-link directed case the experimenter only forwards messages to the dispatcher when they are intended for him. Now, the dispatcher is going to receive an increased number of messages with some addressed not only to him or not primarily to him.

As usual, to perform his part in the experimental process, the experimenter has his set of three PCs; two of them displaying a "passive" track layout and the third one displaying the experimenter message console. The message console on the experimenter's side did not change. It is used exactly has described above.

The experimenter's activity is the basis of the experimental procedure. As explained later, he provides "human" intelligence to the simulation experiment.

2.3.2 The choices for each of the environments

In the following section we will walk through the principal features of all three environments and explain the reasons for our design choices. One should keep in mind that our intention is to evaluate data-link environments with respect to the current dispatching environment. During the design process, tradeoffs were necessary for various reasons: safety reasons, system efficiency reasons, productivity reasons, time reasons, academic reasons and financial reasons.

We will not justify the design of the experimenter's side/console, as the experimenter has no influence on the test results. The interface description can be found above. Most choices were done for our convenience. The main goals were making monitoring easy, ensuring equal treatment of all dispatchers, allowing for flexibility and recording data efficiently. Computer generated cues, availability of all railroad entities' trees, use of three radios… are only a few examples.

2.3.2.1 The radio environment: the reference point

The radio environment is the reference environment for our benchmarking. For various reasons studying an actual dispatching shift at the Amtrak South Station dispatching center, for example, as the reference measurement was impossible. Avoidance of comprising overall safety during railroad operations was the main reason. The restricted amount of data available was another reason (not all the data we are interested in can currently be recorded by CETC systems) as well as the relatively low number of data points given that hazards for example don't occur nearly as often in real life as in our experiment.

Hence, our main goal when drafting the radio environment was to design an accurate replicate of the current dispatching environment. We focused on two elements: first, keeping most of the features dispatchers are used to, and second, keeping the design simple. These two concerns resulted in a realistic routing simulator and in a set of basic communication protocol. We based our design on observations made at the Amtrak South Station dispatching center in Boston and at the Conrail dispatching center in Pittsburgh.

In the following, we will give some of the reasons for our design choice concerning the radio environment. As a reminder here are some of the main features of the radio environment system:

Routing system: An imaginary schedule and scenario on an imaginary track, a classical routing interface and track layout display (two VDUs to display the territory, classical color scheme, interlocking and station names are displayed but signal and track names are not, train attributes and positioning, amount of blocks, naming structure, automatic track unclearing, unclearing delay not implemented, two aspect signal system and individual block blocking) and use of mouse and keyboard.

Radio protocol: protocol sentences adapted from the NORAC rules book, transmission set up protocol, end of transmission protocol, simplified Form D with dictation and repeating, experimenter's play-acting (taped vs. spoken), multiple experimenter, computer aided play-acting,

The routing: An imaginary schedule and scenario on an imaginary track

During an eight-hour shift dispatchers usually don't route much more than 30 trains across their territory. We purposefully chose to use about 15 trains during our one-hour experiment. The first reason for this high traffic volume was the need for messages. As explained in the next section, each message provides us with a data point about the communication system. As our goal is to test the various communication systems, we needed a reasonably large number of messages. Using many more trains than usual allows us to create a high amount of classical messages such as bulletin request, trespasser sighting, bad weather condition reports and so on and therefore a lot of data points. The second reason for this beyond normal increase in traffic volume is our desire to check for variations in the safety, efficiency level and productivity level as well as in the attention allocation pattern when changing from one environment to the other. The scenarios were designed to ensure a high operator load, being careful however about the loss of interest in the payoff function if workload is too high.

Similarly to our schedule, our territory was larger than a typical territory. This again provided us with an increased amount and an increased diversity of realistic messages.

The routing: a conventional interface and track layout display

The routing interface is modeled after the dispatching center visited during the CTA. Both dispatching centers had at least two screens per dispatcher on which the territory was displayed. In our case, given the size of the territory, two screens were necessary. The color scheme of the track layout display is the classical color scheme in order to avoid any confusion. As a reminder, red indicates the presence of trains, green indicates the cleared routes, blue indicates track work, and white indicates dependence on signal-state for passing through. The pertinence of the color scheme has not been tested but this is not the scope of our research.

Concerning the display of "outside world" information, properties are very similar to the current CETC displays. Interlocking and station names are displayed for obvious clarity reasons. The only noticeable difference between our system and the systems used in the dispatching center we visited, is the fact that signal and track numbers are not displayed on the screen. These pieces of information were considered relatively easy to learn and get used to, hence not worth reminding on the screen. This also allows us to have a less cluttered screen, given the track density we have as a result of our territory being displayed on only two screens.

Despite this subtraction to the display, the naming pattern of infrastructure has been kept. To describe a location in the field, the first information is the position with respect to stations and interlockings, the second information is the track number and the third part the block number. Experts will notice that the block number is not currently used by most of the railroads because their CETC systems are not designed to allow for such precise "blocking". The reasons for this choice will be discussed when describing the data-link environments.

Concerning train attributes, here again our routing system is as close as we could get to the real CETC routing system given the resolution of our display and the density of our track network. The main issues here were train positioning, delays, train direction and numbering.

The displayed positioning information about the train is not exact positioning. As in current CETC systems, the position of a train is known only to a precision equal to the length of the block he is moving in. The reason for this is that train representations, i.e. red blocks, move on the screen only when changing blocks. This makes for very imprecise positioning given that at certain locations blocks are roughly seven kilometers long, whereas at others (near stations for example) the length is of the order of a few hundred meters. This choice is motivated by our desire to keep the routing system as close as possible to the state of the art. Here again, the spirit is that testing a new real-time exact positioning system is not the scope of our research. However, as mentioned already, for further applications we will assume that we have at our disposal the exact location of the train.

We also chose to keep the relatively imprecise delay information. In most CETC systems, delay information is updated at each interlocking, the reason being the relatively imprecise position information about the train, when located on other part of the territory. Keeping the positioning vague obliged us to update delay information only within interlockings as well.

Concerning the direction of the train, our display did not allow us to use train representation, i.e. red blocks, with directional arrows. Therefore we used two complementary conventions. First, we added an arrow on the left or on the right of the train identification number to indicate the direction. Then, we also displayed the train number above or below the track depending on the train's direction (above for inbound trains and below for outbound trains).

Finally, train numbers follow the same rules than at the Amtrak South Station dispatching center (who provided the dispatchers). The first figure of the train number indicates the branch the train is schedule to ride on. Odd numbers indicate outbound trains, even numbers indicate inbound trains.

The routing: an adapted signal system

As one can see, we kept most of the routing and track display features of the current CETC systems. The signal system is somewhat different even though we kept the main characteristic, i.e. automatic track unclearing. After the train passes through a cleared interlocking (green colored track), the track unclears automatically, the color goes back to white and a new route can be cleared through the interlocking using these blocks.

One of the main features we didn't implement is the unclearing delay. If the train is about to enter an interlocking and the dispatcher decides to unclear the interlocking, the system doesn't check if the distance to the interlocking's entry signal is enough for the train to brake. However, if the distance is not large enough and the train can't brake in time, the train simply passes through the interlocking. The signal is not physically moved and hence there is no danger of derailing, as would be the case in real life. For programming reasons, it was impossible to implement the unclearing delay usually protecting train from derailments and preventing dispatchers from switching signals too quickly.

In the same vein, given our "dense territory" choice, we had to reduce the number of blocks to a minimum to keep data files within reasonable sizes and to keep the debugging systematic. This also forced us into using a two-aspect signal system to provide the dispatcher with reasonable traveling time estimates. Note however that the simulator can run using up to a nine-aspect signal system.

The last distinct feature we implemented is the possibility to block individual blocks. This is currently not possible in most of the CETC systems. This is done as the result of our assumption that data-link would provide us with in-cab signals and that the dispatcher would be able to protect MOW crew or other railroad entities anywhere on the track, combining position information with in cab signals.

The radio communication: choice of rules and realism

As mentioned above, the radio protocol is adapted from the NORAC rules book. The transmission set up protocol, the end of transmission protocol and the Form D dictation and repeating are the closest, most simplified and most realistic version we could use.

The choice of having experimenters play-act the various entities of the railroad rather than have a set of taped messages was the result of a trade off between desired similarity of treatment (for the taped set of messages) and realism/flexibility. An experimenter play-acting is much more realistic than a taped voice. Also being able to improvise and to adapt to the dispatcher's actions was an advantage we did not want to give up. To counteract the natural tendency of the experimenter to change his words with each dispatcher, we used computer-generated messages to cue the play-acting. This also allowed us to ensure a perfect match of the message with respect to the constantly changing situation the dispatcher creates.

The radio communication: a crowded radio environment

As our goal was to see if the data-link environment would solve the congestion problem in the current radio environment by providing dispatchers with a more efficient and more productive communication tool, we had to simulate the congestion on the radio channel. Therefore we used three play-acting experimenters during the "radio" experiments. One was in charge of simulating the train engineers, the second one was in charge of simulating the MOW crew in the field and the third person was responsible to launch the party line talks such as the additional-tools request from some MOW crew for the mechanical department. There again we had a list of possible party line transmission scheduled, that the computer was cueing and that the experimenter was adapting to the dispatcher's actions. There again play-acting was the most flexible and realistic choice for generating the party line transmissions.

2.3.2.2 The data-link directed (DD) environment's design choices

In the next two sections, we will explain our main design choices for the two messaging systems starting with the data-link directed case. As most of the elements are similar, we will describe the common feature in the data-link directed case. The routing part of the simulator is identical to the routing interface in the radio environment given our research goals.

For memory, the data-link directed environment is a dispatching environment in which communication is realized using an email-like tool: a message console with a set of pre-programmed messages, to be sent to ONE and only ONE recipient. This message console is the only communication tool the dispatcher is allowed to use when taking the experiment. As mentioned previously, the features of the routing simulator stay the same as in the radio environment.

Our goal was to design a safe, more efficient and more productive communication tool without modifying too drastically the dispatcher's environment. The CTA helped us to understand the problems, dispatchers are facing with the radio. We saw a need for data-link communication very early on, it seemed to be the ideal solution to the increasing radio traffic. It would provide a safe complement to the radio. From then on, our goal was to analyze the impact of data-link on the dispatcher's work environment.

The communication: Data-link only during the experiment

Various reasons motivated our choice to ban the radio during the evaluation of the data-link environments. To summarize them, we could say that we want to ensure the accuracy and reliability of the data.

To show that data-link is a safe, efficient and productive tool, we first needed to have dispatchers use it exclusively. Radio is a very powerful communication tool. Along with the telephone, it revolutionized communications. It allows for easy interaction between users and introduces absolutely no delay between questions and answers. It is the closest to face to face conversation one can imagine. As soon one establishes communication, only interference can slow down the rate of information/data transmission. It is also a relatively public way to transmit information, since access is not restricted to the parties communicating. When tuning into the frequency, one is a receiver. All these reasons make it a very convenient tool, and dispatchers would certainly be tempted to use radio even when data-link might be another solution just because reflexes are difficult to change. Therefore, banning the use of the radio was a way to ensure collection of sufficient data points.

Another reason was to convince railroads that using data-link only, even if it seems totally unrealistic, is a viable solution in some rather complex cases. The could provide the warranty of its success as a part of the communication tools of the future.

Finally our goal was also to get some feedback on the quality/usability of the data-link concept and to ensure adequacy of our messaging system (selection of preprogrammed messages). As we will see in the next section, the experiment was designed so that using data-link only would not be too burdensome. Almost all events the dispatcher subject has to act upon could be handled with the messaging system we designed. Some are more difficult and tedious to handle than others with data-link only. These are some of the hypothesis we want to check. Had we allowed the use of the radio, the dispatcher would probably have used the radio for these cases. By forbidding it, we gave him the opportunity to make a judgment after having seen how burdensome or not they are.

The communication: the preprogrammed-messages design

As mentioned above, radio is a very efficient communication tool. Our challenge wasn't easy to complete. Two main attributes of the radio communication proved difficult to reproduce using text based data-link: the time efficient data transmission was the first one, the relatively public nature of the communication, usually called party line feature in the aviation world, was the second one. Both these attributes are lost if the messaging system is a simple text messaging system like the electronic mail system.

To keep these advantages, we used two rather unusual feature for a messaging system in the traffic control world. First, we decided to use a set of pre-programmed message so that dispatchers or other railroad agents would not have to type the message in each time it is needed. This is a feature we implemented in the data-link directed system. Second, we created a partially public system where the information would be transmitted to more than one person, and tried to restore the party line which has proved to be very useful according to the results of the CTA. This second feature we didn't use in the data-link directed system. As we will see later, this is the essential feature tested in the data-link broadcast system.

The pre-programmed set of message was the first feature we decided to test. During the CTA, dispatchers told us very early on that, had they an email system at their disposal, they wouldn't use it because of the tedious keyboard input. Keyboard input is time consuming in the time lost waiting to get the channel in the radio environment would be lost creating the message. Pre-programmed message would partly solve the problem in the sense that the message would be ready to send. This idea would combine the benefits of the text messaging system and the speed of the radio. The only problem is the quality of "speech" thereby created. Pre-programmed messages are very rigid entities even thought the system allows for each dispatcher to create his own set of pre-programmed messages. However in our experiment, dispatchers were given a message tree. The reason for our imposing a message tree was that we did not have time to give each dispatcher the opportunity of creating his own message tree ahead of time. Also, our message tree is relatively small as mentioned earlier. This is due to our focus on easy learning. A complete message tree as found in Appendix A, would be too large to get used to in half a day. Therefore we restricted the amount of message to the strict minimum. Finally, the structure of the message tree was tested on the members of our research group to try and design a tree in which "navigating" is natural. It turned out that the structure described earlier was the most natural and logical: priority, recipient, general subject and final message. Other combinations turned out to be confusing or more time consuming.

Then comes the question, why we did not implement our second feature, i.e. broadcasting of the messages. Taking a closer look at the use of the party line capacity embedded in the radio communication system, we discovered that it is the source of some of the congestion problems encountered by the dispatchers currently. Frequently, useless information is transmitted via the radio channel, increasing usage and user stress. In terms of data-link broadcast, the equivalent of useless transmissions, would be uninteresting messages, so called "junk mail" in the electronic mail world. Our purpose in not adding the broadcast feature to the system right away was to try and measure the importance of party line and the dispatcher's need for such information.

By testing the data-link directed case, we are trying to validate the concept of data-link with pre-programmed messages, checking the adequacy of the messages and their effect on dispatching activities. This concept is obviously a short-term system and is relatively cheap to implement. The more long-term system would be to use speech recognition. But currently speech recognition software does not meet the safety standards required for railroad traffic control.

The message creating: The various windows and their design

The message console design is fairly straightforward. The four screens were chosen to give the dispatcher an overview of the message he is receiving at the same time an overview of the messages he is sending out. The received message section takes up one half of the screen. The sent-out message section takes up the other half. This decision was based on the observation that dispatcher tend to use the sent-out section as often as the received message section. The sent out section allows users to check what was answered and what exactly was given away.

The separation into a "list of messages" window and only one full-text message window is the result of human factor concerns as well as programming restriction. Having a list is meant to give the dispatcher a quick overview of the messages he has to process. The one full-text message window gives him the full text message, i.e. the entire amount of information he needs. Due to programming restrictions, it was difficult to allow the dispatcher to display more than one full-text message window. From a human-factors point of view it would clutter the screen. We tried to eliminate the potential drawback of having only one message fully displayed at a time by using the line devoted to each message in the incoming message window to provide the dispatcher with as much useful information as possible. We had the possibility of displaying things as subject of the message, level of priority and the sender. Our final decision about the window display was based on four test runs, performed using member of our research group and on the advice of a dispatcher. The goal was to make sure that the attributes of this list provided the dispatcher subject with enough information to eliminate his need for having multiple full text messages at the same time. The result was that the only critical information to be displayed in the line devoted to each message was the sender of the message. Also the test showed that a large font was necessary.

The list of incoming messages showed the messages sorted by arrival time. This was done to facilitate the programming. In a real world design, this could be the dispatcher's choice. He would have the choice between arrival time, sender, and priority… as the sorting element.

The priority levels used for the various messages were the result of the task analysis. Given that we designed an experiment with a large amount of hazardous situations, the priority scheme might seem a little strange to the expert. The order of importance of the messages, however, has certainly been respected. The choice of having fixed priorities and to not allow the dispatcher to choose the priority he would attribute each message, is due to our assumption that dispatchers would not know the events they would face well enough to properly prioritize the messages.

Finally concerning the processing level of the various messages: question marks, stars and "Rs" was implemented to help the dispatcher have a better overview of his communication task when looking at his message list. Question marks indicate that the message has not been read, stars indicate that the dispatcher viewed the messages (and perhaps read it) and "Rs" indicate that a reply was sent. To check his reply, the dispatcher can select the message he sent out in the sent-out message window.

The message creating: the highlighting feature

The other main problem to recreate the quick understanding provided by the radio channel, was the speed of reading and understanding. It takes humans typically more time to read and understand a message than to listen to the same message, especially if the message is short. To counteract this drawback we made sure that the essential information is easy to catch. After a quick analysis, we isolated the essential information in the text of the message: location, sender and timing. The sender was easy to emphasize using the line in the message list. The location was somewhat of a problem given the usual naming scheme used. Names are long and are part of the usual input information. We will see later how we dealt with the input problem. The reading and understanding of these long names was made easy by marking the location mentioned in the messages on the track layout. To mark the location, we discussed several different possibilities. The two main possibilities were: highlighting the location using a new color (yellow for example) or indicating the location putting a new sign next to the location (a series of stylized characters for example). The first solution makes the location very easy to spot on the screen; the drawback is the disappearing of the red color indicating when the location is a train position. It is also a problem when unblocking a block. The highlighting doesn't disappear as long as the message in the full text message window has not changed. Therefore the subject might have problems making sure he unblocked the block. The second solution is less easy to spot but does not create the superimposition problem the highlighting does when indicating location on a blocked, hence blue, block. Here again, after running tests on the members of our lab, the highlighting feature was chosen and implemented.

The message creating: information input

To input information into the system, the dispatcher mainly uses messages. Other information-input actions are routing actions. They have been described earlier in the radio environment description and we will not explain our design choice again in this section.

When interviewing the dispatchers during our CTA, we were told that any typing would introduce unnecessary delays. Therefore we came up with a very flexible and easy way to complete the preprogrammed messages. To fill in the blanks in the messages (mainly prompting the dispatcher for locations, times and trains numbers) the dispatcher can use the keyboard to type but also, and this is probably the quickest way, the mouse.

As explained previously, he needs to double click on the information field and then he can click on the train number or on the desired block. The system then fills in the blanks with the appropriate information. This restricts the typing, when filling in most common messages, to the time field when it appears. The other feature we used to reduce the amount of typing is the reply button. When the dispatcher uses this button, some fields are filled in automatically in the message. Typically, there is no need to specify the recipient any more.

To counteract the obvious consequence of such easy messaging, loss of situation awareness, we did not implement the reply feature as completely as we could have. We could have extended the automatic filling of the fields to the location and time in the MOW granted message for example (see figure 2-13). This would have accelerated the communication. However, the assumption that more automation would result in less situation awareness has not been tested in this case but should be in future experiments.

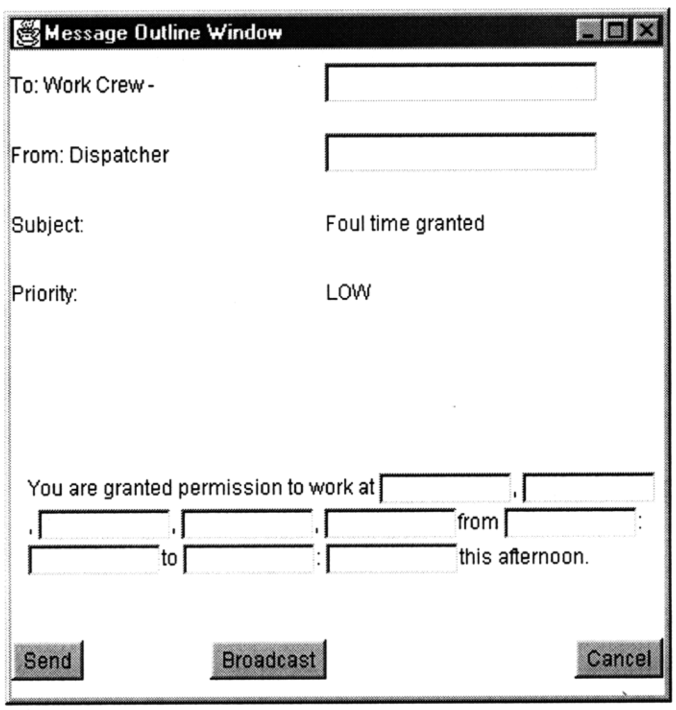

Figure 2-13: MOW request granted message – the blanks to fill in

2.3.2.3 The data-link broadcast (DB) environment's design choices

As mentioned above, the data-link broadcast environment adds the party line feature to the messaging system. Dispatchers, as well as all other member of the railroad, are obliged to broadcast their messages. The recipient is a pair consisting of a primary recipient and a group of secondary recipients. Hence the dispatcher can "overread" the broadcast messages sent to the groups he is a member of, just like overhearing conversations on the radio. It also allows him to send the same information to more than one person without having to create a new message. Once he sends the message to the right group, his only duty is to make sure every body acknowledges the message. This is far less difficult than to keep track of all the people he did not send the message to. The broadcast feature is expected to reduce the number of messages sent out by the dispatcher, as well as his overall stress. On the other hand it is also expected to drastically increase the number of received messages, and more generally the number of messages the system would handle.

One purpose in designing this environment was to see if the dispatcher needs the party line information or if it is more an annoyance. As for data-link directed, data-link broadcast was expected to improve safety by increasing the probability of reception over the radio case. Data-link is less congested and does not require physical presence and immediate availability of the recipient. However it does require acknowledgment of the recipient for liability reasons!

2.4 Scenario description

In the following section we describe the design of the scenarios in detail. We start with the train schedule, then describe the hazard schedule and finally the MOW schedule design. We designed two scenarios for experimental design purposes. The following comments apply to both scenarios. Each experimental run lasts one hour and is supposed to start at the beginning of a new shift.

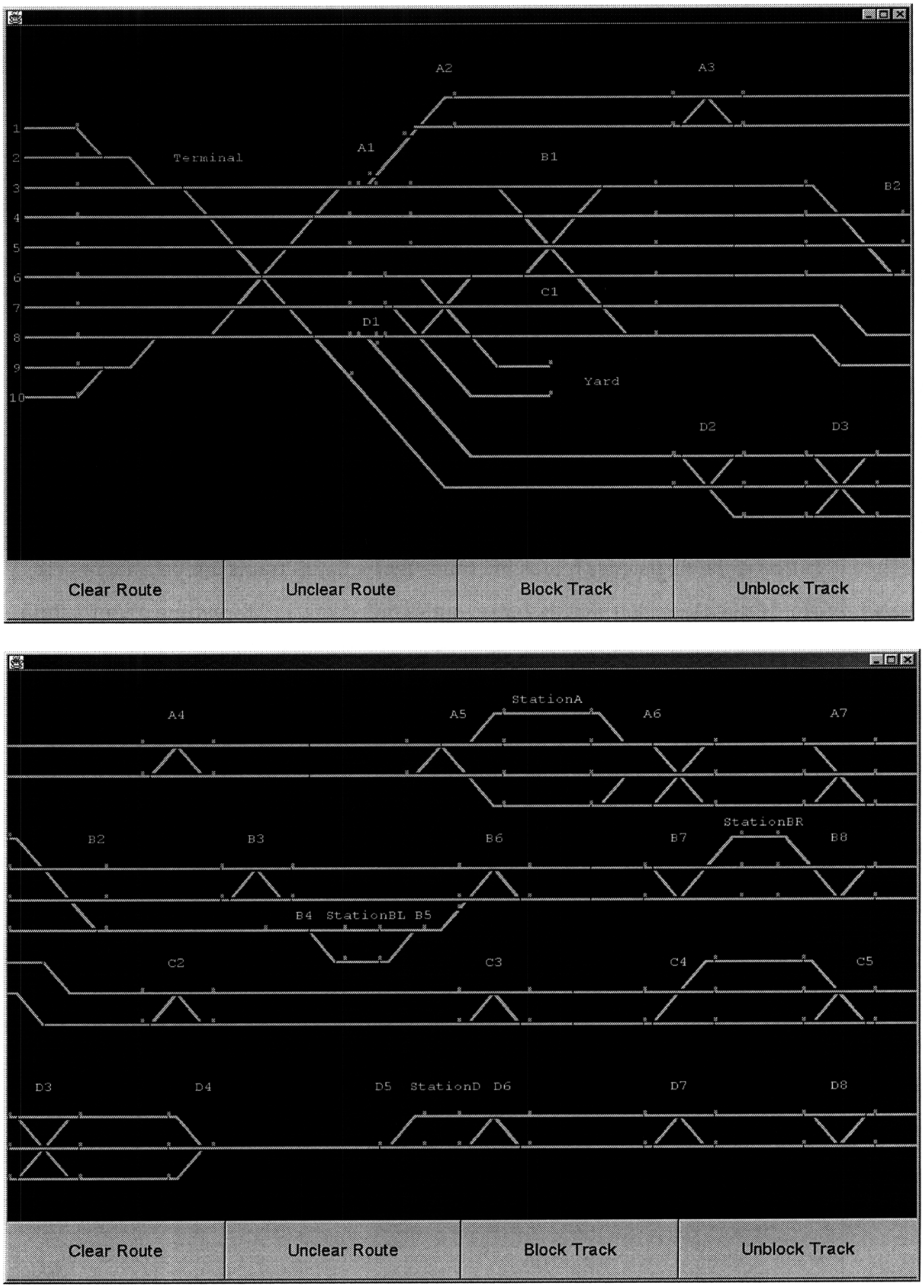

Figure 2-14: Track layout

Figure 2-14 represents the track layout, i.e. the dispatching territory. One can easily notice the four branches A, B, C and D, the Terminal station, which is an in/out station and the Stations A, BL, BR and D which are drive-through stations. Finally, we also have an opening bridge between interlocking D7 and D8. The bridge is not marked on the screen.

2.4.1 The train schedule

As mentioned earlier, we decided to use a substantial number of trains during the experiment compared to the usual number of trains dispatchers would encounter during a typical hour in an eight-hour shift. Reasons for this choice include our desire to get significant changes in measurements when treatments change. All trains have a predefined schedule (programmed in the simulation). The schedule and the territory are designed so that if the dispatcher routes the trains perfectly all trains are on time or slightly early. If the dispatcher makes some routing mistakes, i.e. forgetting about a train for five or ten minutes, the affected train is not be able to make up for his delay for programming reasons. However, small routing mistakes (of the order of one or two minutes) do not appear in the data records. This was done to roughly simulate the fact that engineers sometimes will try to make up for their delays. During the experiment dispatchers had a copy of the schedule readily available.

When the experiment starts, the dispatcher supposedly takes over a shift from somebody else. Supposedly, the previous dispatcher was somewhat lazy and only cleared a very small number of routes. The trains outside of the stations are moving when the simulation begins. They are all on time and have sufficient track to be moving at full speed for the first three minutes of the simulation without any action from the dispatcher. As we will see later, dispatchers were somewhat familiar with the schedule after the preparation sessions. The following is a part of the schedule the dispatchers used.

Br.	Dir.	Train #	Ptf.	Terminal		Interlocking		Interlocking
BRANCH A	IN		1	1:26 PM	A1	1:23 PM	A2	1:21 PM
			2	1:46 PM	A1	1:43 PM	A2	1:41 PM
			3	2:17 PM	A1	2:14 PM	A2	2:12 PM
	OUT	111	1	12:39 PM	A1	12:42 PM	A2	12:44 PM
		113	3	12:58 PM	A1	1:01 PM	A2	1:03 PM
		115	2	1:27 PM	A1	1:30 PM	A2	1:32 PM
		117	3	1:34 PM	A1	1:37 PM	A2	1:39 PM
BRANCH B	IN		6	1:42 PM	B1	1:38 PM	B2	1:32 PM
			4	2:20 PM	B1	2:16 PM	B2	2:10 PM
	OUT	221	3	12:50 PM	B1	12:54 PM	B2	1:00 PM
		223	6	1:06 PM	B1	1:10 PM	B2	1:16 PM
		225	5	1:27 PM	B1	1:31 PM	B2	1:37 PM

Figure 2-15 Partial train schedule

The entire train schedule can be found in Appendix B

2.4.2 The hazard schedule

To be able to evaluate safety in a reasonably realistic way, we had to include hazardous situations during the experiment. Therefore each scenario comprises five scheduled hazardous situations. For each hazardous situation we expect the dispatcher to take appropriate action.

The first type of hazard is the presence of trespassers on the track. Two or three times during each experiment trespassers were present on the track for a certain period of time. If during that period of time, a train passed through that area, the train engineer saw the trespassers and the dispatcher was be alerted. The dispatcher was then responsible for transmitting the information, exactly the same way he would do it in the real world. The dispatcher was expected to transmit the alert to all trains that would travel through that area. Unlike in the real world, he was not required to notify the appropriate police force. If during the period of time when the trespasser was present on the track no train passed, there was no hazard or one should say there was no knowledge of the hazard.

The second type of hazard was the presence of kids stoning the train. This was scheduled to happen twice during each experiment. In the same manner, if trains were routed into the hazardous area at the "right" time, the dispatcher was alerted and had to transmit the information.

To ensure that we had enough data, we scheduled these two hazard to take place in an area with a lot of traffic. We also chose the hazard occurrence time (gray areas in figure 2-16) so that delays of the order of five to ten minutes would not prevent us from gathering enough data. The territory was busy enough and the hazard schedule designed to account for variations in routing.

Figure 2-16 is a piece of the hazard schedule. The gray area indicates the presence of a trespasser in a specific area of the track. The numbers are the numbers of the train that would pass through this area if trains ran on schedule during the experiment. The first number in the gray area is the number of the alerter train; the other numbers is the numbers of the trains the dispatcher had to alert.

	Tresp.		Kids		Bridge	Message
1:06 PM						
1:07 PM	100					#1
1:08 PM						
1:09 PM						
1:10 PM					Disp	#2
1:11 PM			300			
1:12 PM						
1:13 PM	113					
1:14 PM				443		#3
1:15 PM						
1:16 PM		223	331			#4
1:17 PM						
1:18 PM						
1:19 PM						
1:20 PM						
1:21 PM				400		#5
1:22 PM						
1:23 PM						
1:24 PM						
1:25 PM						
1:26 PM						
1:27 PM	102	200				#6, #7
1:28 PM						
1:29 PM						

Figure 2-16: Partial hazard schedule

For details on the hazard-presence times and on the expected "alerter trains" see Appendix B.

2.4.3 The MOW schedule

Finally, a dispatching experiment would not be complete without maintenance of way (MOW) activity. Therefore we planned some MOW activity to take place during the experiment. Here again to have enough data points and to create a workload level that would ensure readable measurements, we exaggerated the number of MOW requests a normal dispatcher would face during a shift with as many trains as we have in our simulation. After testing on a preliminary test dispatcher, we settled for 12 MOW requests for each experiment. These 12 requests include 2 bridge lifting requests and 2 management-scheduled track outages, which in the radio environment require a special track use authority form called "form D". The eight other MOW requests were not scheduled. Finally, at the beginning of each experiment, the dispatcher also took over the protection of two MOW crews that were granted permission by the previous dispatcher on the territory.

There was two types of unscheduled MOW requests. The first type work was the signal work. Signal workers requested protection for work on the signals usually near or at some interlocking. The second type of work was track work. Track work can be requested and performed either by track cars (special trucks riding on the track and checking its state) or by repair crews. The dispatcher had to answer the foul time request exactly as he would do in the real world. In the data-link case we had two different answer messages, one for each type of MOW. Dispatchers were expected to use one reply message or other depending on the type of request. In the radio case dispatchers were not supposed to use the "form D" procedure for any other MOW request than the scheduled track outages. Unscheduled signal work and track work was to be granted only foul time, following the rules mentioned above.

MOW requests were scheduled in order to create interesting "meet and passes" problems for the dispatcher. At least one MOW request could not be granted if trains were on time. The purpose of our experiment was not to analyze the routing decision of the dispatcher or the way he deals with his windows of opportunities. However, we wanted to evaluate if such an experiment would be feasible with the current simulator and its recording features. The entire MOW schedule for both experiments is to be found in Appendix B.

2.5 Experimental design

Remember that our goal was to benchmark data-link communication environments against the current radio communication environment. The focus was on the consequences of the shift from radio to data-link, including direct effects such as an decrease in communication time or radio congestion but also "side effects" such as the possible loss of party line or the changes in the attention allocation pattern.

2.5.1 The independent variables

2.5.1.1 The type of environment

The type of environment was the only independent variable. We had three levels for this one variable. The first level was the radio environment, the second level was the data-link directed (DD) environment and the third level was the data-link broadcast (DB) environment. All three environments were described in detail in the previous sections. As a reminder here are the main features:

- The radio environment: the routing task is simulated by our dispatching simulator using two screens to display an imaginary territory. Communication is performed over the radio. Three experimenters are play-acting all other entities on the railroad aided by computer generated cues. They are also monitoring the experiment. This environment is intended to be the reference point and was designed to be as close as possible to the current dispatching environment.
- The data-link directed environment: here again the routing task takes place on two screens. However, the communication means changes. The dispatcher can use only the message console to communicate with the various entities on the railroad. He can chose messages from a set of preprogrammed-messages and specify one and only one recipient. Therefore the dispatcher receives only the messages intended for him. In the data analysis this environment will be referred to as "DD".

- The data-link directed environment: the environment is almost exactly similar to the data-link directed case. The only difference is the ability of the dispatcher to specify one primary recipient of the message and a to chose a group of secondary recipients. In this case the dispatcher receives all the messages for which he is part of the secondary recipient group. For the data analysis this environment will be referred to as "DB".

2.5.1.2 The scenario and the dispatchers

The two other changing elements in the experimental design, the dispatcher and the scenario are not considered independent variables. This assumption can obviously be debated.

2.5.2 The dependant variables

The dependent variables (i.e. measured variables) can be classified into three groups:

- Safety measurements
- Efficiency measurements of the communication system
- Productivity measurements.

We will describe the measurements more thoroughly in the next paragraphs. Finally, we used a debriefing questionnaire to gather additional information from the dispatchers. This questionnaire uses so-called open questions in an attempt to seize the dispatcher's opinion about data-link environments.

2.5.2.1 Safety of operations – three measurements tools

The first tool was a set of hazardous situations to occur in each scenario. As described earlier in the "hazard schedule" section, the dispatcher was expected to properly transmit the appropriate warning messages to the appropriate trains. For example, if train #120, riding on branch A, reported the presence of trespassers on the track between interlocking A3 and A4, the dispatcher was expected to check which trains were supposed to ride on branch A. Then he should have warned them of the possible presence of trespassers on the track. For each hazard reported there was a fixed number of trains, which were supposed to receive an alert messages. For each train alerted, the dispatcher earned one point. The dispatcher's score, i.e. number of omissions, gave us an indication of the level of safety during the experiment. The timing at which the events were reported would vary slightly depending on the routing performances of each dispatcher. However, the number of trains to be alerted was expected to remain the same, expect if the routing performances were disastrous. According to the hazard schedule in Appendix B, this number should be around 14 or 15 depending on the scenario. We naturally adjusted the maximum obtainable score if necessary and then converted all scores into percentages.

The second safety measurement tool was the number of MOW crew protected properly when granted foul time or given a form D to work. Each MOW crew was asking for very specific pieces of track. We recorded, for each dispatcher, the pieces of track given away and the pieces of track asked for. For each case in which MOW people were protected, the dispatcher obtained one point. Obviously, the number of points would vary with each dispatcher. Therefore we used a percentage measurement again, dividing the number of properly protected MOW crews by the number of MOW requests granted for each dispatcher. This number gave us an indication of MOW safety during the experiment.

The third tool to measure safety was a questionnaire intended to evaluate situation awareness during the experiment. We stopped the experiment half way through and completed the questionnaire with the dispatcher. The questionnaire consisted of 15 questions (16 in the radio and DB environments) divided into four groups: routing related questions, hazard-related questions, MOW related questions and communication related questions. The hazard and MOW related questions were intended to give us a vague indication on the general level of safety during operations. For each question answered properly dispatchers got a "grade". In this case the answers were much more dependent on each individual dispatcher. A dispatcher got one point for each question answered properly given the state of his personal experimental run. If the answer was partially right, he got only partial credit. Here again, we did not expect dispatchers to answer all the questions correctly. Errors represent useful information.

However, this third tool was not intended to be the main tool to evaluate the safety. The primary goal of the questionnaire was to evaluate the situation awareness and to find the "attention allocation pattern" as a function of the independent variable (the type of environment). We did not expect to get very reliable information but a general feeling for the changes in attention allocation, if one of the data-link environments was to be implemented. For details about the questionnaire see Appendix C.

2.5.2.2 Communication efficiency

The communication efficiency attained in each environment was measured by recording a set of three time spans: the caller waiting time (later simply called waiting time), the time the dispatcher needs to before starting to "communicate" the final answer (also called processing time), the time he needs to get his answer to the recipient (answering time). We recorded the total communication time (also called cycle time) from the first call of a person in the field to the last piece of information reaching that person. These times were calculated slightly differently in the each environment.

The following were the five times involved in the in the analysis of the data-link environments:

- DT1: Time of reception of the message, i.e. display on the message console
- DT2: Time at which the dispatcher notices the message on his message console
- DT3: Time at which the composition of the answer is started
- DT4: Time at which the answer message is send out
- DT5: Time at which the message is forwarded to its final destination by the experimenter

The waiting time is DT2- DT1. The processing time is DT2-DT3. The answering time is DT4-DT3. And finally the cycle time is DT5-DT1. One might wonder why we took DT5 and not DT4. One of the reasons we added to the cycle time the delay introduced by the experimenter when forwarding the message to his final destination, is that we never really account for the fact that in the data-link case, there are some network transmission delays. Another reasons for introducing this relatively random delay was, that we do not account for the fact the recipient might not be reading the message right away either (an "absence" delay if you will).

These are the four times involved in the analysis of the radio environment:

- RT1: Time at which the experimenter desires to start transmission
- RT2: Time at which the dispatcher acknowledges he has been called (second step in the transmission protocol described earlier)
- RT3: Time at which he start to answer on the subject of the communication
- RT4: Time at which he terminates the communication

The waiting time is RT2-RT1. The processing time is RT3-RT2. The answering time is RT4-RT3. And finally, the cycle time is RT4-RT1. In this case there is no network transmission delay and no "absence delay" to be added. Both are included in the answering time.

The comparison took place as follows.

	Radio	Data-link (DD or DB)
Waiting time	Caller waiting time	Time of "not yet read message"
Processing time	Thinking about the problem time	Reading message and "thinking" time
Answering time	Total answer-transmission time	Total Composition time
Cycle time	Total communication time	Total communication time (usually 2,3 or 4 messages)

2.5.2.3 Productivity of operations

Finally we evaluated productivity during the experiment. We evaluated the "on time" performances during the experiments and the MOW activity. Both evaluations were primitive. The "on time" performance was easy to evaluate as we had a fixed number of trains for each scenario. The number of trains entering a station was known ahead of time for all dispatchers. We recorded the delays when entering the stations and counted the number of trains for which the delays were more than five minutes. This appeared to be the limit after which dispatchers had to give an explanation to management for delays. As mentioned earlier trains could not catch up delays but the schedule allows for small delays to be unnoticed. The MOW activity was a very easily measurable as well. We recorded the number of MOW requests granted. Both numbers, late trains and MOW granted, constituted the core of our evaluation of productivity.

2.5.3 The testing scheme

Before the experiment we tested our simulator as well as the workload of our scenario in a preliminary experiment with a dispatcher. After this first experiment and a few changes to the scenarios to modify the workload, we started the final experiment campaign.

The experimental design for the experiment campaign reads as follows. For time reasons and financial reasons, we used a balanced incomplete block design (BIBD) [Lindman, 1992]. As stated previously we have 6 dispatchers (Disp.), three environments (Radio, DD and DB) and two scenarios.

	1. Radio	2. DD	3. DB
Disp. #1	Scenario 1	Scenario 2	
Disp. #2	Scenario 2	Scenario 1	
Disp. #3	Scenario 1		Scenario 2
Disp. #4	Scenario 2		Scenario 1
Disp. #5		Scenario 1	Scenario 2
Disp. #6		Scenario 2	Scenario 1

2.6 Participants

The participants were professional dispatchers kindly provided by Steve A. Jones, Asst. Transportation Superintendent at Amtrak for the Boston Division – Northeastern Corridor. He provided one dispatcher for the preliminary testing of the simulator and experiment design as well as the six dispatchers for the final experiment campaign.

Six Amtrak dispatchers from the Boston Division – Northeastern Corridor participated in the final experiments: one woman and five men. Three had 7 to 9 years dispatching experience, the three others had less than 2 years experience. Concerning the type of territory dispatchers were working on, we had all types: busy in terms of train routing, busy in terms of MOW activity, morning shifts and evening shifts. All of them had previous computer experience and were working an electrified territory.

2.7 Procedures

Each dispatcher was present in the laboratory for six to eight hours. As the experimental design shows, each dispatcher took the experiment twice, each time with a different communication environment (we had the independent variable change). Before each experiment, dispatchers were trained on the new interface they would use. During the experiment, we recorded our data and after the experiment we had a short debriefing session. All three steps will be briefly described in the next sections.

2.7.1 Before the experiment

As dispatchers were facing a new system, we designed a short training program to get them used to the various environments they would have to adapt to. The training consisted of two phases. The first phase was to introduce the dispatcher to our system. The second phase was to train the dispatcher on the schedule he would be working with, during both experiments.

For both types of environment (radio and data-link) the first phase was necessary. For the radio environment it was necessary because the routing simulator is slightly different from the system used at the South Station Dispatching Center in Boston, where all dispatchers came from. Some of the features like the individual section blocking was new to the dispatchers (see interface description for details). Also, the radio communication protocol was somewhat different. For the data-link environments, training was necessary to introduce the dispatcher to the new communication tool he would use and to allow the dispatcher to gain familiarity with the message tree and with the behavior rules (when to alert a train and how to alert him).

During this first phase, we first explained the routing procedures as described in the section on the simulator interface with the help of a brief explanatory document (see Appendix D). Initially, we also had the dispatcher only route trains, on a so-called training scenario designed only for this purpose (with eight trains, four inbound trains and four outbound trains, and a yard move). Then we walked the dispatcher through the data-link system (message-tree, individual messages, procedures to fill in the blanks and expected behavior) and had him use the training scenario adding to the routing task, some "communication actions" using the data-link system. During this phase, one experimenter was permanently with the dispatcher at his desk, monitoring the dispatcher and answering questions about the system and how to interact with it. Dispatchers were given the structure of the message tree in written form (see Appendix A).

During the second phase, we prepared the dispatcher more specifically for his experiment. As we were not interested in the routing activity as such, we had no reason to hide the routing task, i.e. the schedule from the dispatcher. In our experiment, routing was supposed to be a background task, something that usually does not challenge them. Therefore we trained each dispatcher on the schedule he would face during the experiment. Before each experiment, dispatchers were given up to an hour to familiarize themselves with the schedule; running the experiment with trains only on the routing part of the simulator. This second phase was repeated before each experimental run as the scenario changed each time.

Finally, just before the experiment we repeated all the reaction rules we expected and checked the communication protocols (transmission rules for the radio environment but also messaging handling for the data-link cases).

The training was not expected to affect the results in any particular manner. We tried to make it as similar as possible for all dispatchers. All dispatchers started with the data-link experiment, so that the data-link results might suffer slightly due to the lack of familiarity with the routing interface. The documents provided to the dispatchers in addition to the schedule for each scenario can be found in Appendix D.

2.7.2 Two experiments, one hour each

Each experiment lasted one hour and was interrupted once after 30 minutes to complete the situation awareness questionnaire. During the entire hour of the experiment, the dispatcher was on his own in the dispatching room. He had the schedule, any notes he prepared during the training, the structure of the message tree and the form D's available. Dispatchers were expected to perform their usual dispatching task given the constraints imposed on them by the new environments.

2.7.3 After the experiment

To better catch the impressions of the dispatchers about the new systems they had tested, each experiment was followed by a brief debriefing questionnaire. We asked dispatchers to evaluate the workload level, the level of comfort they experienced with the system and the usefulness they saw for such tools. To evaluate this we used a scale from 1 to 7 (7 being the best "grade"). We also gathered some more detailed comments about the environment dispatchers just tested. This was done using a set of three open questions. All three questionnaires for all three environments can be found in Appendix C.

Finally, we concluded the day with a last questionnaire. There, we used only open questions (except one question where we ask dispatchers to rank the environments they had experienced from the best to the worst). Dispatchers were free to criticize, comment or compliment the environments they had tested. Here, again the entire questionnaire can be found in Appendix C. Some questions have been asked in the "after experiment" debriefing questionnaire and repeated in the "end of the day" questionnaire. The goal was to catch possible changes in opinion after having tested both environments.

3 Results and discussion

3.1 Methods used to analyze the data

3.1.1 The raw data treatment

3.1.1.1 The communication efficiency data

The dependent variables for the communication efficiency evaluation were obviously not obtained directly. Our main tool was the raw data generated by the simulator after each experiment. In the data-link case, the raw data consisted primarily of a very high number of actions and their associated times. From these times we were able to extract the dependent variables. In the radio case, the raw data consisted of the videotapes of the experiment for the communication part and of the record files from the computer for the routing and blocking actions. Watching the experiment afterwards allowed us to generate the communication times (RT1, RT2, RT3 and RT4) the computer generated for us in the data-link case.

Once we had extracted the basic information from the raw data, we generated for each experiment a table summarizing the experiment. For each scenario, a communication schedule combining the hazard schedule and the MOW request mentioned the time at which a communication was expected to take place and the subject of that communication. The summary tables where created from this communication schedule where we added the various times of interest (RTs or DTs). Using these tables we calculated the four times of interest for the communication efficiency evaluation: waiting time, processing time, answering time and cycle time (see section so and so). The summary tables can be found in Appendix E.

3.1.1.2 The productivity data

In order to obtain basic information on productivity (i.e. trains delays and MOW requests handling), we used the delay records generated by the simulator (based on the schedule programmed into the simulator for each scenario). For the MOW requests and their treatment, we also used the summary tables, as they mention the type of action performed during or after each communication. The productivity "basic information" tables can be found in Appendix E.

3.1.1.3 The safety data

In order to obtain basic information on train safety we used the summary tables again. For each hazard-related communication we checked if all concerned trains were alerted. For each MOW request granted we checked if the sections of track given away were blocked properly using the computer records. Finally in order to "grade" the situation awareness questionnaire, we used the summary table to recreate the state of the territory at the time at which we interrupted the experiment for each dispatcher. We also used the computer records for some questions such as the most delayed train and the estimate of its delay.

We summarized the answers to the closed-questions of the post experiment questionnaires in a table to be found in Appendix C. Answers to the open questions and the comments gathered are discussed below.

3.1.2 The statistical analysis

The summary tables and the record files gave us the basic information from which we could produce the statistical data and the independent variables. Most of our results are means (for efficiency communication) or means of percentages (for safety, productivity and attention allocation). The tables used to discuss the results will show the independent variable (mean or percentage) for each dispatcher, the mean of the independent variable for each environment calculated using the total data gathered in each environment, not the means of each dispatcher, as we are ignoring differences between dispatchers. To evaluate means, we need a confidence interval. The following is the method used [Veysseyre, 1995]. We are assuming that the distribution of means is a Normal distribution.

Given that we do not know the exact value of the standard deviation, we have to use the unbiased estimator of the variance:

$$S^{*2} = \frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2$$

where $\overline{X}$ is the mean of the data points. Then,

$$T(n-1)=\frac{\overline{X}-m}{S^{*}/\sqrt{n}}$$

is a Student distribution with $\nu=n-1$ degrees of freedom, where n is the number of data points and m is the mean of the distribution of the means (assumed to be Normal).

Given a value α, one can find the values $t_{\frac{\alpha}{2}}(n-1)$ so that,

$$P\left(-t_{\frac{\alpha}{2}}(n-1)<T(n-1)<t_{\frac{\alpha}{2}}(n-1)\right)=1-\alpha$$

Hence,

$$P\left(\overline{X}-\frac{S^{*}}{\sqrt{n}}\cdot t_{\frac{\alpha}{2}}(n-1)<m<\overline{X}+\frac{S^{*}}{\sqrt{n}}\cdot t_{\frac{\alpha}{2}}(n-1)\right)=1-\alpha$$

Which gives us a confidence interval for our calculated means. When possible result tables include the confidence term $Conf.=\frac{S^{*}}{\sqrt{n}}\cdot t_{\frac{\alpha}{2}}(n-1)$, the upper limit of the interval and the lower limit of the interval.

For most cases, we have 80 to 100 data points per environment, depending on the independent variable. Waiting time means were calculated using on average 90 data points. For cycle time means, we only had 70 points because some were not answered, or did not need to be answered. We applied the method described above only to the mean for each environment, as the evaluation of the environment was the ultimate goal of the experiment and not the evaluation of each dispatcher's performances.

A conservative choice led us to, $\nu=n-1=80-1\approx 80$ in our case. We chose $\alpha=0.95$. Statistical tables give $t_{\frac{\alpha}{2}}(n-1)\approx 2.0$ for a 95% confidence interval as soon as $n>27$.

3.2 The results

3.2.1 Clear safety improvements

3.2.1.1 Train Safety

In real dispatching operations trains are to be alerted whenever a hazard (trespassers on track or kids stoning the train) is reported by a railroad entity. When notified of a hazard, dispatchers alert concerned trains so that they can reduce speed and watch out when they enter the hazardous area. If a train is not alerted, there is danger and the dispatcher created an unsafe situation. Similarly in our simulation, hazards, mainly reported by trains are to be "forwarded" to other trains. We evaluated train safety by calculating the ratio of the number of alerted trains by the number of trains to be alerted to ensure safety. The percentages in the Train Safety Table (Table 3.1) represent these ratios for each dispatcher (per experimental run). A more detailed table (response per hazard) can be found in Appendix E.

Looking at the means of Table 3.1 one can notice that data-link broadcast is clearly the safest environment. The difference between the radio case and the broadcast case does not seem to be statistically significant as the confidence intervals largely overlap. The outstanding result of the data-link broadcast case is due to its design. In the radio and in the DD case, the dispatcher has to alert each individual train. He calls each train one by one. If he is busy, when the hazard is notified to him, he might decide not to call up trains that are far from the hazardous area right away. It was observed that dispatchers tend to forget the hazardous condition after a certain period of time. In addition to the memory issue, our workload level might have aggravated the situation. In the data-link broadcast dispatchers are free to broadcast the alerting message to all trains on one branch or even to all trains on their territory, hence alerting all train susceptible to enter the hazardous area using only one message. The drawback of that environment is that forgetting one alert message might endanger multiple trains. Dispatcher #4 is a good example. His 20% of trains not alerted is due to one message he did not send.

The other issue raised by these results is about the behavior of the engineer. In our experiment, we assumed we had perfect engineers, i.e. as soon as the dispatcher sends the message, the engineer receives and acknowledges it. This is a very strong assumption and the results might be slightly less impressive if the system were tested with a professional engineer, who sometimes forgets to acknowledge the message.

Train Safety	Radio	DD	DB
Disp #1	0.20	0.57	
Disp #2	0.36	0.40	
Disp #3	0.40		0.93
Disp #4	0.36		0.80
Disp #5		0.53	1.00
Disp #6		0.29	1.00
Mean - Environ.	**0.33**	**0.45**	**0.93**
Conf.	0.14	0.21	0.15
Mean - Max.	0.47	0.66	1.08
Mean - Min.	0.19	0.24	0.78

Table 3-1: Train Safety

3.2.1.2 MOW Safety

Dispatchers normally control the entire track network. However, if repair work is necessary on the track or near the track, dispatchers usually loose control of that section of the track. MOW people are then in control of the track. To make sure he does not use the section of track under repair (for trains for example) and to protect the MOW crew while working, the dispatcher blocks that section. He sets the signals at both ends of the section he gave away to red. Hence no train can enter and MOW people are safe. However, sometimes there is some confusion about the exact section of track the MOW crew requests. The dispatcher might end up blocking more sections of track than necessary or not enough. In the latter case, MOW crew safety is not ensured.

During each experiment, we kept track of the number of MOW crews protected properly. Whenever dispatchers blocked at least the amount of track requested, MOW crews were assumed to be safe. As soon as one requested section of track was not blocked, MOW crews were assumed unsafe. In the radio environment, 24 MOW crews were protected properly out of 37 granted, in the data-link directed case, 29 out of 31 granted and in the data-link broadcast case 25 out of 26.

Table 3-2 shows the results in percentages for each experiment as well as the mean for each environment. We also calculate the confidence interval using the method described above (with $n = 4$, $\nu = 3$ and $\alpha = 0.95$).

	Radio	DD	DB
Disp #1	0.56	1.00	
Disp #2	0.63	0.88	
Disp #3	0.73		0.89
Disp #4	0.67		1.00
Disp #5		0.89	1.00
Disp #6		1.00	1.00
Mean	**0.64**	**0.94**	**0.97**
Conf.	0.11	0.11	0.09
Mean - Max.	0.76	1.00	1.00
Mean - Min.	0.53	0.83	0.88

Table 3-2: MOW Safety

Table 3-2 clearly shows the superiority of both data-link system over the radio communication environment. The confidence intervals for the mean do not overlap. Here again, the specifics of the data-link environment create the advantage. In the radio case, we observed that the description of the individual sections of tracks to be blocked by the dispatcher is a long, tedious and rather uncertain process. The dispatcher has to translate the names and descriptions provided by the MOW person to his references (the track layout display). This process is source of multiple mistakes. In the data-link cases, this process is avoided. The MOW person selects on her “passive” track layout, the sections of track she needs and sends this information to the dispatcher. The dispatcher read the message and sees the section highlighted in yellow on his track layout. There is very little room for error as both, MOW person and dispatcher, use the same reference. The mistakes in the data-link cases came almost always from a particularity of our program. When the dispatcher blocks track, he uses the track displayed in yellow (MOW request) as the reference. And, for programming reasons, he does not know if he blocked the track properly (track turning blue) as long as he is not viewing another message than the previous MOW request. If he is busy or not careful enough, he might not check his action. The idea of having a common graphic communication tool on each side would drastically improve safety.

However, our assumption on having a nearly perfect MOW person, has to be underlined. In real dispatching operations, a data-link system would not be implemented with the kind of restriction we have, but human error has to be accounted for and MOW people make errors. If the dispatcher as a result of data-link blocks the track properly, MOW might not always double check their track selection and start to work on a track they did not ask for. The errors introduced by our specific program could be viewed as some "simulation" of human imperfection.

3.2.2 Interesting communication efficiency improvements

3.2.2.1 Communication efficiency at first sight

In this paragraph, we will present the results of our communication efficiency evaluation. Using the summary table described earlier, we calculated the average waiting time, processing time, answering time and cycle time, for each experiment. We also calculated the overall means for each environment and the 95% confidence interval on these means. Finally, we used histograms (for all four communication-times) combining the data into one set for each environment. We grouped the result into categories using the Sturges formula, which gives the ideal number of categories:

$$k \cong 1 + 3.222 \cdot Log_{10}(n)$$

where n is the number of data points. In our case,

$$k \cong 1 + 3.222 \cdot Log_{10}(n) = 1 + 3.222 \cdot Log_{10}(110) = 7.53 \approx 8$$

as our largest number of data points is $n = 112$.

Given the large variation of the maximum times across environments, we decided to increase the number of categories to $k = 9$, to be able to plot all three environments on the same graph. We also normalized the amount of the data in order to have percentages and to ease comparison; we considered 100 data points of each type (waiting time, processing time, answering time and cycle time) for each environment.

We will present the result in the following order:

- Waiting time
- Processing time
- Answering time
- Cycle time

For each type of data, the order will be the same:

- Means per experiment
- Overall means and confidence interval
- Repartition over time of the messages

We will always compare the three environments.

Waiting time

waiting time	Radio	DD	DB	Mean - Disp.
Disp #1	32.00	85.78		58.89
Disp #2	103.42	45.32		74.37
Disp #3	38.87		24.48	31.68
Disp #4	82.00		136.64	109.32
Disp #5		28.28	33.35	30.81
Disp #6		148.50	53.72	101.11
Mean - Envir.	**64.07**	**76.97**	**62.05**	**67.70**

Table 3-3: Average waiting time for each experiment (in sec.)

Table 3-3, the average waiting time for each experiment table, is obtained by calculating the average of the time difference T2- T1, where T2 is the time at which the dispatcher acknowledges (i.e. answers or reads) the message and T1 is the time at which it was received. This table shows that there seems to be no significant difference between the radio environment and the data-link environment. The means per environment are fairly similar and the results per experiment confirm that there seems to be no particular improvement or degradation when changing from radio to data-link. This observation is not surprising at all given that data-link does not introduce any novelty in the dispatcher's method of checking his communications. Due to our design data-link could even have proven less efficient in term of waiting time because our data-link systems rely solely on the dispatcher's monitoring scheme. For programming reasons we could not implement an audio alarm, signaling the arrival of a message. The radio environment clearly has a clear advantage.

waiting time	Radio	DD	DB
Mean - Environ.	62.68	78.24	59.46
Conf.	23.34	20.93	16.60
Mean - Max.	86.02	99.17	76.06
Mean - Min.	39.34	57.31	42.86

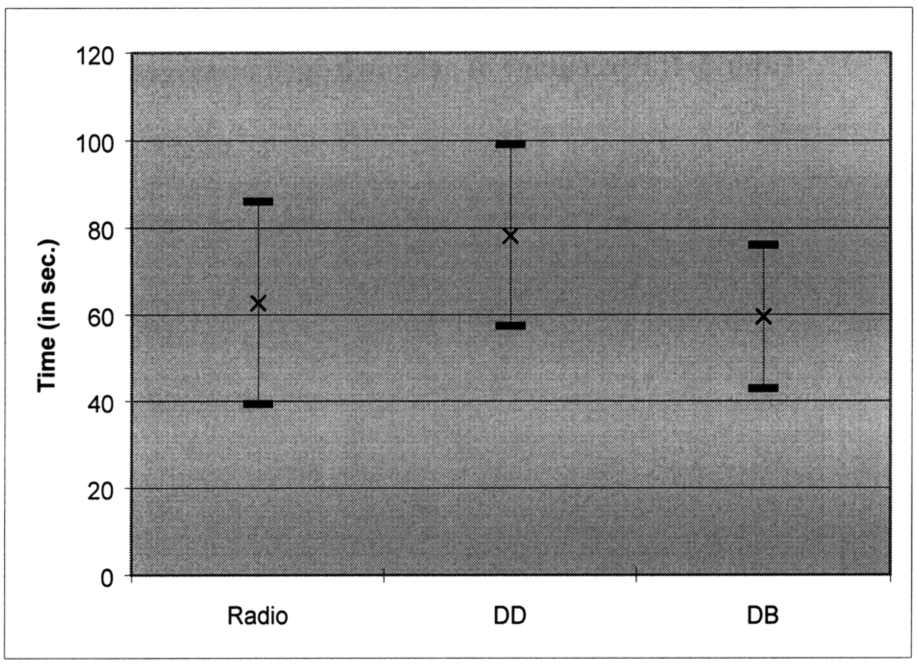

Figure 3-1: Waiting time average for each environment (in sec.)

Figure 3-1, shows the waiting time average (calculated combining per environment the data of each dispatcher) and the 95% confidence interval of the mean (with $n = 111$, $\nu = 110$ and $\alpha = 0.95$). Remember, the limits of the confidence interval are $m - Conf. = m - \frac{S^*}{\sqrt{n}} \cdot t_{\frac{\alpha}{2}}(n-1)$ and $m + Conf. = m + \frac{S^*}{\sqrt{n}} \cdot t_{\frac{\alpha}{2}}(n-1)$. The large and overlapping confidence interval support our previous observation: in terms of waiting time there was no expected difference and there is no difference observed between environments.

Time (in sec.)	wait. time (radio)	wait. time (DD)	wait. time (DB)
0 to 50	73	59	65
51 to 100	12	18	18
101 to 150	5	6	6
151 to 200	3	8	3
201 to 250	2	2	3
251 to 300	1	0	1
301 to 350	1	1	1
351 to 400	0	2	2
above 400	3	4	1
Total	100	100	100

Table 3-4: Percentage of acknowledged messages

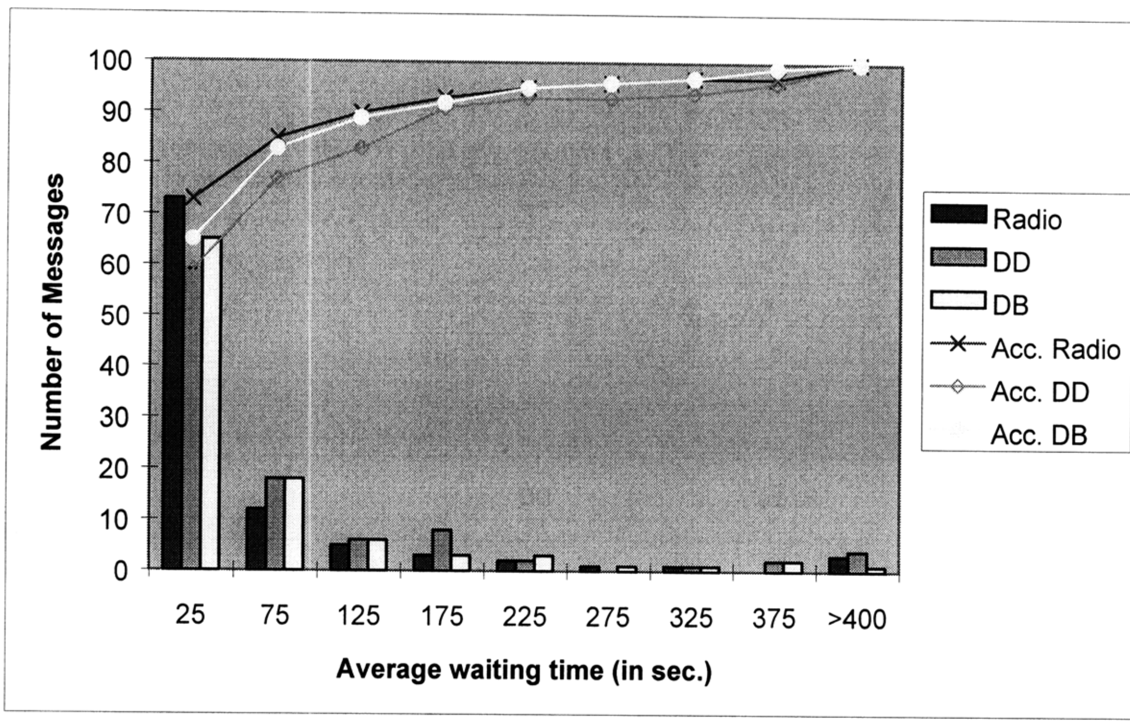

Figure 3-2: Percentage of acknowledged messages

Finally, Table 3-4 and Figure 3-2, show the percentage of acknowledged messages for various time categories and the accumulated number of messages acknowledged as a function of time. These are two additional indications that there is no significant improvement when using data-link. All three environments display the same type of cumulative function, with the data-link systems performing slightly under the radio environment for the reason mentioned above. A real data-link system, directed or broadcast, should obviously integrate a message reception alerter.

Processing time

process. time	Radio	DD	DB	Mean - Disp.
Disp #1	141.84	26.15		84.00
Disp #2	152.00	22.50		87.25
Disp #3	66.14		44.26	55.20
Disp #4	84.80		21.36	53.08
Disp #5		43.28	14.17	28.72
Disp #6		69.67	20.77	45.22
Mean - Envir.	**111.19**	**40.40**	**25.14**	**58.91**

Table 3-5: Average processing time for each experiment (in sec.)

Table 3-5, the average processing time for each experiment, clearly shows a significant time gain when shifting from the radio environment to either data-link environment. All experiments with data-link systems, show an average processing time under the lowest radio environment average, except for Disp #6. To understand the reasons underlying this observation, we have to go back to the way the processing time is defined. The processing time is the time difference T3-T2, where T3 is the time at which the dispatcher starts his final answer to the initial message and T2 is the time at which the initial message was acknowledged. For the radio this includes the time during which the two parties make sure they are talking about the same section of track in the MOW request example. It also includes the time the dispatcher needs to write down the piece of information he was told over the radio, in order to properly transmit it in the case of a hazard. Finally, it includes the time the dispatcher needs to check if the track is available or if there is any speed restriction when a train asks for a temporary speed restriction bulletin. The advantage of data-link environments over the radio comes from the fact that there is no doubt about the incoming information. MOW crews do not need to explain or repeat three times which section of track they need because the dispatcher did not hear it, because he did not write it down or because he is trying to understand which section is being described to him. Our data-link systems create a common ground, a common language between the people in the field and the dispatcher as they provide both with a track layout. They also provide a written support for the dispatcher. This allows him to gain time on the understanding task of the message, hence on the processing time. However one should notice that, for hazard alerting messages, the advantage is less obvious, because they are mainly reported by trains whose location is known to the dispatcher. Hence, confusion is less likely. The engineer does not need to describe the location of the train.

processing time	Radio	DD	DB
Mean - Environ.	109.18	37.89	25.65
Conf.	49.70	18.83	10.63
Mean - Max.	158.87	56.72	36.28
Mean - Min.	59.48	19.06	15.02

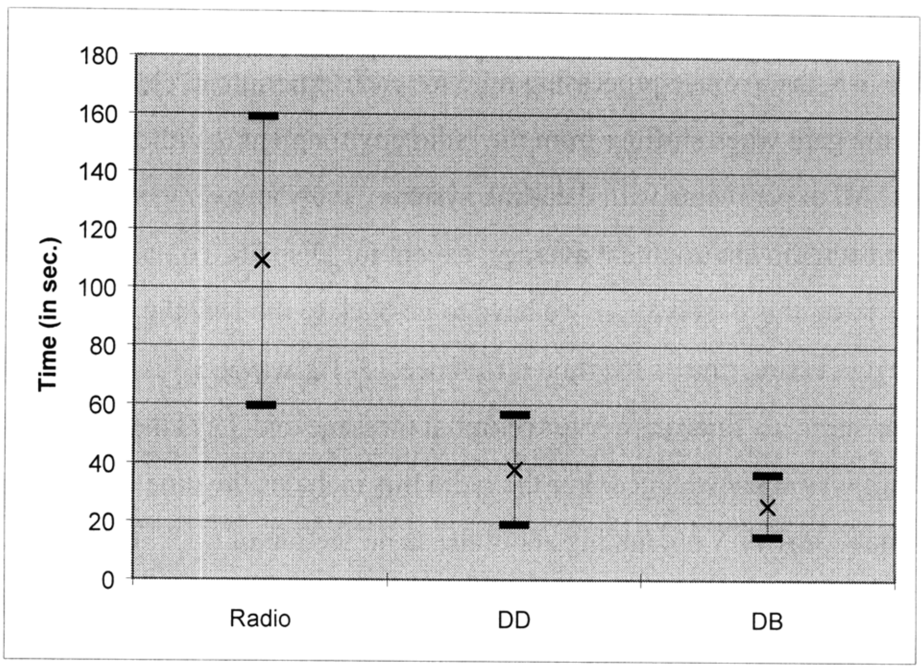

Figure 3-3: Processing time average for each environment (in sec.)

Figure 3-3, shows the processing time average (calculated combining per environment the data of each dispatcher) and the 95% confidence interval of the mean (with $n = 81$, $\nu = 80$ and $\alpha = 0.95$). Here again the means and confidence intervals largely support our analysis. Both data-link environments show a significantly lower processing time average with no overlapping.

Time (in sec.)	processing (radio)	processing (DD)	processing (DB)
0 to 60	68	84	93
61 to 120	10	13	4
121 to 180	6	0	0
181 to 240	1	0	2
241 to 300	3	0	0
301 to 360	0	0	0
361 to 420	1	2	1
421 to 480	2	0	0
above 480	9	1	0
Total	100	100	100

Table 3-6: Percentage of processed messages

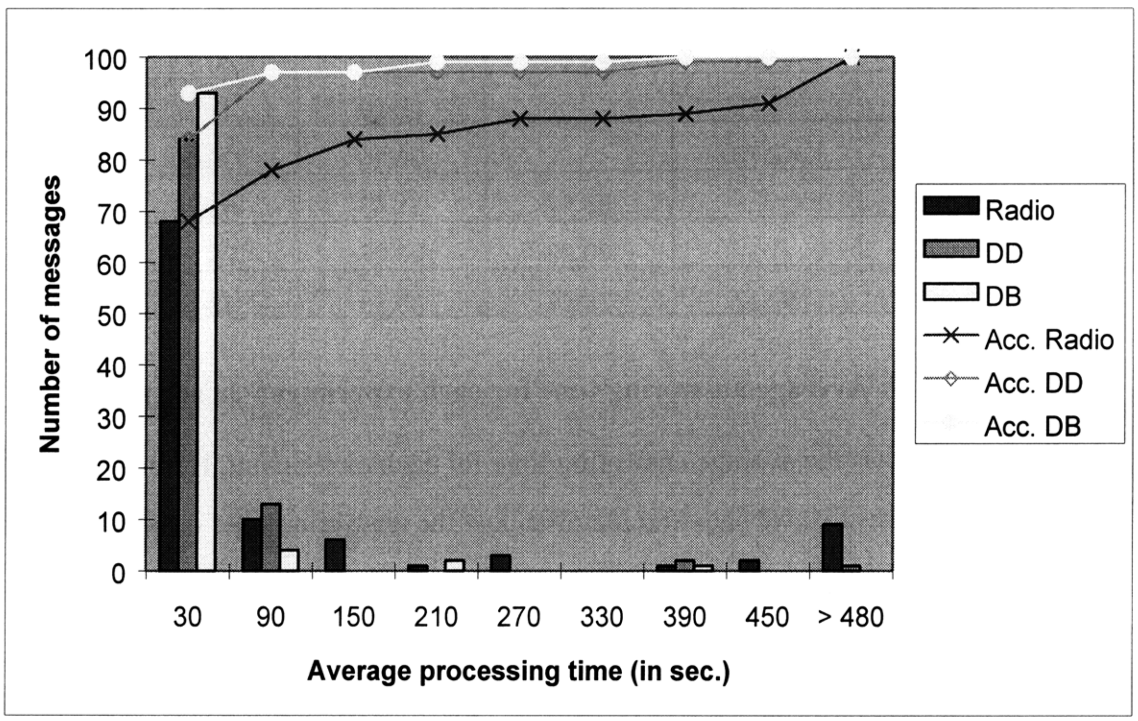

Figure 3-4: Percentage of processed messages

Finally, Table 3-6 and Figure 3-4, the percentage of processed messages for various time categories and the accumulated number of messages processed as a function of time confirm the previous observation. Both data-link environments present very similar results. The radio environment has a very different cumulative function. The percentage of messages processed after five minutes is still only 85%. We observed that some messages are forgotten and that some others are just so complex to transmit over the radio that they simply take more time. Note that in the data-link case, we can also see the forgotten messages: 1% for the DB case and 3% for the DD case. This can not be compared to the 12% observed in the radio environment. The reason for this is that in the radio environment, the dispatcher has no reminder of the message if he did not hear it when transmitted. In both data-link systems, the written support in addition of providing a common "language", provides an easy way to remember calls and callers. We heard at least once during each radio experiment dispatchers ask: "who was that on the radio a couple of minutes ago?"

Answering time

answer. time	Radio	DD	DB	Mean - Disp.
Disp #1	74.74	38.59		56.66
Disp #2	51.81	29.65		40.73
Disp #3	68.22		26.96	47.59
Disp #4	42.70		36.10	39.40
Disp #5		55.17	31.43	43.30
Disp #6		30.93	26.23	28.58
Mean - Envir.	59.37	38.59	30.18	42.71

Table 3-7: Average answering time for each experiment (in sec.)

Table 3-7 shows the average answering time for each experiment. Here again, to fully understand the results, we should remember how the answering time is calculated. It is the difference T4-T3 where T4 is the time at which the transmission terminates (on a given subject) and T3 is the time at which the dispatcher starts his final answer to the initial message. The trend observed is clear: both data-link environments are more efficient than the radio environment in terms of answering time. All data-link experiments (if we ignore Disp. #5) show a lower mean than the lowest radio environment mean of 43 seconds (for Disp #4). A more precise look at all three environments and at their operating-rules was helpful. In the radio environment, dispatchers have to dictate specific information to MOW people when they grant foul time: dispatcher name, date, time span granted, location, number of work crew among others. While the dispatcher is dictating, MOW people have to write the information down on a paper. Then, MOW people have to read back that same information as an acknowledgment. In certain cases (for the so-called form Ds), dispatchers are even required to write down this information on their side. This process usually takes quite a long time. With data-link systems, dispatchers do not need to dictate anything. They fill in the form directly on the computer and the message is transmitted with no error. Then read and finally acknowledged by the MOW crew. The tedious dictation process is avoided because the written version created by the dispatcher is available to both parties.

answering time	Radio	DD	DB
Mean - Environ.	59.41	38.96	30.19
Conf.	18.06	10.18	4.62
Mean - Max.	77.46	49.14	34.81
Mean - Min.	41.35	28.79	25.57

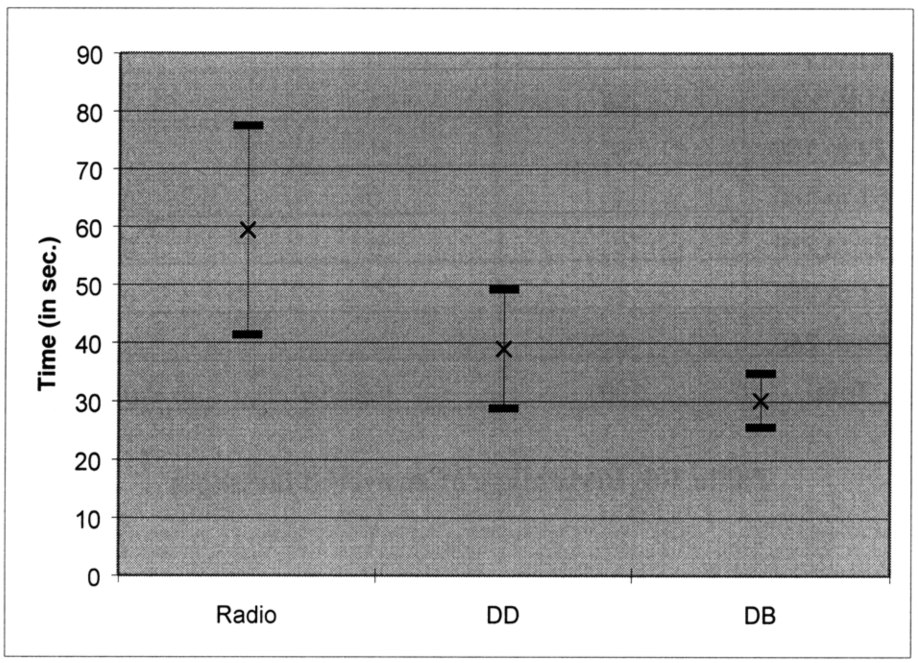

Figure 3-5: Answering time average per environment (in sec.)

Figure 3-5, shows the answering time average (calculated combining the data of each dispatcher) and the 95% confidence interval of the mean (with $n = 71$, $\nu = 70$ and $\alpha = 0.95$). The means of both data-link environments are sensibly below the mean of the radio environment. The 95% confidence intervals overlap slightly in the radio and DD comparison but not in the radio and DB comparison. The means per environment seem to support our analysis of the means per experiment. Data-link systems are definitely more efficient and this is probably due to the gain in transmission time due to the written foul time granted messages. The difference between DD and DB does not seem to be significant. We believe that this is due to unavoidable decisions during the experiment and to the various levels of experience of the dispatchers. In fact Disp #5 and Disp #6 were scheduled to take both data-link experiments and they both took the DD experiment first and the DB experiment later. We believe that the slight superiority of the DB environment over the DD environment could be due to this. However it might very well be that the DB environment just provides dispatchers with the feeling of working in a safer environment (see results on safety) and that therefore they perform better.

Time (sec.)	answering (radio)	answering (DD)	answering (DB)
0 to 30	58	54	55
31 to 60	12	31	36
61 to 90	7	10	7
91 to 120	12	1	1
121 to 150	4	1	1
151 to 180	1	0	0
181 to 210	0	0	0
211 to 240	0	2	0
above 240	6	1	0
Total	100	100	100

Table 3-8: Percentage of answered messages

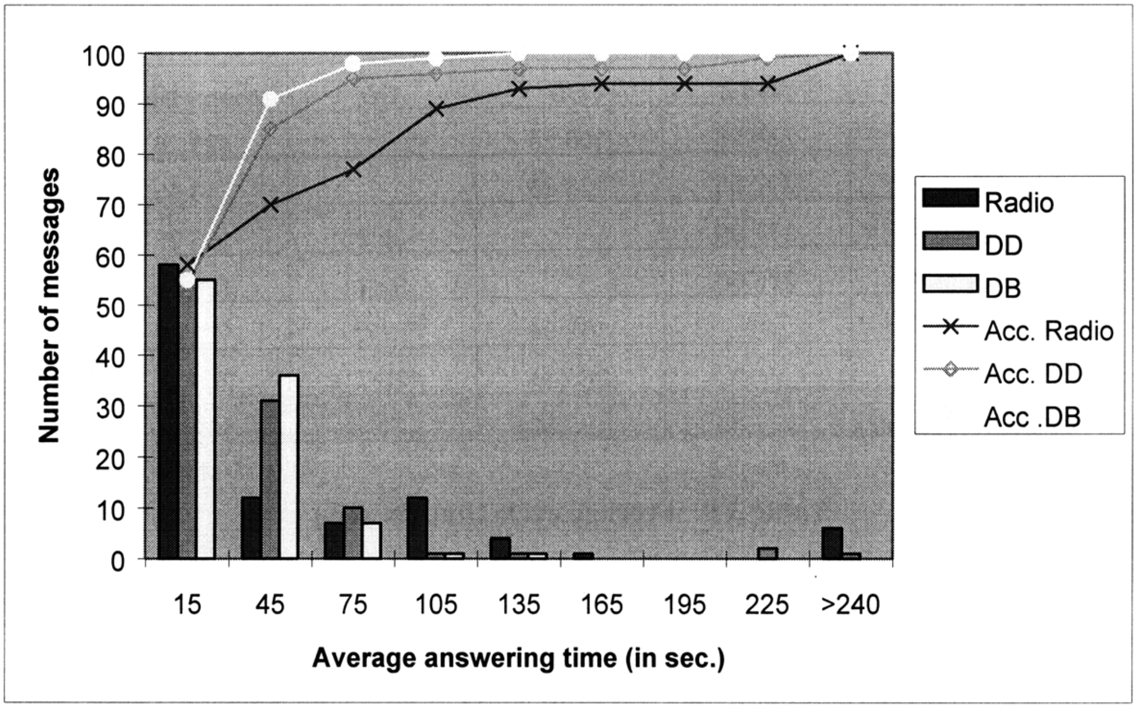

Figure 3-6: Percentage of answered messages

Finally, Table 3-8 and Figure 3-6, the percentage of answered messages for various time categories and the accumulated number of messages answered as a function of time confirm the previous observation. Both data-link environment present a relatively similar curve, with DD performing slightly less well than DB. The radio environment shows a two-stage curve with a very different pattern. Two peaks can be observed on the radio histogram. The first one at the first category (0 to 30 sec.) is probably due to the No Temporary Speed Restrictions, MOW Request Denied and Hazard Alerting transmissions among others. The second peak, between 90 and 120 seconds, is probably due to the MOW Request Granted transmissions with or without form Ds, but where dictation and repeating take a substantial amount of time. Finally the last category contains the mistakes and long problematic messages. No data-link environment shows this kind of difference between messages. There is no second peak noticeable. This assumption about the significance of the two peaks observed on the histogram will be investigated more in the next section.

Cycle time

cycle	Radio	DD	DB	Mean - Disp.
Disp #1	236.26	156.25		196.26
Disp #2	297.95	128.95		213.45
Disp #3	177.95		135.95	156.95
Disp #4	205.60		192.11	198.85
Disp #5		162.94	81.71	122.32
Disp #6		285.31	126.71	206.01
Mean - Envir.	**229.44**	**183.36**	**134.12**	**182.31**

Table 3-9: Average cycle time (in sec.)

Table 3-9, the average cycle time presents the means of the cycle times for each experiment. The cycle time is defined as the total time between the initiation of the communication about one subject and the termination of that same communication. Note that in the radio case this communication sequence might include more than one radio transmission (e.g. when the dispatcher asks a MOW crew to call back or when he "puts a train on stand-by"). Finally in the data-link environments we took into account the time we added to the transmission when forwarding the message to its final destination in the cycle time. This "random time span" added to the message represents a way for us to introduce the delivery time, i.e. the time the message travels from one entity to the other. We also think that this treatment is a way to introduce the time delay created by the train engineer by not always reading the message upon reception, as our forwarding was very much dependant on our amount of workload. The mean of this "random time span" we added turns out to be roughly 20 seconds.

Looking at the means for each individual experiment, we can notice that except for Disp #6 in the DD case and Disp #4 in the DB case, all data-link experiments show a lower mean that the lowest mean for the radio environment (178 seconds on average for Disp #5). The difference is not necessarily clear but the expected trend given the observation for the processing time and for the answering time is still an improvement in terms of overall communication time when shifting from radio to data-link systems. To get an idea of the table without the "random time span", we can subtract 20 seconds to all the data-link results. This would leave us with Disp #6 being the only data-link data point to be above the lowest radio environment means. And the difference between the two environments would become more obvious.

cycle	Radio	DD	DB
Mean - Environ.	227.21	174.20	135.31
Conf.	75.19	37.56	25.16
Mean - Max.	302.40	211.76	160.47
Mean - Min.	152.02	136.65	110.15

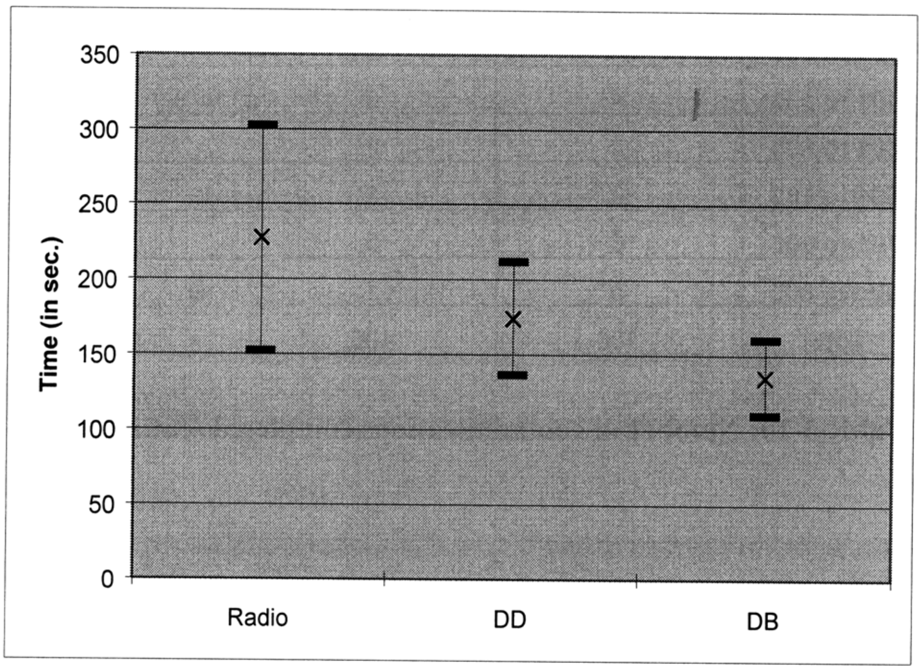

Figure 3-7: Cycle time average per environment (in sec.)

Figure 3-7, shows the cycle time average (calculated combining per environment the data of each dispatcher - with $n = 71$, $\nu = 70$ and $\alpha = 0.95$). The expected lower means for the data-link environments can be observed on the graph. The confidence interval in the DD case overlaps almost entirely on the large radio mean confidence interval. The confidence interval in the DB case is almost not overlapping at all. The difference between DD and DB is believed to come from the fact that the DB experiments benefited from the learning factor (see the Disp #5 and Disp #6 issue). Here again a translation by 20 seconds towards the bottom would give an idea of the results without the "random time span". The DB environment would clearly separate from the radio environment and only half the DD confidence interval would overlap. This would lead us to believe that data-link systems are clearly performing better. However we believe that introducing this time span is necessary to keep the numbers realistic. Therefore we will conclude that the improvement in terms of total cycle time is not as substantial as expected, when considering all types of messages.

Time (in sec.)	cycle (radio)	cycle (DD)	cycle (DB)
0 to 100	56	39	53
100 to 200	11	32	25
201 to 300	5	15	12
301 to 400	10	9	6
401 to 500	4	0	3
501 to 600	3	1	1
601 to 700	0	3	0
701 to 800	6	0	0
above 800	5	1	0
Total	100	100	100

Table 3-10: Number of communications completed (entire cycle)

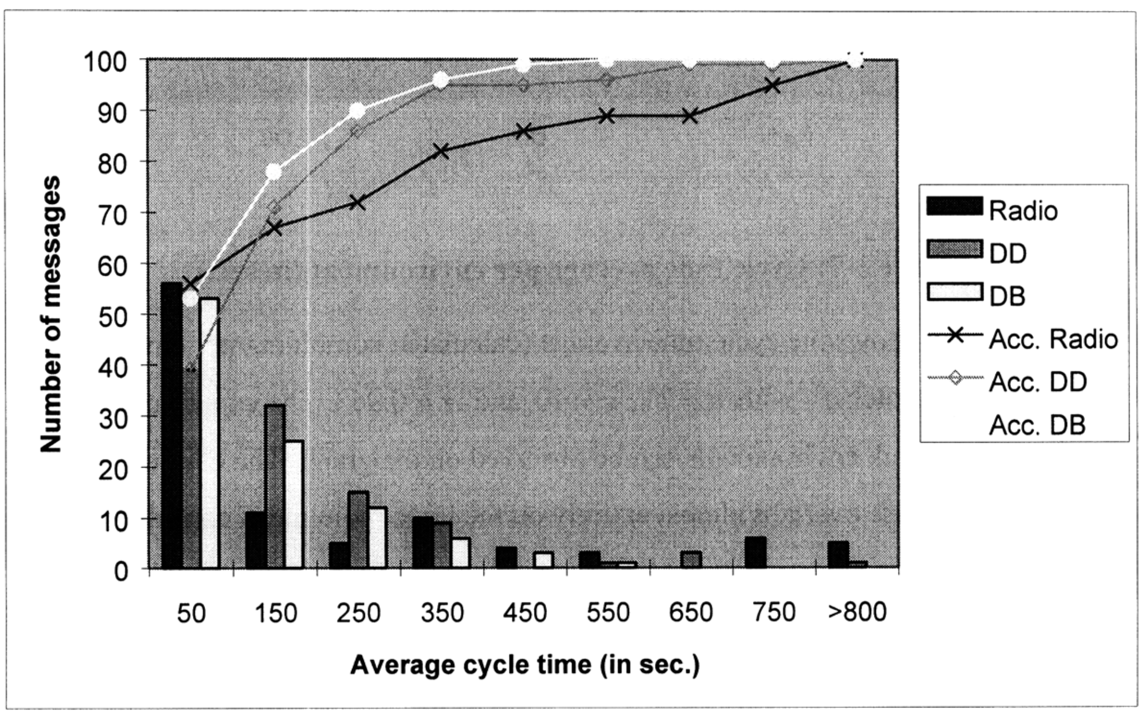

Figure 3-8: Number of communications completed (entire cycle)

Finally, Table 3-10 and Figure 3-8, the percentage of communication completed for various time categories and the accumulated number of communications completed as a function of time both provide insightful information. Again, we can see that the data-link curve has a characteristic shape, even if DB still performs slightly better than DD. The other remarkable feature is the two-peak shape of the radio environment histogram. This shape already observed and commented in the previous paragraph (about answering time) seems to show a strong difference in the radio environment between two types of messages. In the following section we will group into two groups what we believe messages of each type are and take a closer look at the results.

3.2.2.2 Data-link seems very helpful for certain types of messages

Figure 3-8 in the previous section showed the now almost typical, two-peak radio environment histogram for the percentage of communications completed. As explained previously the first peak (first category, 0 to 100 sec.) is assumed to consist of the messages that are easy to react upon: foul time denied communications, temporary speed restriction bulletin (TRSB) requests for trains beginning their ride, alerting communications and MOW crew clearances. The second peak is assumed (fourth category, 301 to 400 sec.) to include the messages where a more complex answer is expected, in our case only the foul time and track outages granted communications. However, real dispatching operations present more candidates for the second group of messages: temporary speed restriction bulletin answers are often form Ds (as opposed to the easy "no Ds, no changes for you today" in our simulation).

To verify our assumption, we separated our messages into two types in our "summarizing" tables. The first type of message, referred to as type T1 messages, includes the denied foul times communications, the TSRBs and the alerting communications. The second type of message, referred to as type T2 messages, includes only one type of communications in our simulation: the foul time granted communications. For each environment we checked if there was a difference in treatment between T1 and T2 type messages. Therefore we plotted on the same graph, the histograms showing the percentage of T1 and T2 messages acknowledged, processed, answered and transmitted (cycle time) and the cumulative functions for each environment separately. The second step, once our assumption was verified, was to evaluate the effect of this new piece of information on our understanding of data-link systems and their effect on the dispatcher communication environment so far. Therefore we compared all three environments and the way each of them handles each type of message. As data-link seemed to be only a slightly more efficient communication means overall, we expected to get a better understanding of its effects, benchmarking it against the radio environment and looking at T1 and T2 type messages separately.

Time (in sec.)	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
0 to 50	83	59	59	60	67	62
51 to 100	7	21	17	20	19	15
101 to 150	4	5	4	13	5	12
151 to 200	2	5	11	0	2	4
201 to 250	0	5	1	4	2	4
251 to 300	0	2	0	0	0	3
301 to 350	1	0	1	0	1	0
351 to 400	0	0	3	0	3	0
above 400	3	3	4	3	1	0
Total	100	100	100	100	100	100

Table 3-11: Number of T1 and T2 type messages acknowledged

Time (in sec.)	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
0 to 60	94	30	87	80	97	85
61 to 120	2	18	9	20	3	4
121 to 180	0	15	0	0	0	0
181 to 240	0	4	0	0	0	8
241 to 300	2	3	0	0	0	0
301 to 360	0	0	0	0	0	0
361 to 420	0	3	2	0	0	3
421 to 480	0	6	0	0	0	0
above 480	2	21	2	0	0	0
Total	100	100	100	100	100	100

Table 3-12: Number of T1 and T2 type messages processed

Time (in sec.)	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
0 to 30	90	9	73	14	70	19
31 to 60	4	24	18	57	26	62
61 to 90	2	16	7	14	2	19
91 to 120	2	27	0	4	1	0
121 to 150	0	9	0	4	1	0
151 to 180	2	0	0	0	0	0
181 to 210	0	0	0	0	0	0
211 to 240	0	0	0	7	0	0
above 240	0	15	2	0	0	0
Total	100	100	100	100	100	100

Table 3-13: Number of T1 and T2 type messages answered

Time (in sec.)	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
0 to 100	87	12	53	13	65	23
100 to 200	7	18	24	46	20	36
201 to 300	0	12	7	29	9	18
301 to 400	4	18	10	8	2	18
401 to 500	2	7	0	0	2	5
501 to 600	0	6	0	4	2	0
601 to 700	0	0	4	0	0	0
701 to 800	0	15	0	0	0	0
above 800	0	12	2	0	0	0
Total	100	100	100	100	100	100

Table 3-14: Number of T1 and T2 type messages transmitted

Tables 3-11, 3-12, 3-13 and 3-14 show the result of our dividing the communications into two types T1 and T2 for each communication-efficiency variable we chose. All number are normalized (i.e. we extended our data to 100 T1-type messages and 100 T2-type messages). These tables are the basis for the histograms and graphs shown in the next pages.

Differences between T1 and T2 type messages in the radio environment

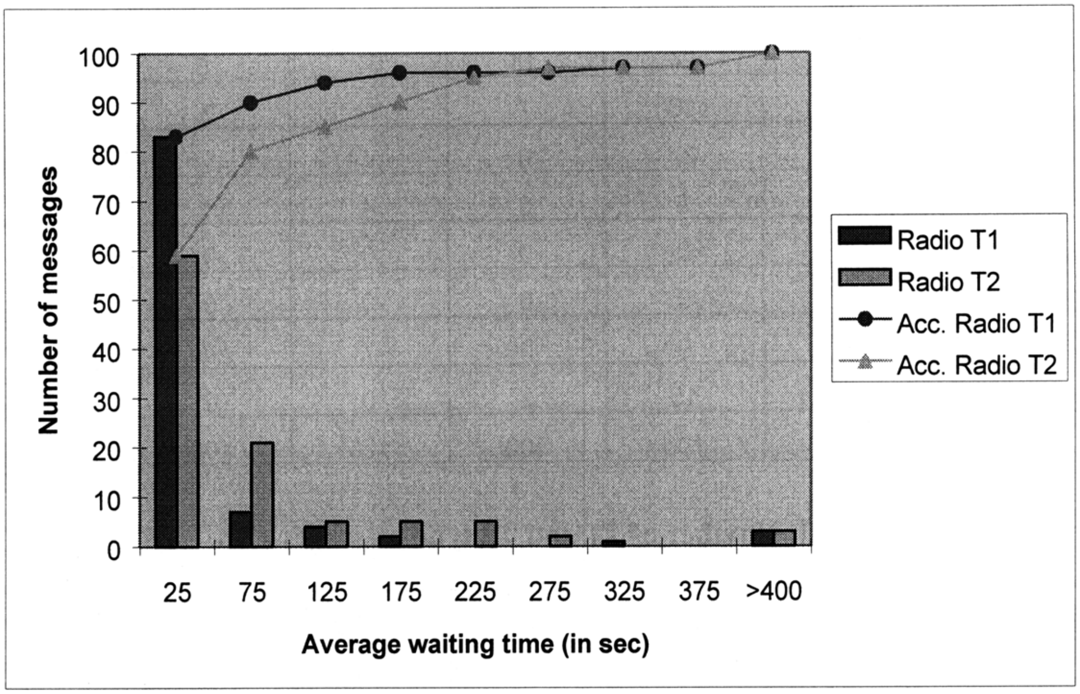

Figure 3-9: Number of T1 and T2 type messages acknowledged in the radio environment

Figure 3-9, shows the number of T1 and T2 type messages acknowledged in the radio environment after a certain amount of time out of 100 messages of each type. We can clearly distinguish a difference in the acknowledgement time between the two types of messages. There seems to be a level of priority for each class of message. T1 type messages are given high priority and are answered relatively quickly. T2 type messages seem to be of lesser importance. At first sight this observation seems odd, because the two groups of messages are based on the type of answer and the dispatcher can obviously not know the answer before knowing the subject; hence we do not treat the two types of messages differently.

However, if we take a closer look at the received calls generating the answer communication in both groups, there is an explanation for this observed difference. The first group, T1 type messages, includes communications triggered by high priority calls coming from trains (TSRBs and hazard alerts) and communications triggered by lower priority calls from MOW people (foul time denied communications). The second group, T2 type messages, only includes communications triggered by low priority calls from MOW people (foul time granted communications). The calls leading to T2 type communications are categorized by dispatchers as low priority calls. This is the reason why we observe a difference in the treatment for the two groups of messages. We could prove our assumption about the two priority levels (for trains calls and for MOW people calls), by comparing the acknowledgement times for messages from trains on one hand and for message from MOW people on the other hand. This would create two different groups of messages, which are not interesting at all for us.

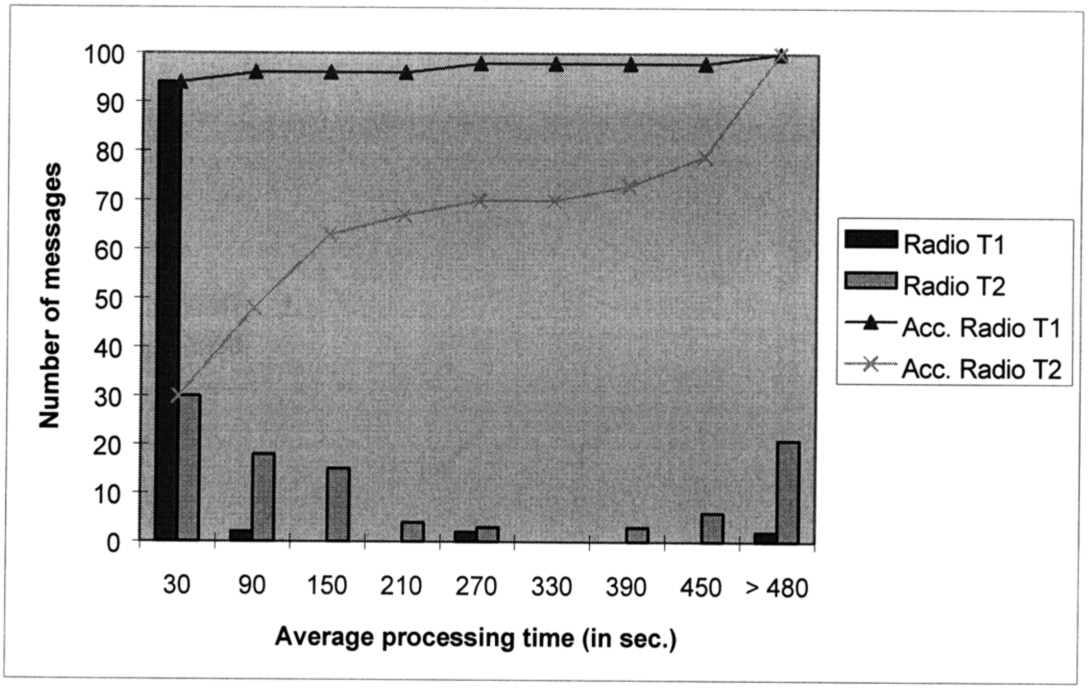

Figure 3-10: Number of T1 and T2 type messages processed in the radio environment

Figure 3-10 shows the number of T1 and T2 type messages processed in the radio environment after a certain time (out of 100 messages of each type). Here we can clearly see the difference in "processing speed for the two types of messages. This supports our initial assumption: T1 type messages are easy and quick to process, T2 type messages are more complex to process and require more time. However, here again, the argument developed for the acknowledgement time, is still valid. The processing time does not only depend on the type of answer given to the call. It also depends on the type of call. The processing for a hazard alert does not pose problem, as the processing does not involve a complex analysis. For MOW requests the problem is less simple. On one hand, the processing of MOW request is a complex task no matter what type of answer the dispatcher gives, as the dispatcher has to plan ahead to evaluate if and how long he can give the track away. On the other hand, the processing of a denied MOW request is simpler and quicker than the processing of a granted MOW request because the latter one involves more steps. We believe that the second argument is the strongest as dispatchers seem to deny foul time only if it obviously impossible to grant. In all other cases, they tend to have the MOW crew wait for a window of opportunity.

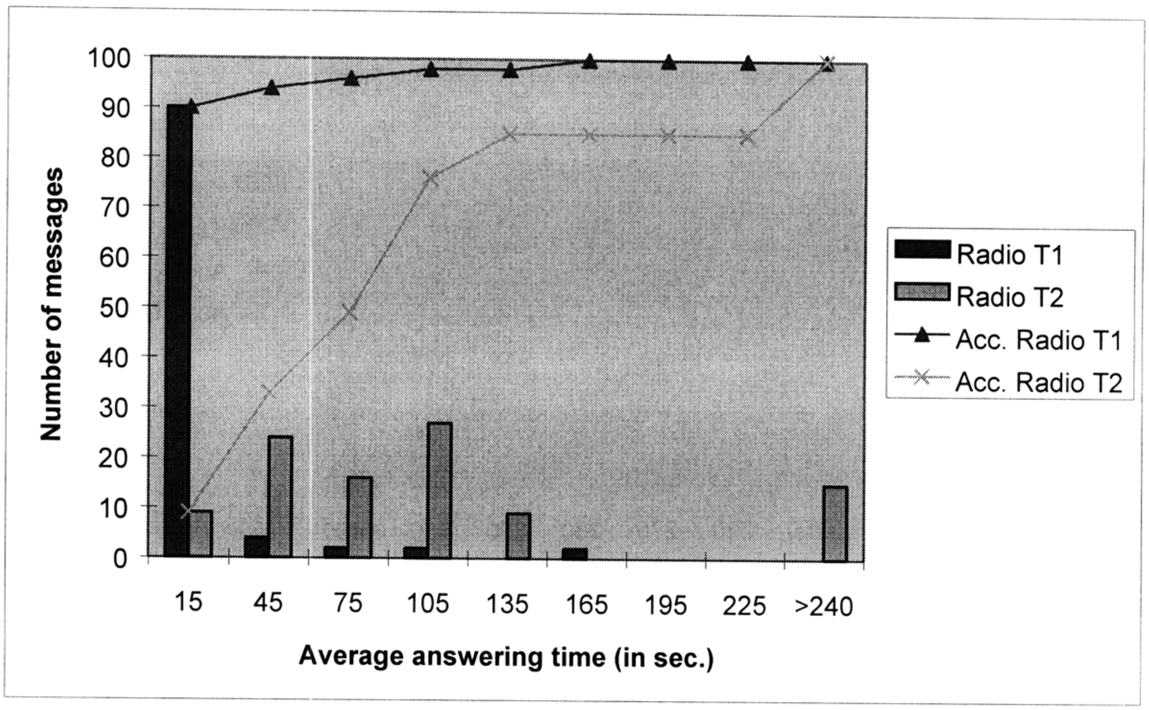

Figure 3-11: Number of T1 and T2 type messages answered in the radio environment

Figure 3-11, the number of T1 and T2 type messages answered in the radio environment after a given amount of time, shows a clear difference between the two types of messages. T1 type messages are obviously very quick to broadcast over the radio. T2 type messages require much more time on average to be transmitted. The number of messages answered is relatively constant over the first two minutes. If the answer message was not transmitted within two minutes, the answering time doubles. To understand this jump, we have to remember that T2 type messages are messages that require dictation and repeating. Errors in the dictation and repeating process or channel congestion oblige the dispatcher to repeat the transmission according to the rules, hence doubling the transmission time.

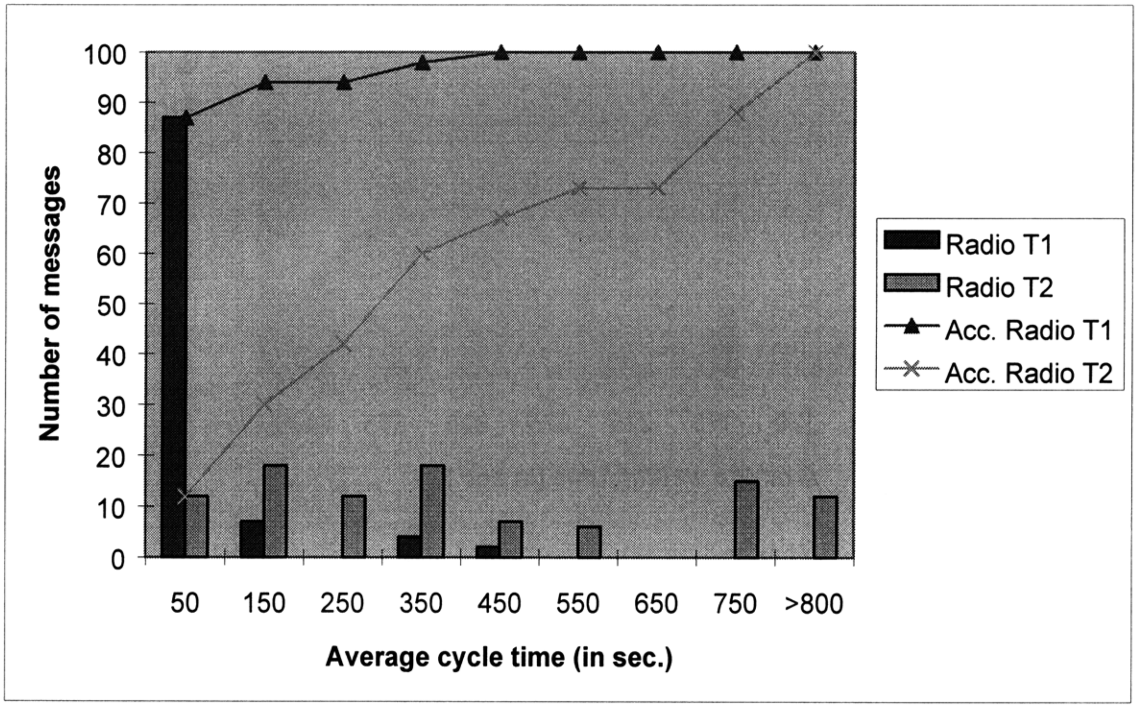

Figure 3-12: Number of T1 and T2 type communications completed in the radio environment

Finally, Figure 3-12 summarizes the result previously described. T1 type messages seem indeed to be communicated very quickly over the radio. Almost all communications are completed within the first five minutes following the initiation of the communication. T2 type messages seem to take more time because of their complexity but also because of the way the radio environment's design and rules. The complexity (easy or difficult description of the requested section of the track for example) creates the relatively constant distribution over time of the amount of communication completed during the first 10 minutes following the initiating of the communication. The mistakes and associated rules are the reason for the large communication times observed for some T2 type messages.

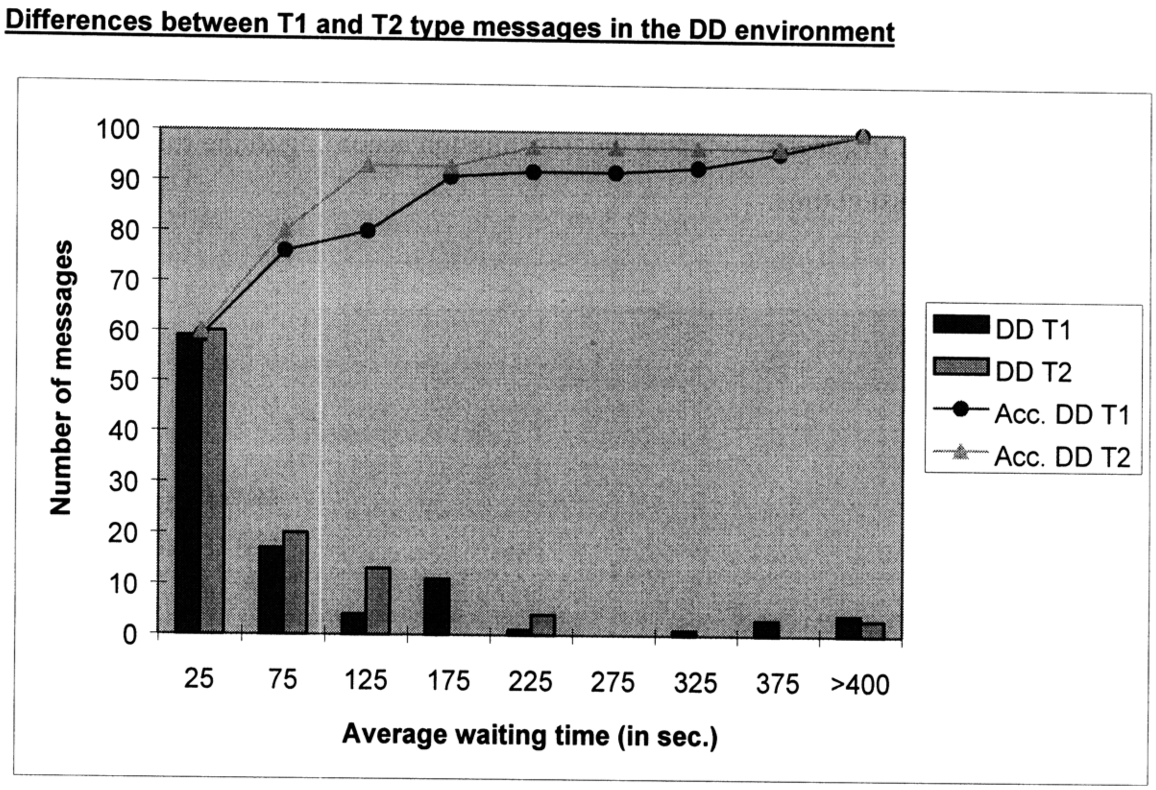

Figure 3-13: Number of T1 and T2 type messages acknowledged in the DD environment

Figure 3-13, shows the number of T1 and T2 type messages acknowledged in the data-link directed environment after a certain amount of time (out of 100 messages of each type). The observation, made earlier in the radio case, does not hold for the data-link directed environment. This is easily understandable if we remember that there is no sound alert for incoming messages and no information about the sender as long as the messages has not been acknowledged. Hence dispatchers have no way to acknowledged train messages and MOW messages differently and to give them different priorities, as was the case in the radio environment. Note that we are not talking about T1 and T2 type messages here. Both message types are handled the same. As a result the cumulative functions are very similar, with a slightly quicker acknowledgement time for the supposedly complex message!

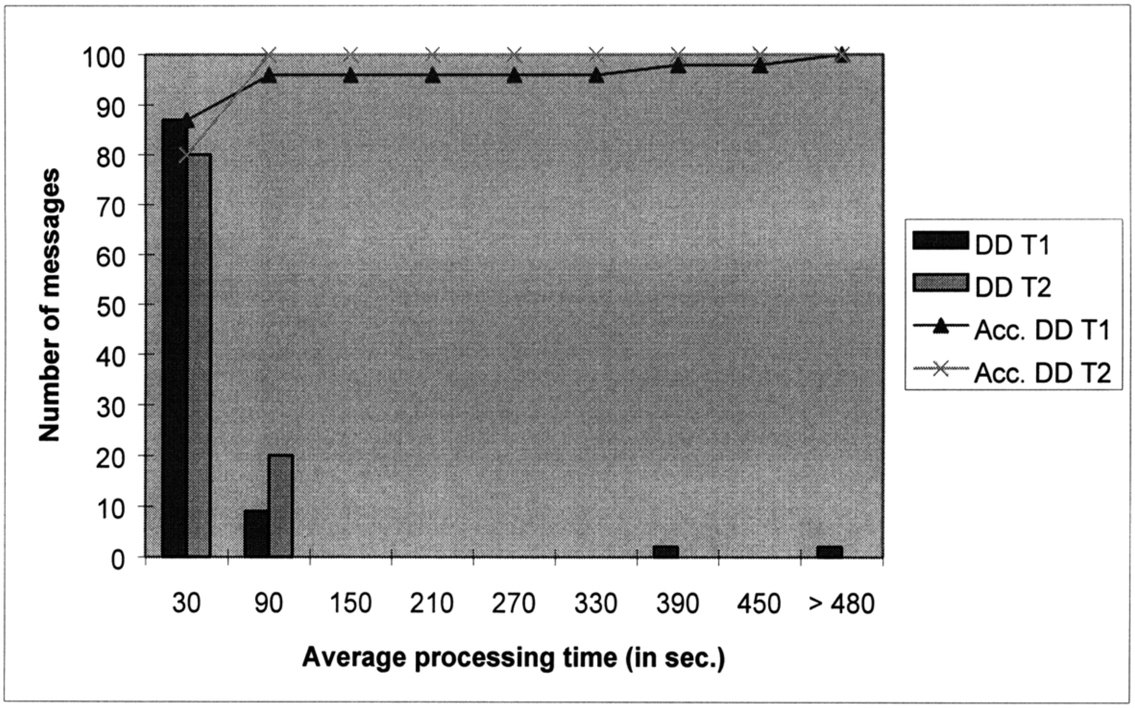

Figure 3-14: Number of T1 and T2 type messages processed in the DD environment

Figure 3-14 shows the number of T1 and T2 type messages processed in the DD environment at a given point in time. We can clearly see that T2 type messages tend to be processed slower than T1 type messages. Once the dispatcher acknowledged the messages, he knows the identity of the sender and is able to prioritize the messages. T2 type messages consist only of complex MOW requests. Therefore their processing time is slightly higher than T1 type messages, which include not only some complex MOW requests but also some easier messages to process such as the TSRB requests and alerting messages from trains. As in the radio case, we believe that the critical factor for the priority is not necessarily only the caller but also the dispatcher decision. Again, we observed dispatchers waiting for a window of opportunity to give away the requested track. Denial decisions are usually taken very quickly. Finally it is interesting to observe that almost every message is processed within the first two minutes. We will come back to this observation later when comparing the three environments. The messages in the three last categories are mainly forgotten messages, TSRBs, with late trains as a result.

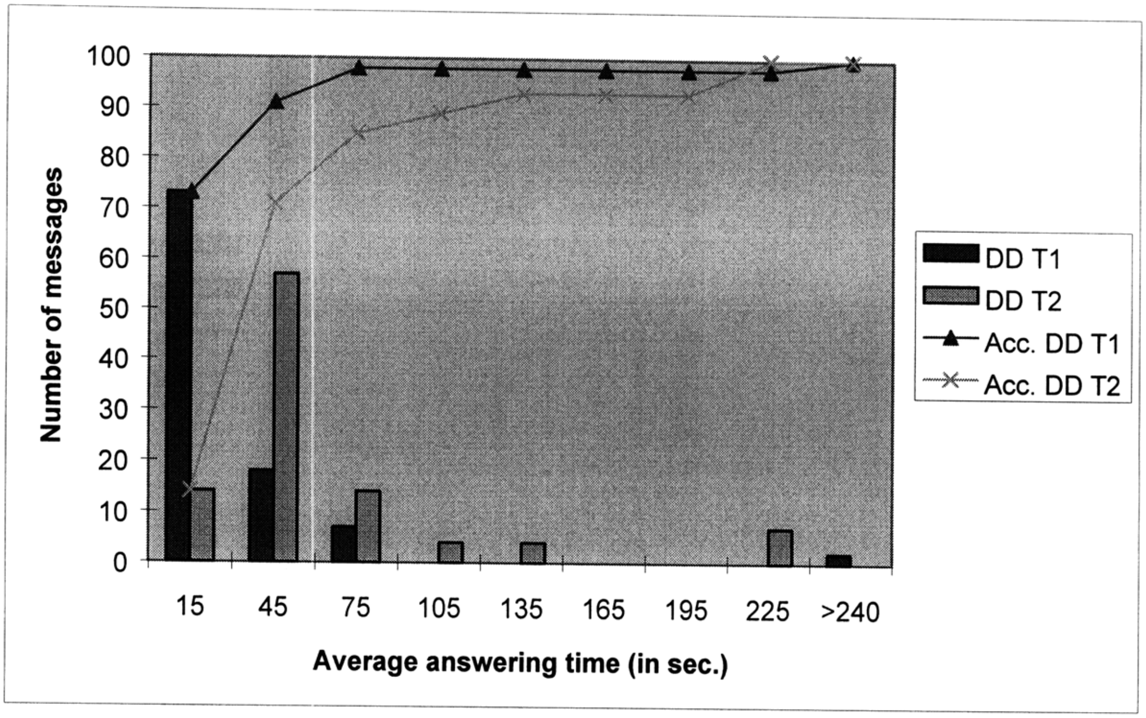

Figure 3-15: Number of T1 and T2 type messages answered in the DD environment

Figure 3-15, showing the number of T1 and T2 type messages answered in the DD environment after a certain amount of time clearly proves a difference in terms of writing/completing time. T1 type messages are completed very quickly, with 98% of the message written/completed in 90 seconds or less. T2 type messages are completed more slowly. The shape of the cumulative function and the peak in the histogram clearly show a higher average composition time. This is understandable when we look at the type of action required in both cases. For T1 type messages, the longest messages are the alerting message with the number of the train to be filled in and the location of the hazard (a total of two fields). For T2 type messages there are the location fields and the time fields (a total of nine fields). The messages on the far right of the graph are very often mistakes of the dispatcher, canceled messages mainly. Note that the pattern is very different from the radio case (explanation see below).

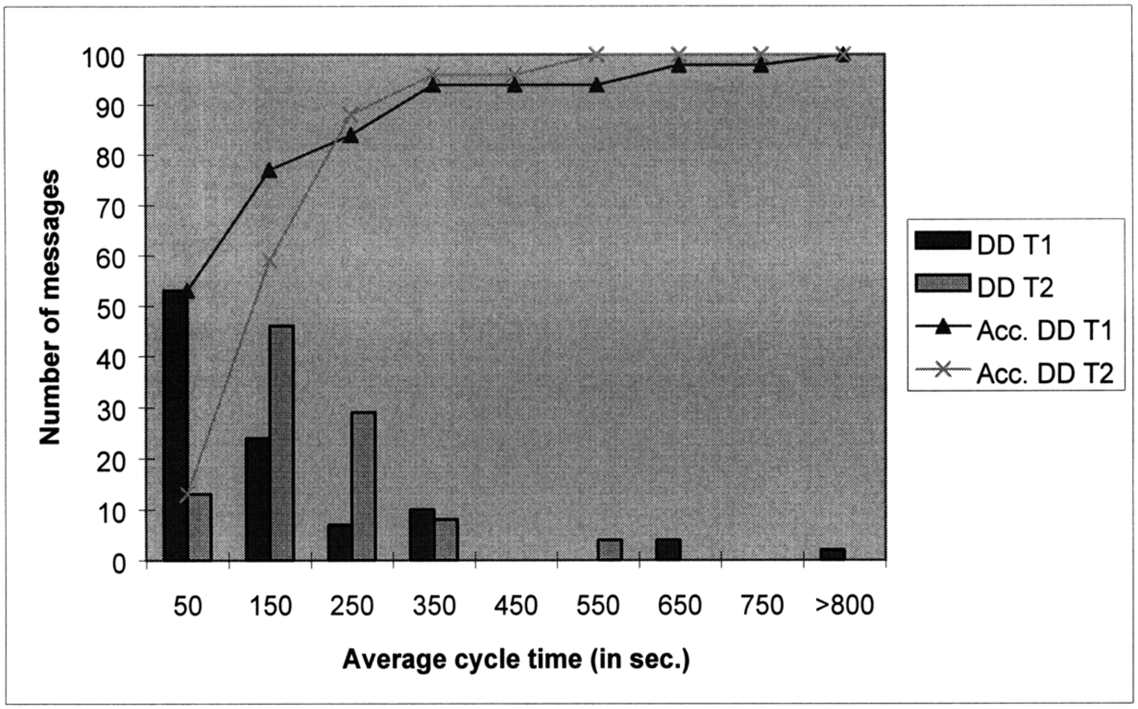

Figure 3-16: Number of T1 and T2 type communications completed in the DD environment

Finally, Figure 3-16 shows the number of T1 and T2 type communications completed in the DD environment as a function of time. The observations made for the previous three graphs are summarized in this figure. As in the radio environment, the total cycle time seems to be very different depending on the type of message considered. Communications triggering T1 type answers are relatively quickly completed. Communications triggering T2 type messages are slower to be completed. Finally, unusually long communication cycles are mostly due to forgotten messages or mistakes from the dispatcher.

Differences between T1 and T2 type messages in the DB environment

The following figures, Figures 3-17, 3-18, 3-19 and 3-20 are the DB equivalent figures to Figures 3-13, 3-14, 3-15 and 3-16 in the DD environment. The observations are identical in both data-link environments. There is a clear difference between T1 type messages and T2 type message in the DB environment as well. This is nothing surprising given that DD and DB environment are very similar.

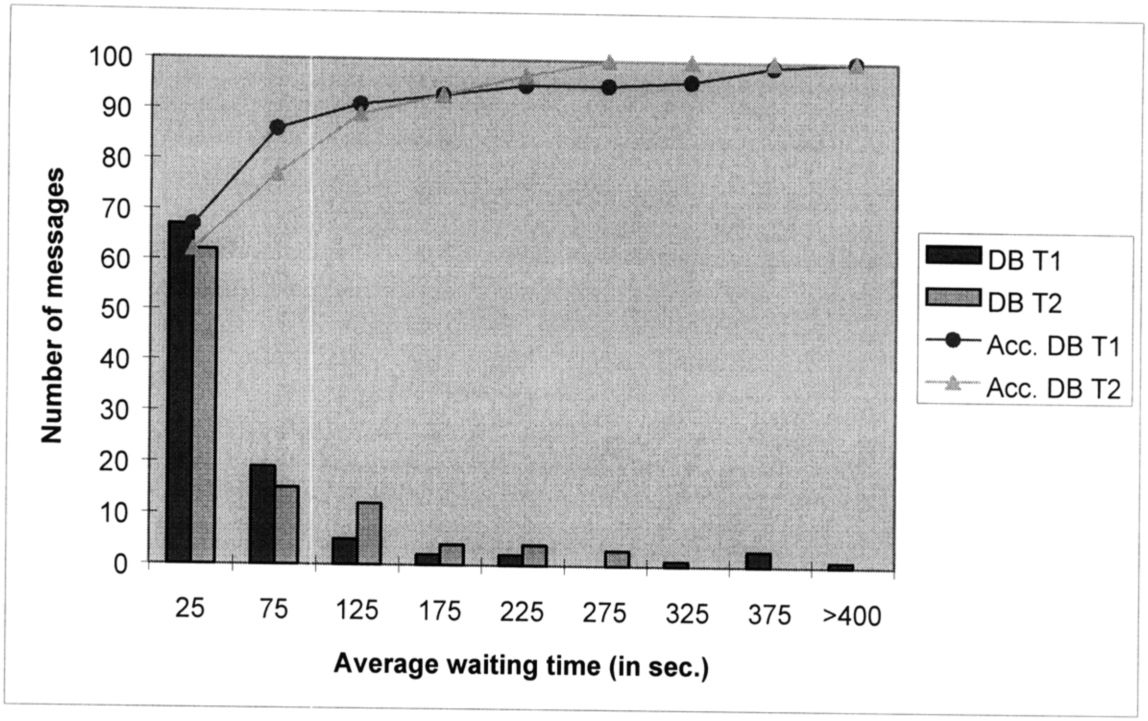

Figure 3-17: Number of T1 and T2 type messages acknowledged in the DB environment

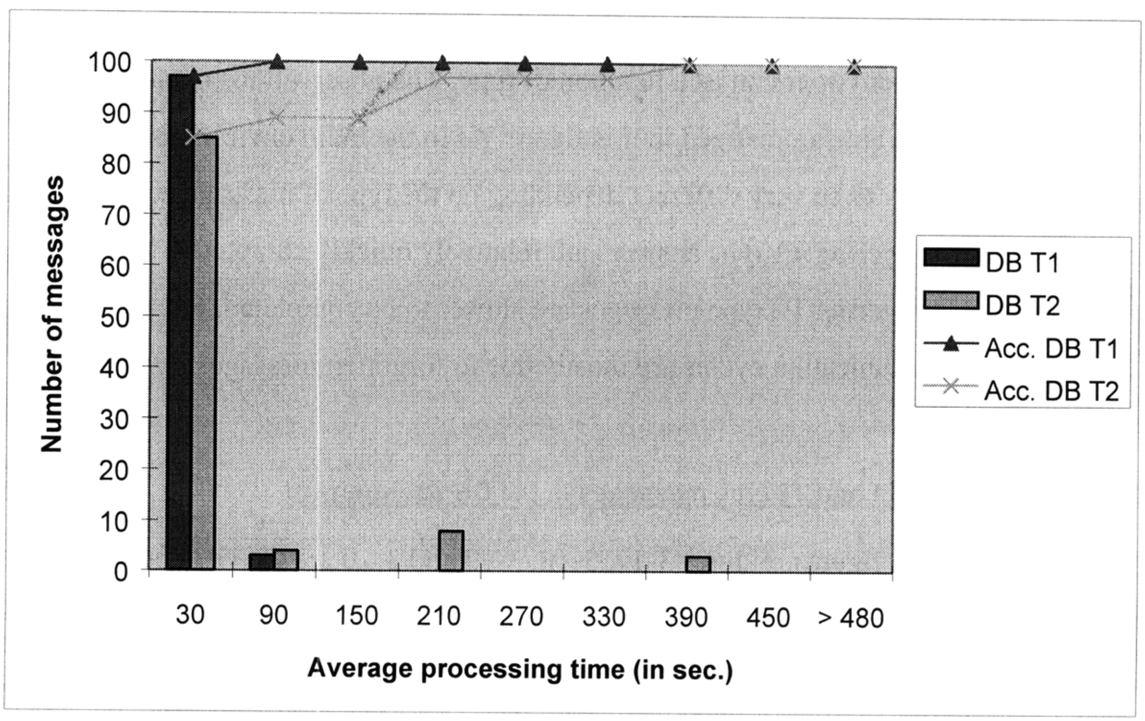

Figure 3-18: Number of T1 and T2 type messages processed in the DB environment

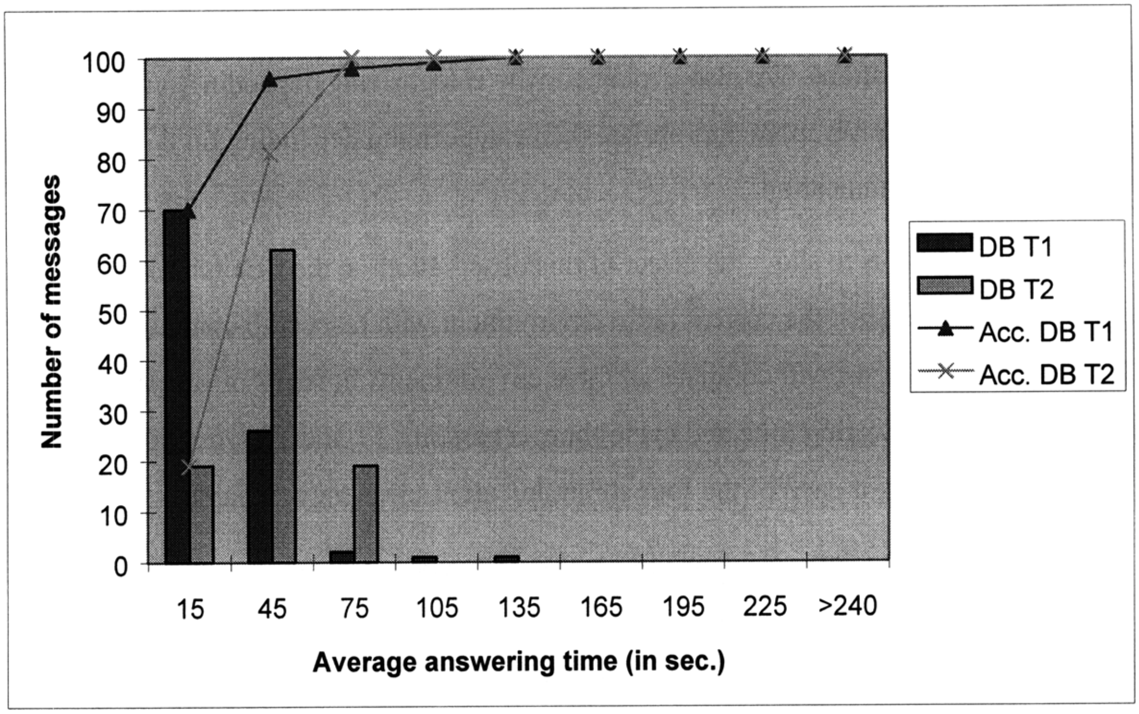

Figure 3-19: Number of T1 and T2 type messages answered in the DB environment

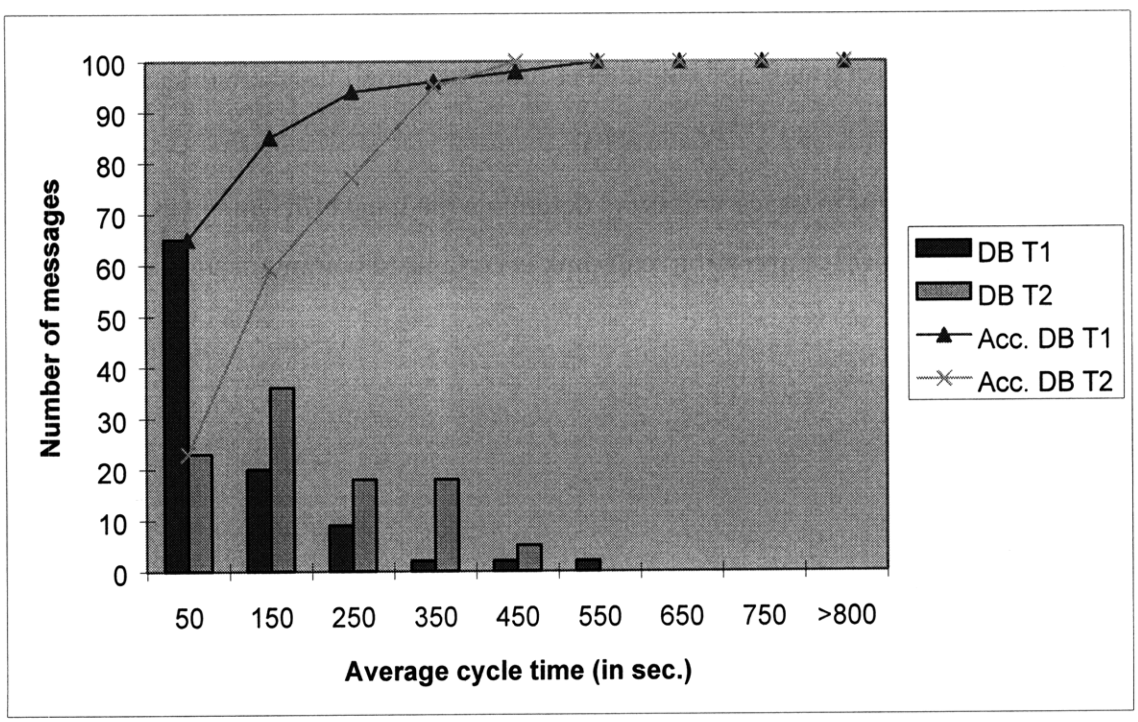

Figure 3-20: Number of T1 and T2 type communications completed in the DB environment

In the previous pages, we showed that there is indeed a difference in the handling of certain communications. We also explained why categorizing depending on the type of answer communication is more appropriate than categorizing depending on the type of initiator of the communication.

Our last goal is to show the effect of this observation on the benchmarking of data-link systems against the current radio environment with respect to communication efficiency. Therefore we will compare all three environments in terms of waiting time, processing time, answering time and cycle time, separating T1 and T2 type messages. We will present in order for each of the four communication-efficiency variables:

- The means with a 95% confidence interval for T1 type messages, i.e. the group of messages for which communication times are short
- The percentage histograms and cumulative functions for all three environments for T1 type messages on one graph
- The means with a 95% confidence interval for T2 type messages, i.e. the group of messages for which communication times are long
- The percentage histograms and cumulative functions for all three environments for T2 type messages.

For each type of message will try to determine the most efficient environment in order to fine-tune our first impression: data-link is certainly a communication efficient tool.

Waiting times for T1 type messages across environments

waiting T1	Radio	DD	DB
Mean - Environ.	47.67	83.06	57.85
Conf.	24.19	26.20	19.92
Mean - Max.	71.85	109.26	77.77
Mean - Min.	23.48	56.87	37.93

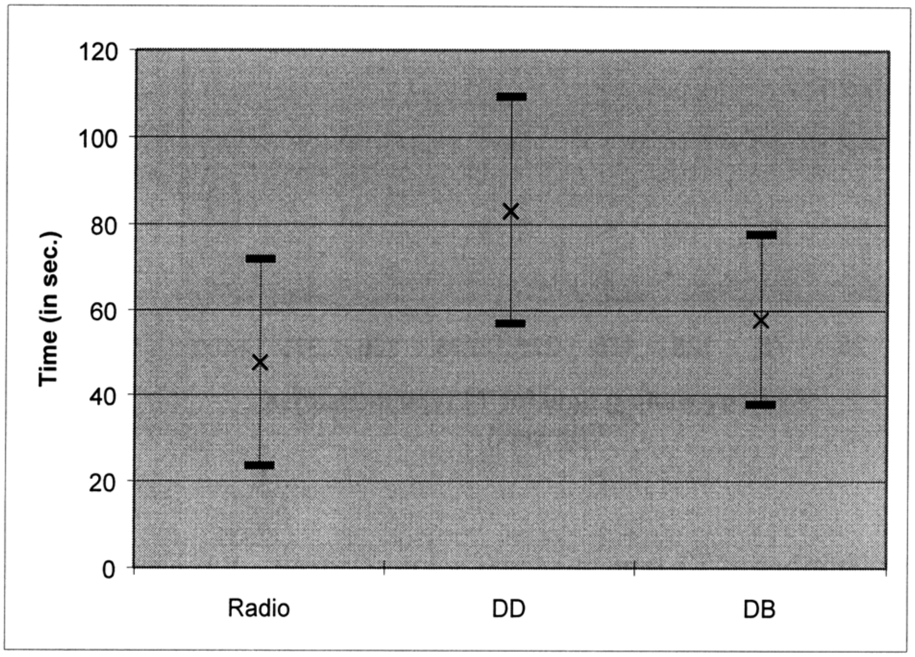

Figure 3-21: Acknowledgement time average for T1 type messages

Figure 3-21, shows the acknowledgement time average for T1 type and the 95% confidence interval of the mean (with $n = 71$, $\nu = 70$ and $\alpha = 0.95$).

The first important observation is that there is no statistical difference between the results as all confidence intervals are greatly overlapping. However, we can still compare the means and notice that the environment with the lowest mean when acknowledging T1 type messages is radio environment. The reason for this is probably the important role of the radio call as an audio alerter. The implementation of such a feature for the data-link environments on the simulator proved impossible and this might explain the difference between data-link and radio. In addition to the audio alert, the radio provides the dispatcher with information about the caller right away. Hence he can start his prioritization process based on the caller. T1 type messages including mainly trains as caller have a higher priority and therefore this might also explain the better mean.

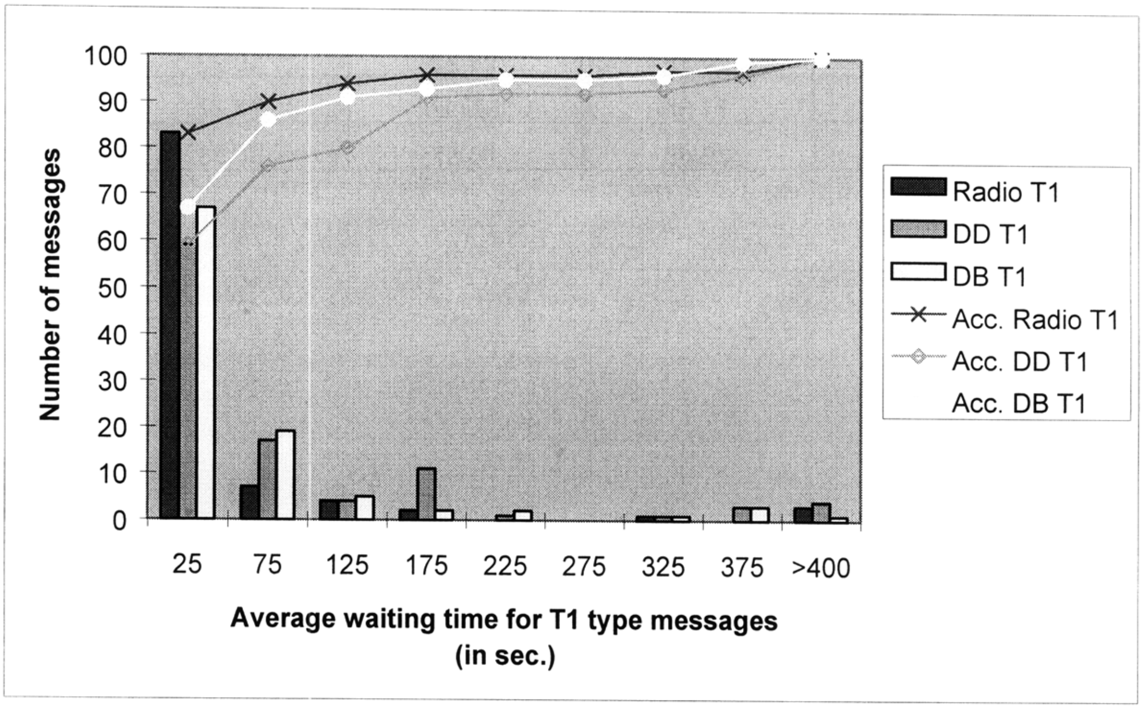

Figure 3-22: Number of T1 type messages acknowledged – Environment comparison

Figure 3-22, showing the number of T1 type messages acknowledged as a function of time confirms the previous observation that the radio environment performs better for T1 type messages (reasons being the presence of an alerter and the knowledge of the caller identity). However, all three cumulative functions have roughly the same shape; hence, there seems to be no significant difference between environments.

Waiting times for T2 type messages across environments

waiting T2	Radio	DD	DB
Mean - Environ.	89.23	65.70	64.73
Conf.	47.75	32.38	28.49
Mean - Max.	136.98	98.08	93.23
Mean - Min.	41.48	33.32	36.24

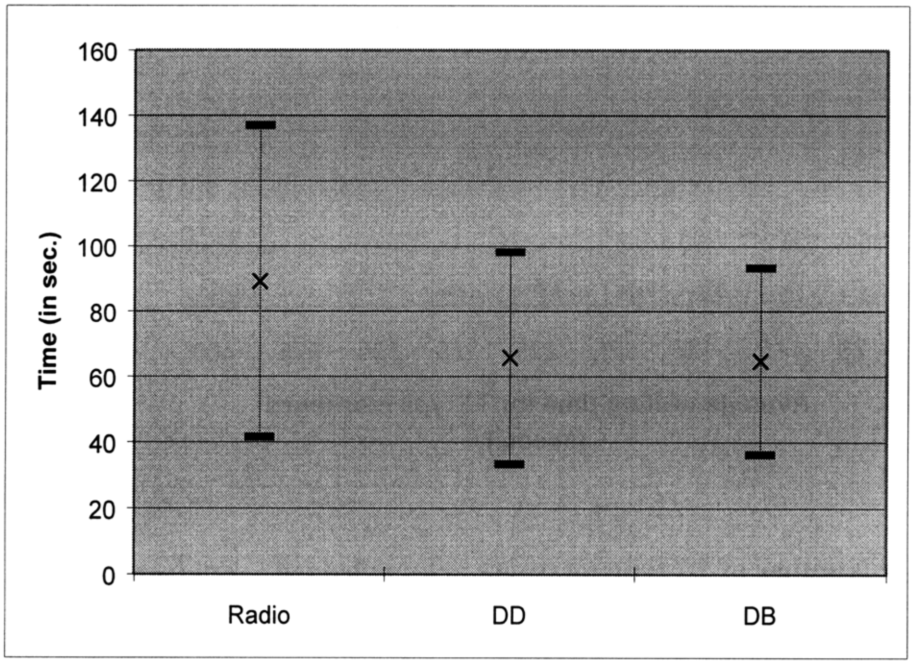

Figure 3-23: Acknowledgement time average for T2 type messages

Figure 3-23, shows the acknowledgement time average for T2 type messages and the 95% confidence interval of the mean (with $n = 41$, $\nu = 40$ and $\alpha = 0.95$). Here again the graph shows no statistically significant result as all the confidence intervals are overlapping. For T2 type messages, the radio environment has the largest average acknowledgement time. The average acknowledgement time has almost doubled in the radio case and not significantly changed in both data-link systems. This supports the assumption about caller prioritization, made earlier. When looking at T2 type messages, the audio alerter still plays in favor of the radio environment. The fact that in the process, the caller is immediately identified allows the dispatcher to perform a prioritization strategy (not between T1 and T2 types messages however!) not available to him in the data-link system unless he read the message. This plays against the radio environment and the result is that the acknowledgment mean is higher.

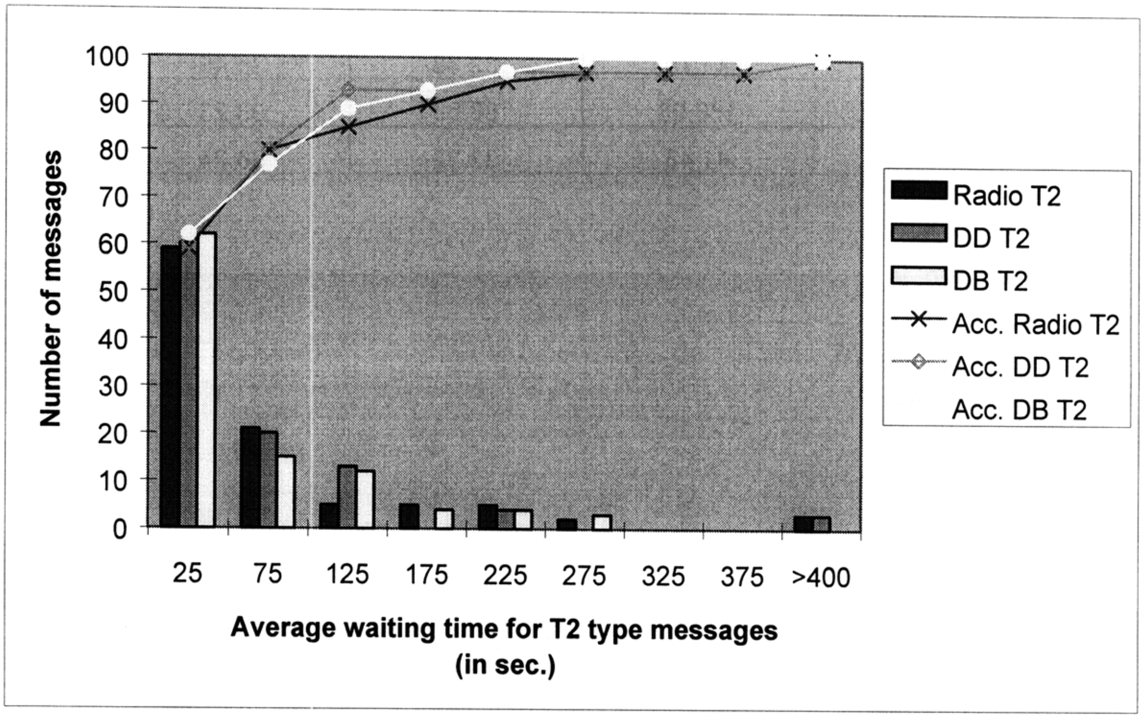

Figure 3-24: Number of T2 type messages acknowledged – Environment comparison

Figure 3-24, showing the number of T2 type acknowledged messages as a function of time confirms that there is no significant difference between environments. All three cumulative functions have roughly the same shape. There seems to be no best environment with respect to waiting time if we base our judgment on sheer statistics. Human factor considerations however would lead us to implement an audio alert for incoming message in data-link systems. The conclusions are the same than without T1 and T2 messages separation.

Processing times for T1 type messages across environments

processing T1	Radio	DD	DB
Mean - Environ.	8.87	39.18	13.40
Conf.	12.30	30.85	4.05
Mean - Max.	21.18	70.03	17.44
Mean - Min.	0.00	8.33	9.35

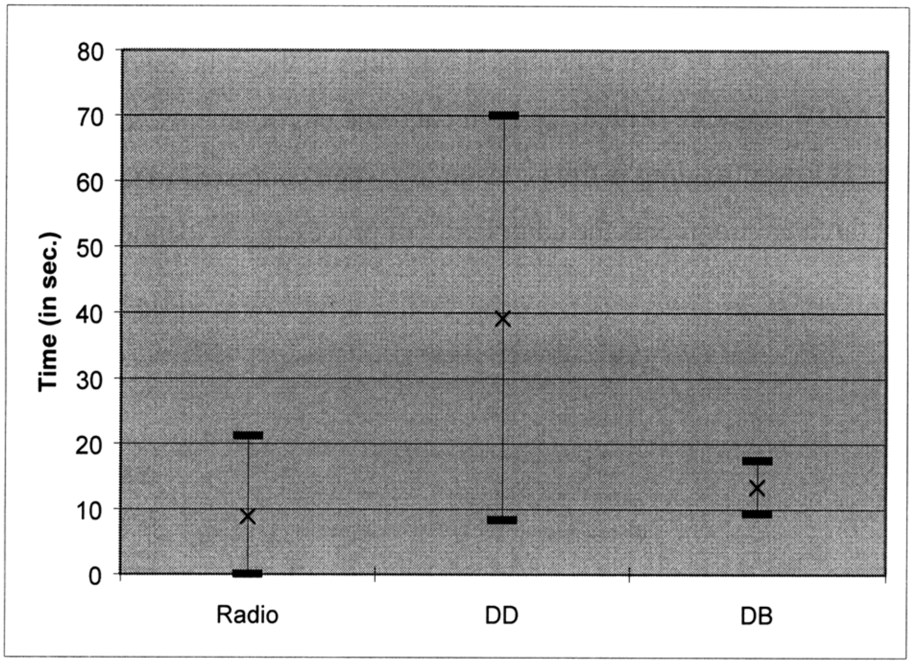

Figure 3-25: Processing time average for T1 type messages

Figure 3-25, shows the average processing time for T2 type messages and the 95% confidence interval of the mean (with $n = 51$, $\nu = 50$ and $\alpha = 0.95$).

The first important observation is that the graph shows no statistically significant result as all the confidence intervals are greatly overlapping. Nevertheless, we will discuss briefly the trend observed on the means. The means show two interesting features: first the rather large difference between both data-link environment and second the apparent superiority of radio over data-link systems with respect to T1 type messages.

The difference between the DD and DB environment is surprising even if it does not seem to be statistically significant, as the confidence interval of the DB environment is totally included in the confidence interval of the DD environment. We believe that the particularities of the experiment (introducing a bias due to the learning factor) led to this difference in means. It is also interesting to observe that even with the learning factor included, data-link systems do not perform as well in terms of processing time average as the radio environment does. When taking a closer look at the two types of messages, the relative position of the means comparing data-link and radio makes sense. There are two key elements in the processing time: the speed at which the dispatcher understands the subject of the communication and the complexity of the processing. Typically, for T1 type messages, the speed of understanding is very high in the radio environment (if we leave out the MOW requests denied). In both data-link environments, the speed of understanding is lower; reading is time consuming when compared to talking over the radio. For all three environments the complexity of processing is identical.

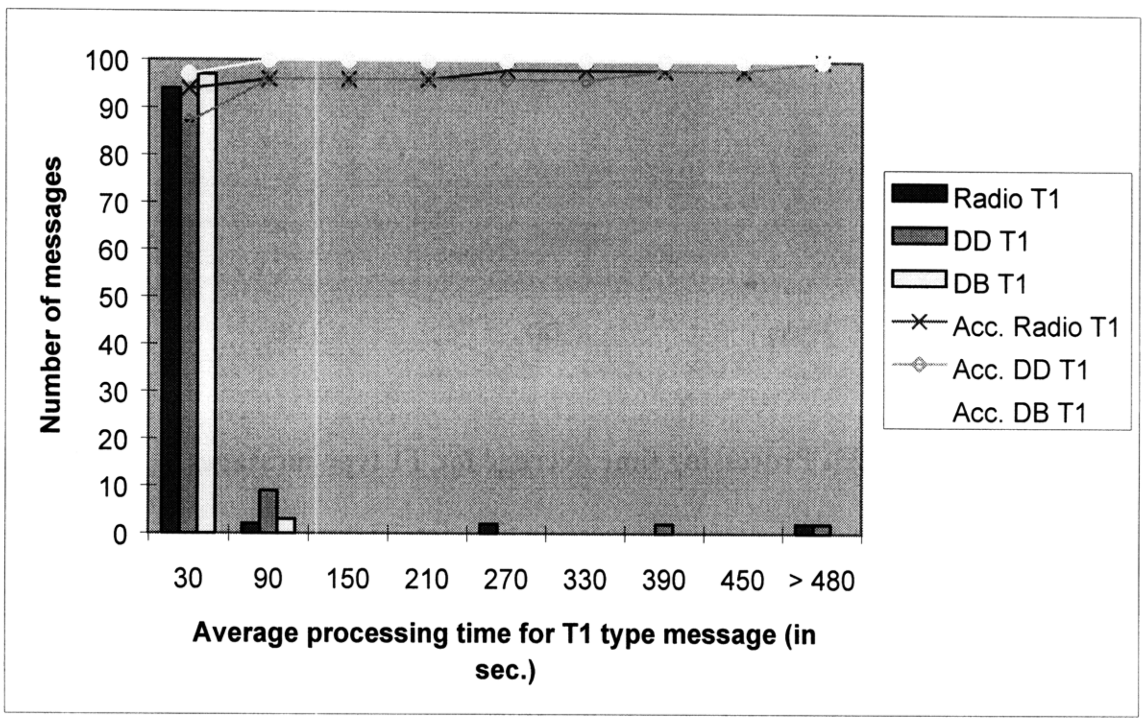

Figure 3-26: Number of T1 type messages processed - Environment comparison

Figure 3-26 allows us to compare for all three environment the number of T1 type messages processed as a function of time. The almost identical shape observed for all three environments proves that there is no difference between them in terms of processing speed for T1 type messages. For T1 type messages the conclusion we came to when considering all messages is not valid any more. There is superiority of data-link systems for T1 type messages.

Processing times for T2 type messages across environments

processing T2	Radio	DD	DB
Mean - Environ.	252.03	35.97	55.35
Conf.	100.65	9.75	32.63
Mean - Max.	352.68	45.71	87.97
Mean - Min.	151.38	26.22	22.72

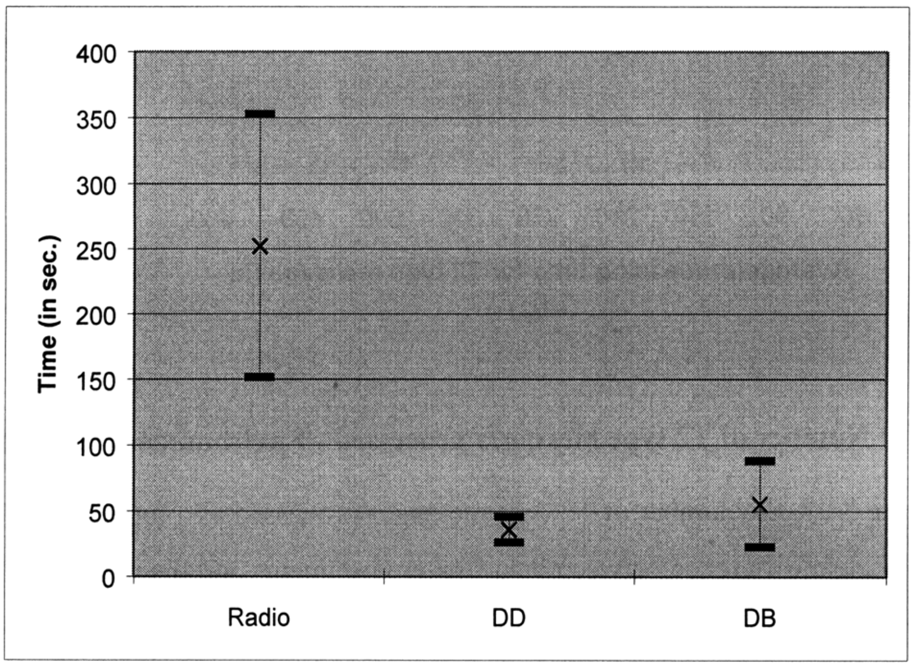

Figure 3-27: Processing time average for T2 type messages

Figure 3-27, shows the average processing time for T2 type messages and the 95% confidence interval of the mean (with $n = 31$, $\nu = 30$ and $\alpha = 0.95$). The first important observation is that the graph shows a clear statistical difference between the radio environment and both data-link environments. The second important observation is that data-link environments perform much better for T2 type messages than the radio environment. This can be easily understood if we look at the two main components of processing time and at the type of message considered. T2 type messages are complex to transmit. This complexity affects the speed of understanding in the radio environment.

Now it takes less time to read a message than to transmit the same message over the radio because of the message complexity. The complexity of processing remains the same.

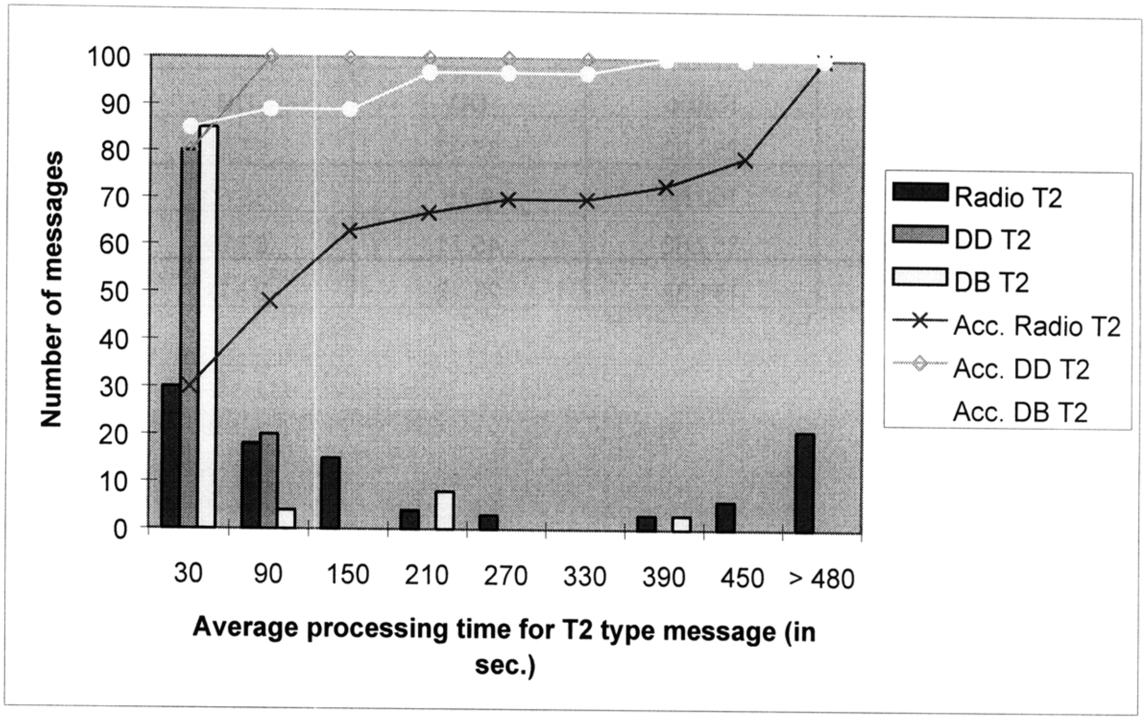

Figure 3-28: Number of T2 type messages processed - Environment comparison

Figure 3-28, the number of T2 type messages processed as a function of time shows a very clear difference between data-link environments and the radio environment. This is due to the tremendous advantage of having a common language when applied to complex messages. T2 type messages are difficult to transmit over the radio because the description of the exact section of the track for MOW activities is long and tedious over the radio. Having a visual aid such as the highlighting feature helps communication efficiency tremendously. For T2 type message the observation made in the general case about the superiority of data-link systems holds.

Answering times for T1 type messages across environments

answering T1	Radio	DD	DB
Mean - Environ.	21.64	27.25	24.58
Conf.	8.03	10.15	5.42
Mean - Max.	29.67	37.40	30.00
Mean - Min.	13.61	17.10	19.15

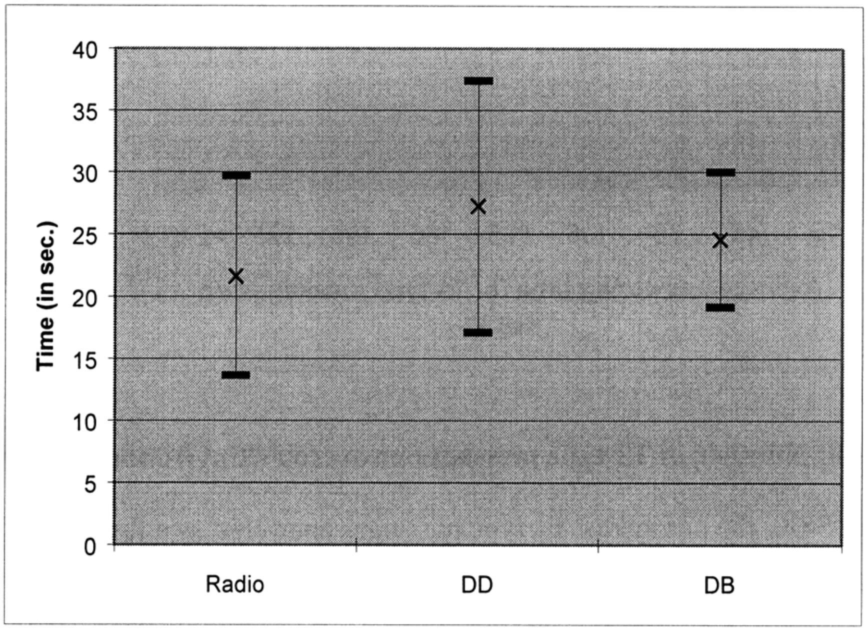

Figure 3-29: Average answering time for T1 type messages

Figure 3-29, shows the average answering time for T1 type messages and the 95% confidence interval of the mean (with $n = 41$, $\nu = 40$ and $\alpha = 0.95$). The main observation is that there is no difference in meaningful difference in means. This is an important result given the superiority of the data-link systems when treating all messages together.

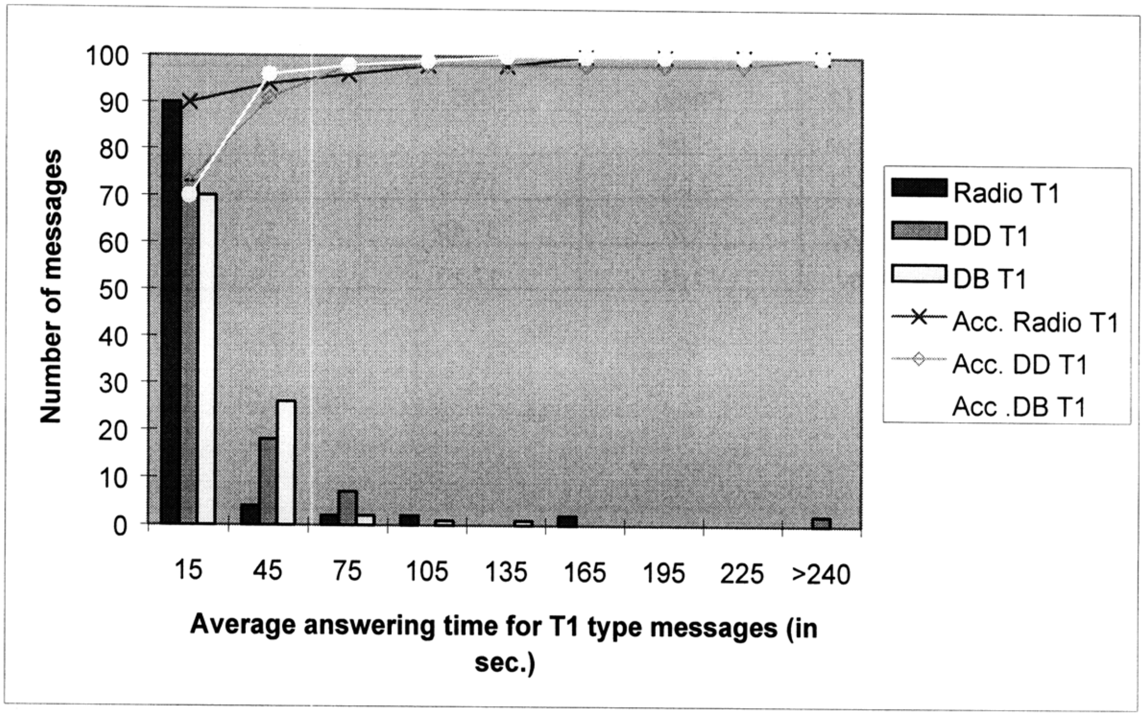

Figure 3-30: Number of T1 type messages answered - Environment comparison

Figure 3-30, the number of T1 type messages answered as a function of time, shows better the difference between data-link systems and the radio systems. The shapes of the cumulative functions are fairly similar. However the radio environment starts with a much higher number in the first category. Taking another look at Figure 3-29, we can see that the radio mean is slightly lower than the two others are. The reason is that T1 type messages are quick to transmit over the radio. Composing the messages, even with the help of the preprogrammed messages and the various fill-in features, is still longer. "No Ds, no changes, no speed restriction for you today" is said quicker over the radio than by sending the preprogrammed message hidden somewhere in the messages tree!

Answering times for T2 type messages across environments

answering T2	Radio	DD	DB
Mean - Environ.	116.64	64.04	43.27
Conf.	35.66	19.65	6.34
Mean - Max.	152.30	83.69	49.61
Mean - Min.	80.97	44.38	36.93

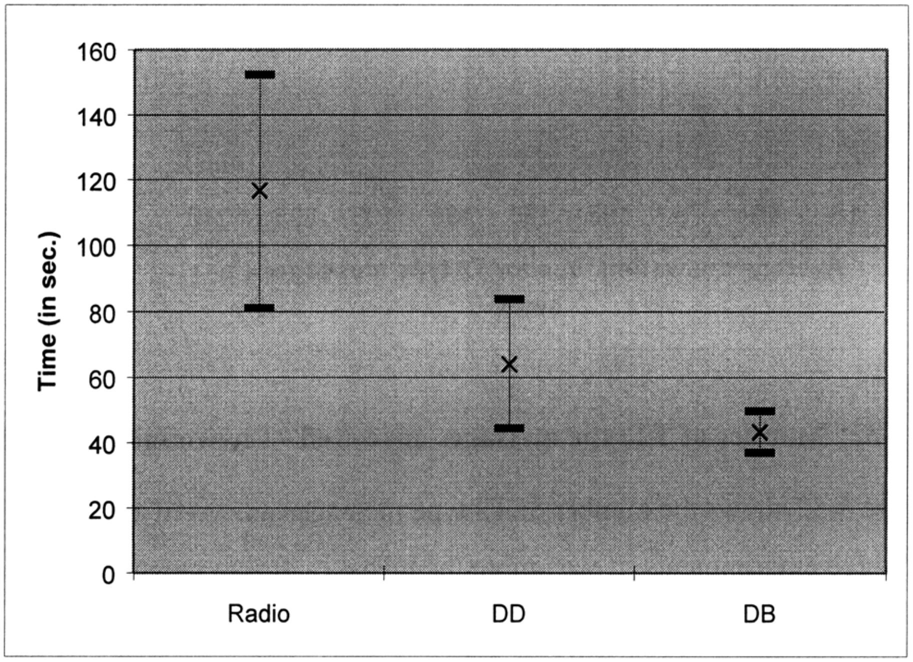

Figure 3-31: Average answering time for T2 type messages

Figure 3-31, shows the average answering time for T2 type messages and the 95% confidence interval of the mean (with $n = 31$, $\nu = 30$ and $\alpha = 0.95$). The main observation is that there is a clear difference now between data-link systems and the radio environment. The confidence intervals do not overlap unlike when treating all the messages together. Data-link systems provide a substantial advantage for T2 type messages. The complexity of the messages makes data-link more efficient in term of answering time. A computer-generated written message exchange between the dispatcher and the MOW crew is quicker than the tedious dictation and repeating process. The room for mistakes is reduced and the congestion of the radio is avoided.

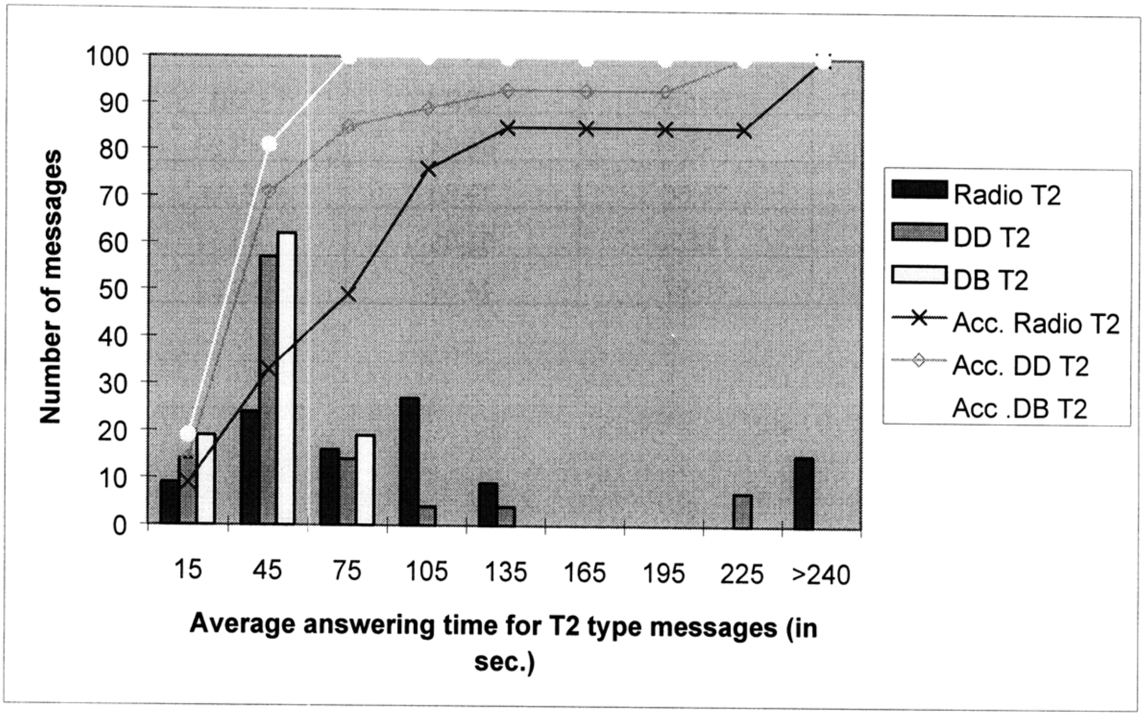

Figure 3-32: Number of T2 type messages answered - Environment comparison

Figure 3-32 shows the number of T2 type messages answered as a function of time for all three environments. If we ignore the mistakes during message composition in the DD case ("225 category"), both data-link environment show a very similar shape with a peak between 30 and 60 seconds. This is the category with the most T2 type messages answering time (composition in data-link systems). For the radio environment, we observe a relatively constant number of messages answered during the first two to three minutes. This is mainly due to the various levels of complexity in the description of the track sections granted. As observed when considering all messages together, mistakes and Cycle double the transmission time over the radio (see the above 240 seconds category).

Cycle times for T1 type messages across environments

cycle T1	Radio	DD	DB
Mean - Environ.	61.87	161.20	110.53
Conf.	28.39	52.68	27.00
Mean - Max.	90.26	213.88	137.53
Mean - Min.	33.48	108.52	83.52

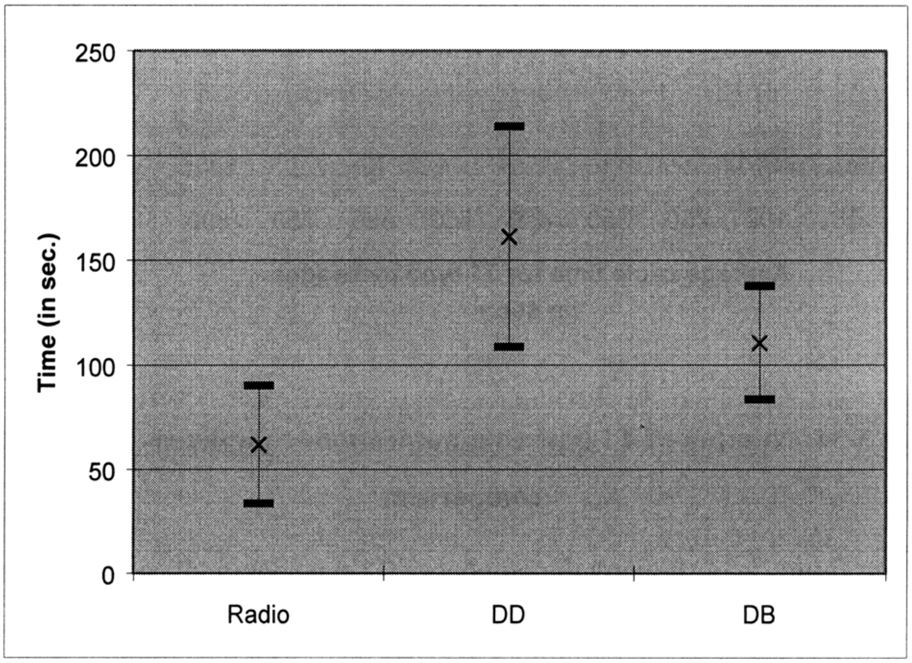

Figure 3-33: Average cycle time for T1 type messages

Figure 3-33, shows the average answering time for T1 type messages and the 95% confidence interval of the mean (with $n = 41$, $\nu = 40$ and $\alpha = 0.95$). This figure provides the most surprising result of the entire section. When observing the means and their confidence intervals, we can see that both data-link systems perform clearly worse than the radio environment. No previous result on waiting time, processing time and answering time for T1 type messages was as clear as this one. All of them indicated a slightly better mean for the radio case but no statistically significant difference. Added up all these little advantage to the radio environment turn out to be significant. Even if we subtract the average "random time span" added in the cycle time (roughly 20 seconds, see above), the result still holds: for T1 type messages the radio is more efficient.

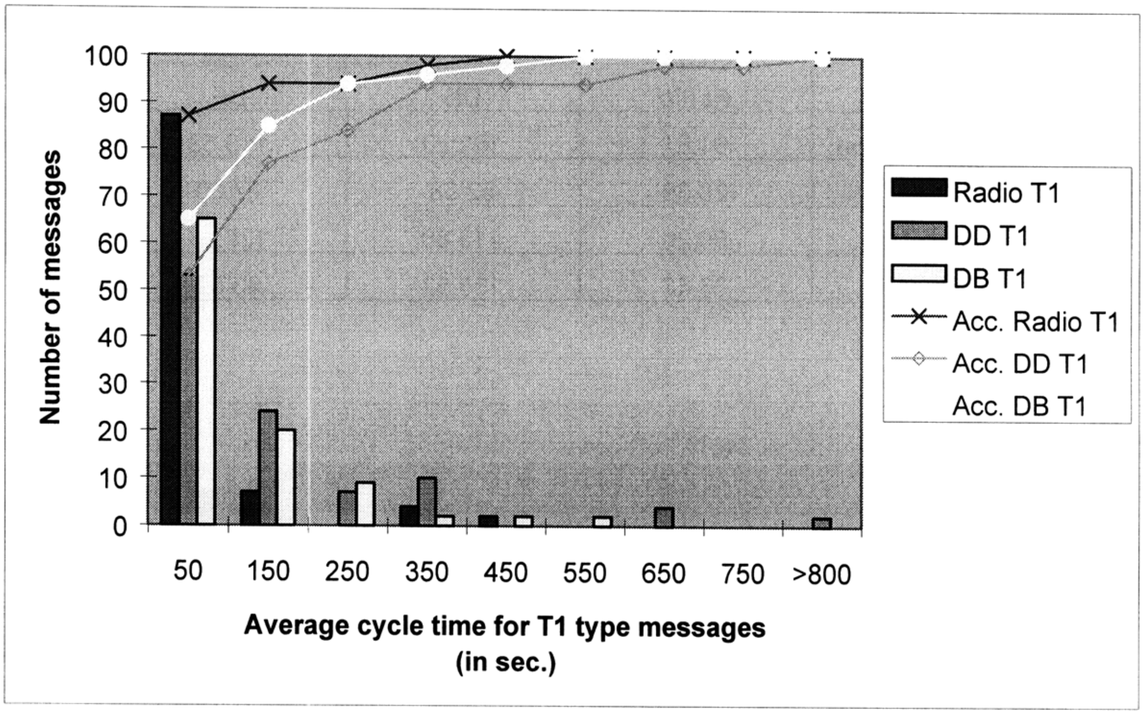

Figure 3-34: Number of T1 type communications completed- Environment comparison

Again, figure 3-34 showing the number of T1 type communications completed as a function of time, supports the result established with the previous figure. Radio is clearly more efficient. This does not contradict the result obtained when considering all types of messages but refines the analysis: for T1 type messages, the result obtained earlier (data-link is more efficient in terms of communication) does not hold any more.

Cycle times for T2 type messages across environments

cycle T2	Radio	DD	DB
Mean - Environ.	462.70	198.58	197.27
Conf.	142.78	43.32	48.02
Mean - Max.	605.48	241.90	245.29
Mean - Min.	319.91	155.27	149.25

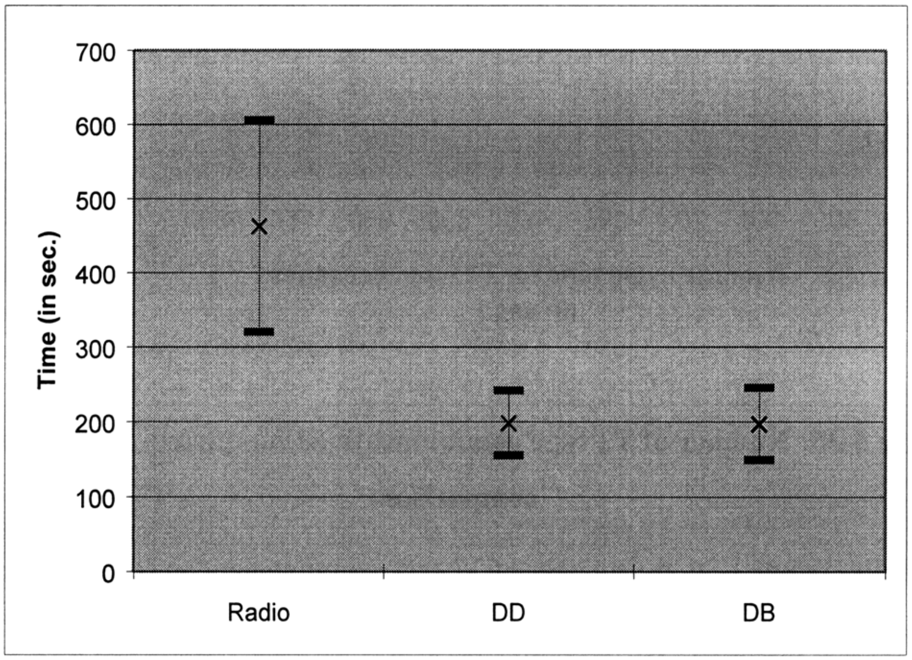

Figure 3-35: Average cycle time for T2 type messages

Figure 3-35, shows the average answering time for T2 type messages and the 95% confidence interval of the mean (with $n = 31$, $\nu = 30$ and $\alpha = 0.95$). The trend observed for the processing time and the answering time is clearly established here. For T2 type messages data-link systems are clearly superior. They cut the total communication time in half. The observation made when treating all messages together still holds for T2 type messages.

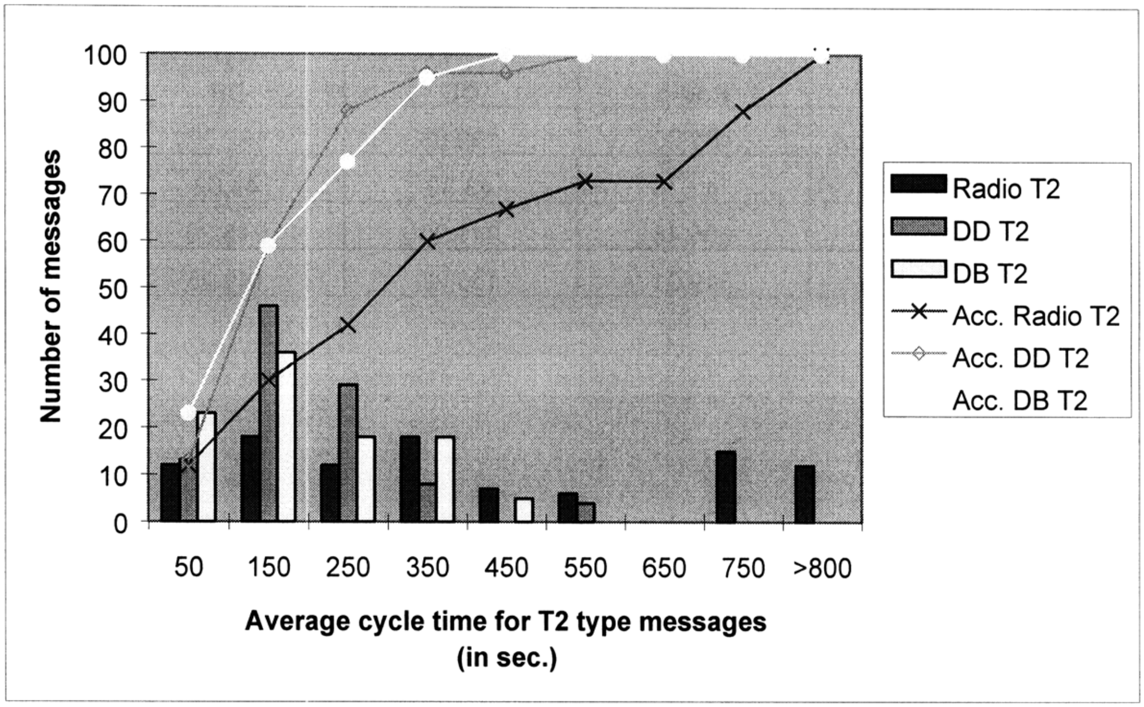

Figure 3-36: Number of T2 type communications completed- Environment comparison

Finally, figure 3-36, the number of T2 type communications completed as a function of time, supports the results shown on the previous figure. Data-link environments are clearly more efficient than the radio environment, even with the additional 20 seconds average "random time span". There seems to be no major difference between both data-link environments as the shapes of their cumulative functions are relatively similar. They exhibit a clear peak between 100 and 200 seconds with all T2 type communications completed within 10 minutes of the initiating message. Figure 3-36 also proves clearly our explanation for the two peaks seen when treating all the messages together. The second peak indeed consists of the MOW request granted. As observed when analyzing the answering time for T2 type messages, in the radio environment the number of T2 type communications completed remains constant over the first 10 minutes. All radio communications longer than 10 minutes appear to be the result of mistakes and repeats during the communication process.

The result obtained from this last figure adjusts the general observation made when considering all the messages together. Data-link is a more efficient environment overall because it provide enormous savings in terms of average communication time on T2 type messages.

3.2.2.3 Conclusion

Means	Radio	DD	DB
Waiting T1	48	83	58
Waiting T2	89	66	65
Processing T1	9	39	13
Processing T2	252	36	55
Answering T1	22	27	25
Answering T2	117	64	43
Cycle T1	62	161	111
Cycle T2	463	199	197

Table 3-15: Means for T1 and T2 type messages (in sec.)

Given that the histograms and cumulative functions tended to support the observations about the means, we summarized the result of the split analysis (T1 type messages and T2 type messages) in table 3-15. This second look at the communication efficiency gave us very insightful information about the effect of data-link on the communication environment of the dispatcher. The result, when not separating the messages into two groups, was that data-link was somewhat more efficient. After separating what we believed were two types of messages with different characteristics (in terms of communication requirements), we see that T1 type messages are much more adapted to the radio communication channel and that T2 type messages are much more adapted to a data-link communication channel. The relatively fuzzy results (in terms of confidence intervals) when comparing the three environments using all the messages turn out to be almost clear cut when separating the messages into two very specific groups.

3.2.3 Attention allocation patterns

The evaluation of the situation awareness in the various fields: routing, hazards, MOW and communication, was a challenge to begin with and we did not expect it to give significant results. Table 3-16, Table 3-17, Table 3-18 and Table 3-19 however show some interesting changes when switching from the radio environment to any of the data-link environments.

All four situation-awareness tables (routing table, hazards table, MOW table and communication table) show the percentage of questions answered properly for the respective section in the situation awareness questionnaire (see Appendix C). Each table includes the percentages per experiment, per dispatcher and the mean per environment. We also calculated the confidence interval of the mean to have a better idea of the significance of the values calculated. Detailed "grading" for each experiment can be found in Appendix E.

When looking at the following tables one can easily notice that the differences in means are mostly not statistically significant. Nevertheless we will use them as an indication on situation awareness evolution, as the tendency is almost consistently the same: an improvement with the shift towards data-link.

Routing	Radio	DD	DB	Disp- M
Disp #1	0.9	0.8		0.85
Disp #2	0.4	0.4		0.4
Disp #3	0.2		0.6	0.4
Disp #4	0.2		0.5	0.35
Disp #5		0.8	0.6	0.7
Disp #6		0.5	0.8	0.65
Mean	**0.425**	**0.625**	**0.625**	**0.558**
Conf.	0.53	0.33	0.20	
Mean - Max.	0.95	0.95	0.83	
Mean - Min.	0.00	0.30	0.42	

Table 3-16: Routing Situation Awareness Table

Table 3-16, the routing situation awareness table, shows an improvement in situation awareness in the field of routing when changing from the radio environment. Both data-link environments show better results, on average. Dispatchers seem to know more about the schedule, the trains and the delays in the radio environment. This might prove that with data-link, dispatchers tend to have more time to study the schedule and to monitor trains. Given that the means are not statistically significant, we have to analyze briefly each dispatcher's results. In the radio case, Disp #1 is the only participant to have a high 0.9 score out of four points. This data point might be somewhat special. If taken away, all data-link case values are higher than the best radio case value of 0.4 for Disp #2. This quick look at each dispatcher performance supports our first observation: data-link seems to improve the routing situation awareness.

Hazards	Radio	DD	DB	Disp- M
Disp #1	0.5825	0.8325		0.7075
Disp #2	0.25	0.75		0.5
Disp #3	0.75		0.8325	0.79125
Disp #4	0.6875		0.625	0.65625
Disp #5		1	0.5	0.75
Disp #6		0.8125	1	0.90625
Mean	0.5675	0.84875	0.739375	0.718541667
Conf.	0.35	0.17	0.35	
Mean - Max.	0.92	1.00	1.00	
Mean - Min.	0.21	0.68	0.39	

Table 3-17: Hazards Situation Awareness Table

Table 3-17, the hazard situation-awareness table, shows a clear situation awareness improvement with data-link. In this case, relying solely on the means to analyze the results is appropriate, as the confidence intervals do not overlap too much (the lower limits of the data-link values are close to the radio observed value). Again both data-link environment show an improvement in terms of hazard awareness. And if we ignore Disp #4 and Disp #5's relatively low results (respectively 0.625 and 0.5), all data-link's values are higher than the radio's. Here again, we believed that this observation supports the results read on the means. In the data-link case, dispatchers see the hazardous area displayed on the screen when they view the alerting message. They also have to click on the area when filling in the alerting message. Both these actions are believed to emphasize the hazards more than in the usual radio environment where dispatchers would in the ideal case write a personal note mentioning the hazardous area or report it in the "desk book". The means as well as the individual results show the advantage of written communication over audio communication in terms of memory, hence situation awareness. Audio communication is more ephemeral and therefore it is logical for radio to perform worse than data-link given the current procedure used by dispatchers (i.e. no requirement to write anything down).

MOW	Radio	DD	DB	Disp. M
Disp #1	0.89	0.89		0.89
Disp #2	0.50	0.67		0.58
Disp #3	0.89		0.55	0.72
Disp #4	1.00		1.00	1.00
Disp #5		0.83	0.33	0.58
Disp #6		1.00	1.00	1.00
Mean	**0.82**	**0.85**	**0.72**	**0.80**
Conf.	0.35	0.22	0.53	
Mean - Max.	1.00	1.00	1.00	
Mean - Min.	0.47	0.63	0.19	

Table 3-18: MOW Situation Awareness Table

Table 3-18, the MOW situation awareness table, is presenting us with three very close means. No major difference can be observed between the three environments. This can be easily explained using the written vs. audio communication reasoning. In the current radio environment, dispatchers write down their foul time requests or form Ds using either an actual form D or a foul time sheet. They also block up track on the screen for the MOW crews. The information coming over the radio translated very early on into a written reminder. In the data-link, dispatchers don't write down their requests, but the system was designed to ensure that dispatchers would be aware of their granted MOW requests (seeing the track highlighted in yellow, blocking the track and finally filling in the answer message). Here again, the advantage of having a written tool (be it a paper or a computer message) is critical to warranty a high situation awareness level and because all three environment provide that tool, a significant difference in the result would be surprising.

Comm.	Radio	DD	DB	Disp. M
Disp #1	0.25	0.33		0.29
Disp #2	0.63	1.00		0.81
Disp #3	0.75		0.50	0.63
Disp #4	0.63		1.00	0.81
Disp #5		1.00	0.75	0.88
Disp #6		0.50	0.38	0.44
Mean	**0.56**	**0.71**	**0.66**	**0.64**
Conf.	0.34	0.55	0.44	
Mean - Max.	0.91	1.00	1.00	
Mean - Min.	0.22	0.16	0.22	

Table 3-19: Communication Situation Awareness Table

Table 3-19, the communication situation awareness table, is the least clear. Nevertheless, when shifting from the radio environment to the data-link environments, there is small increase in the situation awareness level. We believe this rather small difference is due to the fact that the advantage of having a written trace of the communication was not used to its full extend (to refresh the memory and improve situation awareness) given the high level of workload during the experiment. Dispatchers rarely looked up previous messages and almost never consulted the sent-out message screen. Despite these particularities of the experiment, the results about communication situation awareness still support the overall tendency of data-link to improve all domains of situation awareness.

	Radio	DD	DB
Routing	0.43	0.63	0.63
Hazards	0.57	0.85	0.74
MOW	0.82	0.85	0.72
Mess.	0.56	0.71	0.66

Table 3-20: Situation Awareness Table

Table 3-20 is the summarizing the previous four tables showing only the means. We can clearly observe a permanent superiority of data-link over the radio whenever it was expected. This, all the more that radio was the second environment for all dispatcher testing it. Therefore, they had the opportunity to get ready for the situation awareness test and hence perform better. This advantage along with the unavoidable familiarity advantage did not prevent data-link from proving superior. The overall situation awareness seems to be improved, even if the confidence interval analysis indicates that the results are not statistically significant. The attention allocation pattern does not seem to change, in an unbalanced way. That is, there is no indication of a possible degradation in one of the four areas (routing, hazards, MOW and communication) as a result of an improvement in some other area. Data-link does not seem to divert the attention from the routing towards the communication by overloading the visual channel. The assumption that radio is a parallel channel (audio) to the routing (visual), and that the dispatcher is prevented from performing multiple tasks at the same time in data-link environments does not seem to hold in our experiment. This might be the result of our great number of complex messages, for which the dispatchers can not use "multitasking". It could also indicate a more general result about dispatching activities, i.e. there is very little "multitasking".

Finally in terms of overall safety, the situation awareness results indicate that data-link systems clearly have the potential of improving the work environment on railroads. The main reason for this potential is the advantage of written communication over audio communication in terms of memory.

3.2.4 Long term productivity improvements

One of the critical elements for railroads is productivity. Even though it was not the main emphasis of our study, productivity was an important issue. If data-link is to be implemented, it has to be profitable for the railroads and not only for the potential user. The investment necessary to implement data-link technology has to be balanced by the additional revenues generated by the increase in productivity. Therefore we looked at two very simple variables: the number of trains entering a station late (i.e. with a delay above 300 seconds – 5 minutes) and the number of MOW requests granted during each experiment.

	Radio	DD	DB	Total - disp.
Disp #1	10	8		18
Disp #2	13	6		19
Disp #3	0		3	3
Disp #4	7		7	14
Disp #5		1	4	5
Disp #6		12	1	13
Total	**30**	**27**	**15**	**72**
Mean	7.50	6.75	3.75	18
Conf.	8.86	7.28	3.98	
Mean - Max.	16.36	14.03	7.73	
Mean - Min.	0.00	0.00	0.00	

Table 3-21: Trains Late

Table 3-21 shows the number of trains late per dispatcher per experiment out of 28 trains entering a station at some point during the simulation (per experiment). Table 3-3 also shows the total amount of trains late for each environment (out of $4 \times 28 = 112$ trains) as well as the mean of trains late for each environment.

One can easily see that confidence interval for the mean (with $n = 4, \nu = 3$ and $\alpha = 0.95$) is very large. Mainly this shows us that we have no reliable information on the average number of late trains in either environment. However it is still interesting to look at the means. The radio and the data-link directed environment have very similar results.

The data-link broadcast case shows an astoundingly low number of late trains compared to the two other cases. We believe that there are two reasons for this. First, if we look at the total number of late trains for each dispatcher, Disp #3 and Disp #5 perform very well in terms of routing with respectively only 3 and 5 trains late. They are also the more experienced dispatchers with 7 and 9 years dispatching experience. These dispatchers account for 50% of the DB results. Second, as mentioned earlier, Disp #5 and Disp #6 both took the DD environment first and the DB environment. Therefore the DB results might benefit in terms of routing of the learning factor. An analysis of variance might provide us with a better estimate of the influence of the factor "dispatcher" on the results. As for the learning, there also some more powerful analysis tools are available. However we chose not to perform these tests because we only have two data points per dispatcher.

	Radio	DD	DB	Total - disp
Disp #1	7	7		14
Disp #2	7	8		15
Disp #3	8		9	17
Disp #4	8		4	12
Disp #5		9	6	15
Disp #6		7	7	14
Total	**30**	**31**	**26**	**87**
Mean	7.50	7.75	6.50	14.50
Conf.	0.92	1.52	3.31	
Mean - Max.	8.42	9.27	9.81	
Mean - Min.	6.58	6.23	3.19	

Table 3-22: MOW requests granted

Table 3-22 shows the number of MOW requests granted during each experiment. We also have the average MOW request per environment and its confidence interval using the four data points. There seems to be no significant difference between environments in terms of MOW work. The careful appendix reader might notice that the number of MOW requests granted to obtain the MOW safety data and the numbers used in Table 3-22, differ slightly for the radio environment. In fact, in the radio environment, when the section of track asked for was not available immediately, dispatchers asked the MOW crews (i.e. us) to call back. Typically, this would results in the following transmission: "I can't give you foul time right now. Train ### is due out there in 3 to 5 minutes. Call me back when he passes by you and I'll see what I can do". As we did not provide the dispatcher with this type of message in the data-link environments, we decided to count as valid for the MOW productivity variable, only the MOW requests granted without the crew being asked to call back. The difference in dispatching experience mentioned earlier does not seem to have a significant impact here. This is another reason why we did not perform any additional analysis to try and evaluate the influence of the factor "subject".

The results on productivity do not seem to be clear cut. The good result of the data-link broadcast environment should be used somewhat carefully. However given all the other results, we will argue that productivity improvements will not necessarily appear early on but more surely they will in the long term. It is our belief that productivity will increase due to a safer dispatching environment and a more efficient communication tool.

3.2.5 Two roughly identical scenarios

Our fundamental assumption when designing the experiment was that both scenarios would be identical in terms of workload (but different enough to prevent the learning factor to be too influential). So far, this assumption did hold. Note that even if it did not, the experimental design was balanced with respect to the scenarios so that the easier scenario would have affected all three environments equally. Nevertheless, we decided to check our assumption in a simple way. We calculated the mean of late trains per scenario and the mean of MOW requests granted per scenario. Table 3-23 shows the results along with a 95% confidence interval ($n = 6, \nu = 5$ and $\alpha = 0.95$).

	Scenario #1			Scenario #2		
		Late Trains	MOWs		Late Trains	MOWs
Disp #1	Radio	10.00	7.00	DD	8.00	7.00
Disp #2	DD	6.00	8.00	Radio	13.00	7.00
Disp #3	Radio	0.00	8.00	DB	3.00	9.00
Disp #4	DB	7.00	4.00	Radio	7.00	8.00
Disp #5	DD	1.00	9.00	DB	4.00	6.00
Disp #6	DB	1.00	7.00	DD	12.00	7.00
Mean		**4.17**	**7.17**		**7.83**	**7.33**
Conf.		4.27	1.81		4.27	1.08
Mean- Max.		8.44	8.97		12.11	8.42
Mean - Min.		0.00	5.36		3.56	6.25

Table 3-23: Scenario Comparison

The means of MOW requests granted are fairly similar and so is their confidence interval. As for the trains late, the confidence interval turns out to be very large and to overlap. Therefore we believe that the difference in means is not significant, and that the scenarios are indeed roughly similar. There again, a high level statistical analysis to assess the influence of the factor "scenario" in the results was possible, but rejected given the small number of data points and the "balanced" design.

3.2.6 The debriefing questionnaires.

Summary of the debriefing	Radio	DD	DB
Workload	6.3	6	5.8
Comfortable	5.9	5	4.3
Realistic	2.1		
Helpful		5.4	4.8
Routing first or communicating first?	depends	depends	depends
Would you like this environment in add.?		yes	yes

Table 3-24: Summary of the debriefing

The debriefing questionnaire was a very useful tool. It allowed us to make sure dispatchers took the experiment seriously. It was also a way to check that our goals in terms of scenario design were reached. Finally, it gave the dispatchers an opportunity to comment on our data-link design as well as our replica of the radio. Table 3-24 is a summary of the closed questions used during the debriefing questionnaires (one after each experiment and one after the eight hours). Detailed answers can be found in Appendix E.

All dispatchers seemed to take the experiment seriously. Four out of six dispatchers told us that the experiment was stressful, proof that they took it at least partially seriously. Also, the comments made were serious and helpful (see below). The workload turned out to be very high, as expected, with an average around 6 out of 7 in all three environments. The realism of the radio environment 2.1 out of 7 might be surprising but the main comment given along with the low grade was: "no way is a territory that busy…". One dispatcher said: "No way can a man deal with that during eight hours…it is totally unrealistic". This only shows us that the grade is mainly due to the high workload and not to a lack of similarity to the current radio environment (procedure, simulation, train behavior). No dispatcher criticized the radio environment as such.

All dispatchers felt relatively comfortable with the data-link environments (see table 3-24). We also observed that most dispatchers started with a negative attitude a priori on the data-link system. However, after the experiment, they all felt that it would be useful and helpful in addition to their current radio environment. When asked to rank various types of environment combination, all four dispatchers that saw the data-link broadcast environment ranked the Radio+DB combination highest. Out of the two remaining dispatchers, one ranked Radio only as the highest and one ranked Radio+DD highest.

Here is a summary of the comments on the experiment:

- The "shifts" are too busy to be realistic.
- The simulator could be used as a training tool, e.g. to teach the prioritization strategy.
- Change nomenclature for the track network and for the MOW crews.
- Radio is noisy and data-link provides a more calm environment.

Finally, here is a list of all the comments we had about data-link:

- The dispatcher needs a safe way to know that the recipient reads the answer message. The acknowledgement has to be worked on in the future. It is a safety issue.
- A sound alert for incoming messages would be welcome in the data-link environments.
- A hard copy of the MOW messages (and eventually of all of them at the end of the shift) is essential.
- The answered message should be marked in a different way in the data-link systems.
- When foul time is given back dispatcher should acknowledge reception.
- Use voice recognition.
- Data-link would be good for TSRB (with speed restrictions announcements), for form Ds, for form Ds for engineers, for medium long foul time, for trains crew and consist information, for car placement information, for planned track outage information, for emergency phone numbers.
- Data-link supports the dispatcher's memory demand. He can look back and see who called.
- Data-link allows messages acknowledgement when you have time. There is no audio pressure.
- The highlighting feature makes MOW request very clear however blocking actions should remove the yellow color.
- The broadcast feature was useful to alert a number of people very quickly (assuming a safe acknowledgement procedure is implemented).
- The broadcast feature might be misused. MOW crews might work without permission behind or before another crew. The passive track layout provides MOW crews with a lot of information; sometimes it can save them from a dispatcher's mistake but there again it might be misused.
- For emergency situations radio is better in order to get a response immediately.

4 Conclusion

One of the problems evident in the current dispatching environment is the congestion of the radio channel. Our first objective was to see if we could improve the current communication environment using data-link technology. Our second objective was to see how the introduction of data-link technology affects the dispatcher's task and strategies.

4.1 A solution to the congestion problem

We showed that data-link is an efficient communication tool and claim that it could be combined successfully with the radio in order to solve the congestion problem and to improve the overall dispatching-environment. Our results clearly exhibit the characteristics of the messages that should be transmitted using each of the channels.

The radio proved to be very efficient, in terms of communication time, for short and easy-to-transmit messages as well as for urgent and safety-critical information. A typical example is the answer to a train calling to request a temporary speed-restriction bulletin, when there is no speed restriction to report. Another example would be a call alerting a train about the presence of a trespasser on the track. For these types of messages, data-link tends to double the communication times.

Whereas, the data-link systems proved to be efficient, in terms of communication time, for messages whose complexity is a limiting factor on the transmission speed in the radio environment and for heavily regulated messages. A MOW request granted is a good example of a complex message, which is difficult to transmit over the radio. Transmitting a form D to a train is another example of where the rules (the train has to be at a stop) are the limiting factor on the radio transmission speed. For this second class of messages, data-link reduced the communication times by a factor of two. There is no doubt that data-link provides a highly efficient replacement channel for these messages assuming it is designed with a concern for safety.

Finally the comparison of both data-link system in terms of communication efficiency did not show any significant difference. The idea of not having to repeat a message many times was very appealing to the dispatchers.

4.2 The effect of data-link technology

With respect to our second objective, the results were not always statistically significant but a general trend can still be observed. Both data-link systems seem to:

- improve MOW safety
- improve the overall situation awareness
- make the task less stressful
- improve train safety

However, it is interesting to notice that the extend of the improvement is different for both data-link systems. This is due to their different designs.

Both systems clearly improved MOW safety by providing a common language and reference to MOW crews and dispatchers. The yellow highlighting made the MOW requests easy to understand and to process. Both systems showed a fair improvement in the overall situation awareness. The support provided by the written aspect of data-link systems, which we believe is the reason for this observation, mitigates the high demand placed on memory. The quiet environment and the gain in communication time might also be a factor. Finally the latter might also explain why the general feeling regarding data-link was that it was less stressful.

Comparing both data-link systems for all four improvement-areas, the main difference in results was in train safety. The broadcast version showed a clear superiority in terms of train safety over the directed version (already an improvement upon the radio). Its design provided the dispatcher with a solution to the high workload and demand on memory faced when a hazard is reported. In the broadcast version, a single message is enough to alert all endangered trains. The data-link directed system produced mediocre results because its design is closer to the radio environment in the handling of hazards.

However, the data-link broadcast version also has drawbacks in terms of information distribution and acknowledgment procedures. As indicated by some dispatchers, information can and will be misused when broadcast. The directed version does not present these drawbacks and as the party line did not seem to be a major advantage of the broadcast system, data-link directed seems to be a good solution to transmit most messages.

Finally, productivity improvements (decrease in the number of late trains and increase in number of granted MOW requests) were not observed. They are expected to appear as a result of the general improvement in the dispatching environment rather than as a direct consequence of the use of data-link technology. One of the reasons why we could not observe any, might also be the crudeness of our measurement variables.

4.3 The ideal system

An ideal system should combine all three environments tested. The radio would be used for simple and urgent messages to one recipient, the data-link directed system for complex and confidential messages and the data-link broadcast system for confidential or non-confidential messages to multiple recipients. This allocation of messages to the various channels would result in an increased communication-efficiency as well as in an increase level of safety.

Also, our data-link designs need multiple improvements including:

- an audio alerter for incoming messages
- the modification of highlighting properties
- a clear way to distinguish processed messages from unprocessed messages
- to eventually incorporate voice recognition capabilities
- a better designed graphical interface
- paper backups for liability reasons (e.g. printing granted/denied MOW requests)
- displaying information which is currently difficult to obtain or unavailable to dispatchers (e.g. real time positioning of train, or even MOW people)
- and most importantly, a simple, straightforward and guaranteed messages acknowledgment procedure

4.4 Future research

Our analysis shows that data-link technology has the potential to greatly improve the dispatching environment in terms of safety and communication efficiency. However, as always the introduction of new technology and new interfaces raises new issues along with solving old problems.

There are at least three main issues to be investigated before any data-link system can be implemented successfully. First, the acknowledgement issue. For safety reasons as well as for liability reasons, the acknowledgement procedure has to be investigated. Second, the consequence of information distribution. Providing MOW crews with a passive track layout could enable them to catch dispatching errors and would increase the level of safety. MOW crews could also decide to work without the dispatcher's permission and hence decrease the level of safety. Finally, the party line issue. It is not at all clear from our results, whether dispatchers really need party line information. However the heavy workload in our experiment probably made the need for party line unnoticeable.

We believe data-link should be part of the railroad world of the 21^{st} century.

5 Appendices

5.1 Appendix A – Various message trees

In this appendix we have the complete message tree drafted after the cognitive task analysis. We also have the message tree used during the experimental campaign. The first tree should give a feeling for the type of tree dispatchers could build in the real world. The second tree is part of the documents the dispatcher had available during the experiment. Finally we included the experimental message tree and the additional tree dispatchers used to specify the group of secondary recipients in the data-link broadcast environment.

Complete Dispatcher Message tree (designed after the CTA)

High priority:

Dispatcher to engineer

- Trespasser hit
  - Notified RT – protection set up.
  - Med. Assistance – help under way.
- Train derailment
  - Notified RT – help under way.
- Passenger death/injury
  - Notified RT – decision under way.
- Police intervention
  - Terrorist on board
  - Bomb on track
  - Found corpse near the track
- Threat for passengers
  - Chemical released
  - Bomb on track
- CETC problem
  - Field signal's failure – message routing required
  - Field signals OK - Special routing termination
  - Computer system restored
  - CETC screen failure

Dispatcher to rescue team

- Trespasser hit
  - Alert Rescue Team
- Passenger death/injury
  - Alert Rescue Team
- MOW fatality
  - Alert Rescue Team
- Train derailment
  - Alert Rescue Team

Medium priority

Dispatcher to engineer

- Trespasser
  - Trespassers on track ahead
  - Trespassers are gone
  - Trespassers have been taken car of.
- Obstruction on track
  - Vehicle on track
  - Train stuck on track
  - Trees across the track
  - No trees any more.
- Kids throwing stones
  - Kids are playing
  - Kids are gone
- Station with no bridge crossing
  - Entering unprotected station

Dispatcher to MOW

- MOW on the wrong track
  - Notification

Dispatcher to electrical department

- Loss of power
  - Repair needed

Low priority

Dispatcher to engineer

- Bulletin – Special restrictions
  - No bulletin
  - Bulletin follows
  - Bulletin update
  - Special speed restrictions
- State of engine
  - State of engine – OK
  - State of engine – Trouble
  - State of engine – Risk of serious failure
- Information
  - Delay – try to speed up
  - Slow crew – speed up please.
  - Earlier meet point
  - Requesting positioning
  - Dignitaries on the train
  - Special train acknowledged.
- Electrification failure
  - Train stopped - Elect. Dept under way
  - Delays and rerouting – Repair.
  - Delays and rerouting
- Track problem
  - Track was repaired – reduced speed
  - Track out of service – delay and rerouting
- Bad weather zone
  - Might encounter obstruction
  - Leafs on track - Reduce speed
- Special Car
  - Pick notification
  - Do not bother!
- Re-crewing
  - Re-crewing necessary
- Power change
  - Location of stop and wait
- Message routing
  - Special movement
- In Cab system failure
  - Field signals are reference

Dispatcher to MOW

- Track Work
  - Track Work - Foul time granted
  - Track Work - Foul time refused
  - Foul time refused – other proposal
  - Protection for Track Work set up
  - Foul time ending
  - Additional time granted
  - Additional time refused
- Signal work
  - Signal Work - Foul time granted
  - Signal Work - Foul time denied
  - OK – no protection however.
  - Signal Work – Protection ready
- Track Car stuck
  - Garage guys under way

Dispatcher to Yard

Track wishes

Not possible – other track or wait

OK for required track.

Dispatcher to Lifting Bridge

Bridge Lifting

OK to lift bridge

Impossible to lift the bridge

The Dispatcher Message Tree using during the experiment

High Priority

To Engineer - Fatalities	
Trespasser hit	Train derailment
Notified RT – protection set up.	Notified RT – help under way
Med. Assistance – help under way	To other trains – routing delays
	To MOW – train derailed – busy time

To Rescue Team	
Trespasser hit	Train derailment
Alert Rescue Team	Alert Rescue Team

Medium priority

To Engineer – Danger warning		
Trespasser	Obstruction – Train stalled	Kids throwing stones
Trespassers on track ahead	Vehicle on track	Kids are playing
Trespassers are gone	Train stuck on track	Kids are gone
Trespassers have been taken car of.	Information request about your stalled train	
	Locomotive is coming	

To MOW – Danger Warning
MOW on the wrong track
Notification

Low priority

To Engineer – Standard Communication			
Temporary Speed restrictions	Track problem	State of engine	Special train movements
No TSRB	Track was repaired – reduced speed	Special routing due to risk of total failure	Special movement
TSRB follows	Track out of service – delay and rerouting		
TSRB update			
Special speed restrictions			

Dispatcher to MOW - Standard Communication		To Yard – Routing preferences		To Lifting Bridge
Track Work	Signal work	Track wishes	Need a locomotive	Bridge Lifting
Track Work - Foul time granted	Signal Work - Foul time granted	Not possible – other track or wait	Can we have a locomotive?	OK to lift bridge
Track Work - Foul time refused	Signal Work - Foul time denied	OK for required track		Impossible to lift the bridge
Foul time refused – other proposal				
Foul time ending				

Special Message – Blank Message

Broadcast Group selection

The broadcast group selection has two layers. The first layer is the type of recipient and the second is the location of these recipients. The broadcast group selection tree used in the experiment has the following structure:

(Recipient) Trains
- (Location)
  - *On branch A*
  - *On branch B*
  - *On branch C*
  - *On branch D*
  - *All*

Trains and MOW
- *On branch A*
- *On branch B*
- *On branch C*
- *On branch D*
- *All*

MOW
- *On branch A*
- *On branch B*
- *On branch C*
- *On branch D*
- *All*

Everybody

Experimenter's message tree

ENGINEER MESSAGE TREE

High priority

- *Engineer to Dispatcher*
  - Trespasser hit
    - Train hit a trespasser
    - Medical help is needed
  - Passenger dead/injured
    - Assistance in station
    - Assistance right away?
  - Train derailed
    - Need help

Medium priority

- *Engineer to Dispatcher*
  - Trespasser
    - Seen on track
    - No there any more
  - Engine failure
    - Train stuck on track
    - Freight train stuck.
    - Power insufficient – need power/loco
  - Threat for people in the train
    - Chemicals released
    - Bomb on the track
  - Kids throwing stones
    - Kids throwing stones
    - Not there any more
  - Obstruction
    - Engine failure - train stuck on track
    - Trees across the track
    - No trees any more
    - Additional locomotive needed – freight train
  - Failures
    - Total power loss – Train stuck
    - In cab system failure
  - Re-crewing
    - Crew outlawed
    - Re-crewing position OK
  - What is up?!
    - Need information – What are you doing?

Low priority

- *Engineer to Dispatcher*
  - Engine state
    - Engine OK
    - Engine state – serious trouble
  - Track problem
    - Track damaged
  - Bad weather
    - Thunderstorm – reduce speed
    - Leafs on the track – reduce speed
  - Special events
    - Dignitaries on the train

Bulletin
  - Bulletin request

Warning
  - Long/large/high train!

Position report
  - Current position

Engineer to Support staff

Engine state
  - Engine OK
  - Engine state – serious trouble

MISCELLANIOUS MESSAGE TREE

<u>High priority</u>

Police to Dispatcher

Police intervention
  - Stop the train
  - Corpse near the track

Rescue Team to dispatcher

Fatality
  - Everything under control

Train derailment
  - Everything under control

Passenger dead/injured
  - Everything under control

MOW fatality/injury
  - Everything under control

System to Dispatcher

MOW in danger
  - Protection forgotten
  - Gave foul time but unprotected!

<u>Medium priority</u>

System to Dispatcher

MOW person on the wrong track
  - Worker not protected

Trespasser
  - Trespasser on track

Obstruction
  - Vehicle stranded on grade crossing

Unprotected station
  - Station with no bridge crossing

Electrification problem
  - Power cable failure
  - Loss of electrification/power

Re-crewing
  - Crew outlawed

Loco power problem
  - Power insufficient

CETC problem
  - Not updating – shift to radio communication
  - Field signal problem – messaging routing

Electrification Department to Dispatcher
- Power loss
  - Power outage on track.
  - Power problem repaired

<u>Low priority</u>

System to Dispatcher
- Engine state
  - Engine OK
  - State of the engine – serious trouble
- Information
  - Rescue operation – World information
  - Unprotected station – World information
  - Notified - Height limitation on given track
  - Notified - Speed limitation on given track
  - Emergency phone numbers
- Special events
  - Dignitaries on train
  - Special train
  - Special car
- Delays
  - Slow crew
  - Scheduled meet not possible
- Bulletin
  - Bulletin request
- Warnings
  - Long/large/high train!
  - Operation at limit capacity
  - Reminder – Train priorities
  - Signal workers on track
  - Two meets and passes at same time
  - Time to recover - alert
- Possible dispatching mistakes
  - Omitted a warning
  - Unnecessary route cleared
  - Routing mistake – Lack of protection?
  - Too much track given away
  - Routing mistake – No power!

Yard to Dispatcher
- Train servicing
  - Request particular track

System to Engineer
- Engine state
  - Engine OK
  - State of the engine – serious trouble
- Bulletin
  - No bulletin
  - Bulletin – restrictions
  - Bulletin – update

Bridge Lifting to Dispatcher
- Bridge Lifting
  - Ship waiting for bridge
  - The ship passed

MOW MESSAGE TREE

High priority

- *MOW to Dispatcher*
  - MOW fatality/injury
    - Railroad person dead (heart attack)
    - Medical assistance needed

Medium Priority

- *MOW to Dispatcher*
  - Track Work
    - Track Work permission request
    - Track Work protection request
    - Work completed
    - Additional time requested
  - Signal Work
    - Signal Work permission request
    - Signal Work protection request
  - Track car failure
    - Track car stuck
    - Track car out of the way
  - Track problem
    - Track damaged
    - Work performed – Speed restrictions
  - Power loss
    - Power outage on track.

5.2 Appendix B – Various schedules

Appendix B contains the various schedules for the trains, the hazards and for the MOW work. The train schedule was provided to dispatchers during the experiment. The two other schedules are results from the experimental design and were used in the data analysis to create the summary tables.

The following is the train schedule for scenario #1

Br.	Dir.	Train #	Ptf.	Terminal		Interlocking		Interlocking		Interlocking		Interlocking		Interlocking	
BRANCH A	IN		1	1:26 PM	A1	1:23 PM	A2	1:21 PM	A3	1:14 PM	A4	1:07 PM	A5	1:00 PM	A-t3
			2	1:46 PM	A1	1:43 PM	A2	1:41 PM	A3	1:34 PM	A4	1:27 PM	A5	1:20 PM	A-t4
			3	2:17 PM	A1	2:14 PM	A2	2:12 PM	A3	2:05 PM	A4	1:58 PM	A5	1:51 PM	A-t2
	OUT	111	1	12:39 PM	A1	12:42 PM	A2	12:44 PM	A3	12:51 PM	A4	12:58 PM	A5	1:05 PM	A-t2
		113	3	12:58 PM	A1	1:01 PM	A2	1:03 PM	A3	1:10 PM	A4	1:17 PM	A5	1:24 PM	A-t1
		115	2	1:27 PM	A1	1:30 PM	A2	1:32 PM	A3	1:39 PM	A4	1:46 PM	A5	1:53 PM	A-t2
		117	3	1:34 PM	A1	1:37 PM	A2	1:39 PM	A3	1:46 PM	A4	1:53 PM	A5	2:00 PM	A-t1
BRANCH B	IN		6	1:42 PM	B1	1:38 PM	B2	1:32 PM	B3	1:27 PM					NS
			4	2:20 PM	B1	2:16 PM	B2	2:10 PM	B3	2:05 PM					NS
	OUT	221	3	12:50 PM	B1	12:54 PM	B2	1:00 PM					B4	1:05 PM	BL-t1
		223	6	1:06 PM	B1	1:10 PM	B2	1:16 PM					B4	1:21 PM	BL-t1
		225	5	1:27 PM	B1	1:31 PM	B2	1:37 PM					B4	1:42 PM	BL-t2
BRANCH C	IN		7	1:21 PM	C1	1:17 PM	C2	1:13 PM	C3	1:10 PM	C4	1:05 PM	C5	1:01 PM	No
			7	2:00 PM	C1	1:58 PM	C2	1:52 PM	C3	1:49 PM	C4	1:44 PM	C5	1:40 PM	No
	OUT	331	8	1:08 PM	C1	1:12 PM	C2	1:16 PM	C3	1:19 PM	C4	1:24 PM	C5	1:28 PM	No
		333	4	1:42 PM	C1	1:46 PM	C2	1:50 PM	C3	1:53 PM	C4	1:58 PM	C5	2:02 PM	No
BRANCH D	IN		8	1:35 PM	D1	1:33 PM	D2	1:25 PM	D3	1:21 PM	D4	1:17 PM	D5	1:10 PM	D-t1
			9	2:20 PM	D1	2:18 PM	D2	2:10 PM	D3	2:06 PM	D4	2:02 PM	D5	1:55 PM	D-t2
	OUT	441	8	12:42 PM	D1	12:44 PM	D2	12:52 PM	D3	12:56 PM	D4	1:00 PM	D5	1:07 PM	D-t2
		443	7	1:04 PM	D1	1:08 PM	D2	1:14 PM	D3	1:18 PM	D4	1:22 PM	D5	1:29 PM	D-t2
Yard	IN	225EQ	5	ar. 1:15 PM		To terminal									
	OUT	300EQ	7	ar. 1:30 PM		To Yard									

Station		Interlocking		Interlocking		Interlocking		Station		Interlocking	F.D.	Train #	Dir.	Br.
12:59 PM	A6	12:56 AM	A7	12:49 AM							1	100	IN	BRANCH A
1:19 PM	A6	1:09 PM	A7	1:02 PM							2	102		
1:50 PM	A6	1:44 PM	A7	1:37 PM							3	104		
1:16 PM	A6	1:18 PM	A7	1:25 PM									OUT	
1:29 PM	A6	1:31 PM	A7	1:38 PM										
1:56 PM	A6	1:58 PM	A7	2:05 PM										
2:04 PM	A6	2:06 PM	A7	2:13 PM										
			B6	1:26 PM	B7	1:19 PM	BR-t2	1:17 PM	B8	12:50 PM	6	200	IN	BRANCH B
			B6	2:04 PM	B7	1:57 PM	BR-t3	1:55 PM	B8	1:50 PM	4	202		
1:10 PM	B5	1:11 PM	B6	1:13 PM	B7	1:20 PM	NS-t3	1:22 PM	B8	1:24 PM			OUT	
1:23 PM	B5	1:24 PM	B6	1:26 PM	B7	1:33 PM	NS-t3	1:35 PM	B8	1:37 PM				
1:45 PM	B5	1:46 PM	B6	1:48 PM	B7	1:55 PM	NS-t3	1:57 PM	B8	1:59 PM				
											7	300	IN	BRANCH C
											7	302		
													OUT	
1:09 PM	D6	1:03 PM	D7	1:01 PM	D8	12:58 PM					7	400	IN	BRANCH D
1:54 PM	D6	1:49 PM	D7	1:46 PM	D8	1:43 PM					9	402		
1:18 PM	D6	1:18 PM	D7	1:21 PM	D8	1:24 PM							OUT	
1:32 PM	D6	1:32 PM	D7	1:35 PM	D8	1:38 PM								
										ar. 1:15 PM	5	225EQ	IN	Yard
										ar. 1:30 PM	Yard	300EQ	OUT	

The following is the train schedule for scenario #2

Br.	Dir.	Train #	Pff.	Terminal		Interlocking		Interlocking		Interlocking		Interlocking		Interlocking	
BRANCH A	IN		1	4:31 PM	A1	4:28 PM	A2	4:26 PM	A3	4:19 PM	A4	4:12 PM	A5	4:05 PM	A-t3
			2	5:05 PM	A1	5:02 PM	A2	5:00 PM	A3	4:53 PM	A4	4:46 PM	A5	4:39 PM	At3
			1	5:32 PM	A1	5:29 PM	A2	5:27 PM	A3	5:20 PM	A4	5:13 PM	A5	5:06 PM	A-t3
	OUT	191	3	4:00 PM	A1	4:03 PM	A2	4:05 PM	A3	4:12 PM	A4	4:19 PM	A5	4:26 PM	A-t2
		193	2	4:32 PM	A1	4:35 PM	A2	4:37 PM	A3	4:44 PM	A4	4:51 PM	A5	4:58 PM	A-t1
BRANCH B	IN		3	4:19 PM	B1	4:15 PM	B2	4:09 PM	B3	4:04 PM					NS
			4	4:28 PM	B1	4:24 PM	B2	4:18 PM					B4	4:13 PM	BL-t1
			6	4:44 PM	B1	4:40 PM	B2	4:34 PM	B3	4:29 PM					NS
	OUT	291	4	4:01 PM	B1	4:05 PM	B2	4:11 PM	B3	4:16 PM					NS
		293	5	4:23 PM	B1	4:27 PM	B2	4:33 PM					B4	4:38 PM	BL-t2
BRANCH C	IN		8	4:27 PM	C1	4:23 PM	C2	4:19 PM	C3	4:16 PM	C4	4:11 PM	C5	4:07 PM	No
			7	4:37 PM	C1	4:33 PM	C2	4:29 PM	C3	4:26 PM	C4	4:21 PM	C5	4:17 PM	No
			8	4:58 PM	C1	4:54 PM	C2	4:50 PM	C3	4:47 PM	C4	4:42 PM	C5	4:38 PM	No
	OUT	391	8	4:03 PM	C1	4:07 PM	C2	4:11 PM	C3	4:14 PM	C4	4:19 PM	C5	4:23 PM	No
		393	7	4:22 PM	C1	4:26 PM	C2	4:30 PM	C3	4:33 PM	C4	4:38 PM	C5	4:42 PM	No
BRANCH D	IN		9	4:31 PM	D1	4:29 PM	D2	4:21 PM	D3	4:17 PM	D4	4:13 PM	D5	4:06 PM	D-t2
			10	4:54 PM	D1	4:52 PM	D2	4:44 PM	D3	4:40 PM	D4	4:36 PM	D5	4:29 PM	D-t1
			9	5:20 PM	D1	5:18 PM	D2	5:10 PM	D3	5:06 PM	D4	5:02 PM	D5	4:55 PM	D-t2
	OUT	491	8	3:54 PM	D1	3:56 PM	D2	4:04 PM	D3	4:08 PM	D4	4:12 PM	D5	4:19 PM	NS-t1
		493	9	4:20 PM	D1	4:22 PM	D2	4:30 PM	D3	4:34 PM	D4	4:38 PM	D5	4:45 PM	D-t2
Yard	OUT	360EQ	8	ar. 4:40 PM		To Yard									
		120EQ	1	ar. 4:40 PM		To Yard									

Station		Interlocking		Interlocking		Interlocking		Station		Interlocking	F.D.	Train #	Dir.	Br.
4:04 PM	A6	3:59 PM	A7	3:52 PM							1	120	IN	BRANCH A
4:38 PM	A6	4:31 PM	A7	4:24 PM							2	122		
5:05 PM	A6	4:57 PM	A7	4:50 PM							1	124		
4:35 PM	A6	4:37 PM	A7	4:44 PM									OUT	
5:00 PM	A6	5:02 PM	A7	5:09 PM										
			B6	4:03 PM	B7	3:56 PM	BR-t2	3:54 PM	B8	3:42 PM	3	240	IN	BRANCH B
4:12 PM	B5	4:09 PM	B6	4:08 PM	B7	4:01 PM	BR-t3	3:59 PM	B8	3:45 PM	4	242		
			B6	4:28 PM	B7	4:21 PM	BR-t3	4:19 PM	B8	4:10 PM	6	244		
			B6	4:17 PM	B7	4:24 PM	BR-t2	4:33 PM	B8	4:35 PM			OUT	
4:43 PM	B5	4:44 PM	B6	4:46 PM	B7	4:53 PM	BR-t3	4:56 PM	B8	4:58 PM				
											8	360	IN	BRANCH C
											7	362		
											8	364		
													OUT	
4:05 PM	D6	3:58 PM	D7	3:55 PM	D8	3:52 PM					9	480	IN	BRANCH D
4:28 PM	D6	4:19 PM	D7	4:16 PM	D8	4:13 PM					10	482		
4:54 PM	D6	4:49 PM	D7	4:46 PM	D8	4:43 PM					9	484		
4:20 PM	D6	4:20 PM	D7	4:23 PM	D8	4:26 PM							OUT	
4:50 PM	D6	4:50 PM	D7	4:53 PM	D8	4:56 PM								
										ar. 4:40 PM	Yard	360EQ	OUT	Yard
										ar. 4:40 PM	Yard	120EQ		

The following is the hazard schedule for scenario #1 (with MOW crew calling times)

	Tresp.		Kids		Bridge	Messages	MOW	MOW out	Total Mess.
1:00 PM		221							
1:01 PM							SW #1		1
1:02 PM									
1:03 PM									
1:04 PM									
1:05 PM									
1:06 PM									
1:07 PM	100					1			2
1:08 PM									
1:09 PM									
1:10 PM					Disp	2			3
1:11 PM			300				RC #5		4
1:12 PM									
1:13 PM	113							SW #1	5
1:14 PM				443		3			6
1:15 PM							SW #3		7
1:16 PM		223	331			4			8
1:17 PM								RC #1	9
1:18 PM									
1:19 PM									
1:20 PM									
1:21 PM				400		5			10
1:22 PM									
1:23 PM									
1:24 PM							RC #6	RC #2	11,12
1:25 PM									
1:26 PM									
1:27 PM	102	200				6,7	RC #3		13,14,15
1:28 PM									
1:29 PM								SW #3	16
1:30 PM									
1:31 PM									
1:32 PM									
1:33 PM									
1:34 PM							TC #2		17
1:35 PM									
1:36 PM									
1:37 PM		225							
1:38 PM							SW #4		18
1:39 PM									
1:40 PM									
1:41 PM									
1:42 PM	115					8	TC #3		19,20
1:43 PM									
1:44 PM									
1:45 PM							RC #4		21
1:46 PM									
1:47 PM									
1:48 PM									
1:49 PM	117		302			9			22
1:50 PM			333		Disp	10			23
1:51 PM							SW #5		24
1:52 PM									
1:53 PM									
1:54 PM								TC #2	25
1:55 PM									
1:56 PM									
1:57 PM									
1:58 PM	104								
1:59 PM									
2:00 PM									

The following is the hazard schedule for scenario #2 (with MOW crew calling times)

	Tresp.		Kids		Bridge	Number of M	MOW	MOW End	Total Mess.
4:00 PM									
4:01 PM							SW #1		1
4:02 PM									
4:03 PM									
4:04 PM		240		491		1			2
4:05 PM							RC #2		3
4:06 PM									
4:07 PM									
4:08 PM								RC #1	4
4:09 PM									
4:10 PM					Disp.	2			5
4:11 PM		291	391				RC #5		6
4:12 PM	120					3			7
4:13 PM		242							
4:14 PM									
4:15 PM	191						RC #3		8
4:16 PM									
4:17 PM			360	480		4.5		SW #1	9,10,11
4:18 PM									
4:19 PM									
4:20 PM									
4:21 PM								RC #6	12
4:22 PM									
4:23 PM									
4:24 PM									
4:25 PM							TC #2		13
4:26 PM									
4:27 PM			362						
4:28 PM									
4:29 PM		244				6	RC #8		14,15
4:30 PM			393	493					
4:31 PM									
4:32 PM									
4:33 PM		293							
4:34 PM									
4:35 PM							TC #1	RC #2	16,17
4:36 PM									
4:37 PM									
4:38 PM							RC #7		18
4:39 PM									
4:40 PM				482					
4:41 PM									
4:42 PM									
4:43 PM									
4:44 PM		293				7			19
4:45 PM							RC #4		20
4:46 PM	122					8			21
4:47 PM	193							RC #5	22
4:48 PM			364			9			23
4:49 PM									
4:50 PM					Disp.	10			24
4:51 PM									
4:52 PM							TC #3		25
4:53 PM									
4:54 PM									
4:55 PM									
4:56 PM								TC #2	26
4:57 PM									
4:58 PM									
4:59 PM									
5:00 PM									

The following are the MOW schedules respectively for scenario #1 and scenario #2

Id - Scenario #1	where	asking	starting	ending	type
Repair Crew #1	before A3		0	17	FT
Repair Crew #2	between Term and B1		0	24	FT
Repair Crew #3	between B1and B2	27	32	180	Form D
Repair Crew #4	between B3 and B6	45	50	90	FT
Repair Crew #5	before C2 and at C2	11	16	180	FT
Repair Crew #6	between C4 and C5	24	29	240	Form D
Track Car #2	before D2 and at D2	34	39	54	FT
Track Car #3	at D6	42	47	75	FT
Signal Worker #1	at B3	1	6	13	FT
Signal Worker #3	between D3 and D4	15	20	29	FT
Signal Worker #4	at C3	38	43	70	FT
Signal Worker #5	at B7	51	56	65	FT
bridge @10	between D7 and D8	20			
bridge @50	between D7 and D8	50			

Id - Scenario #2	where	asking	starting	ending	type
Repair Crew #1	between A2 and A3		0	8	FT
Repair Crew #2	between term and B1	5	10	35	FT
Repair Crew #3	between B1 and B2	15	20	120	Form D
Repair Crew #4	between B3 and B6	45	50	95	FT
Repair Crew #5	between C1 and C2	11	16	47	FT
Repair Crew #6	between C4 and C5		0	21	FT
Repair Crew #7	between D1 and D2	38	43	180	FT
Repair Crew #8	at C4	29	34	180	Form D
Track Car #1	and between D3 and D4	35	40	60	FT
Track Car #2	between D6 and D7	25	30	56	FT
Track Car #3	at B7	52	56	75	FT
Signal Worker #1	before station A	1	6	17	FT
bridge @10	between D7 and D8	20			
bridge @50	between D7 and D8	50			

5.3 Appendix C - Questionnaires

Appendix C includes all the questionnaires: the situation awareness questionnaire, the post-experiment questionnaires for all three environments and the final debriefing questionnaire.

Situation Awareness Questionnaire

Please answer the following questions as best as you can. Keep your answers as short as possible. You will have very little time and will not be allowed to use the dispatching system, hence you are not expected to answer all questions properly.

1. What is the number of the most delayed train?
2. Can you estimate the time delay for that train?
3. What is the number of the least delayed train?
4. Can you estimate the time delay for that train?
5. When is your next train due out of the terminal?
6. Do you see any routing conflicts?
7. Do you have "hazards" somewhere on the territory?
8. Where?
9. Any particular restrictions on the track usage?
10. Where are your MOW crews?
11. Which MOW crew will complete its work next?
12. What track could you give away for a 15 minutes span to a MOW crew?
13. Whom did you last talk to?
14. When did you last talk?
15. What was the subject of your communication?
16. What was the last message you heard that wasn't intended for you directly? (used only in the radio environment and in the DB environment)

Post Experiment Questionnaire

Radio environment

Please answer the following questions as best as you can. If you have any problems, we are here to help. Don't feel limited by the questions.

- Did you route before answering the messages, answer messages before routing or neither – it depends on the situation-?
- How realistic do you think the replica of the radio environment?

  Very Unrealistic | | | | | | Very Realistic

  1 2 3 4 5 6 7
- How would you rank the workload during the experiment?

  Very Low | | | | | | Very High

  1 2 3 4 5 6 7
- How comfortable did you radio communication environment?

  Very Uncomfortable | | | | | | Very Comfortable

  1 2 3 4 5 6 7
- Any suggestions to make the system better. Improvements. Any comment is welcome. Feel free to write anything, especially critics!

DD environment

- Would you like the data-link directed environment in addition to your current radio environment? Why?
- Did you route before answering the messages, answer messages before routing or neither – it depends on the situation-?
- How would you rank the workload during the experiment?

  Very Low | | | | | | Very High

  1 2 3 4 5 6 7
- How comfortable did you feel with the data-link directed system?

  Very Uncomfortable | | | | | | Very Comfortable

  1 2 3 4 5 6 7

– How helpful would it be to have such data-link capacities in your current environment?

<u>Very Unhelpful</u> <u>Very Helpful</u>

1 2 3 4 5 6 7

– Any suggestions to make the system better. Improvements. Any comment is welcome. Feel free to write anything, especially critics!

DB environment

– Would you like the data-link broadcast environment in addition to your current radio environment? Why?

– Did you route before answering the messages, answer messages before routing or neither – it depends on the situation-?

– How would you rank the workload during the experiment?

<u>Very Low</u> <u>Very High</u>

1 2 3 4 5 6 7

– How comfortable did you feel with the data-link broadcast system?

<u>Very Uncomfortable</u> <u>Very Comfortable</u>

1 2 3 4 5 6 7

– How helpful would it be to have such data-link capacities in your current environment?

<u>Very Unhelpful</u> <u>Very Helpful</u>

1 2 3 4 5 6 7

– Any suggestions to make the system better. Improvements. Any comment is welcome. Feel free to write anything, especially critics!

Final Debriefing Questionnaire

Please answer the following questions as best as you can. If you have any problems, we are here to help. Don't feel limited by the questions.

- Which environment did you like most (Data-link Directed, Data-link Broadcast or radio)? Why?
- Would you like the data-link directed system in addition to your current radio environment? Why?
- Could you please rank the following starting with the best?

  Radio only

  Data-link Directed only

  Data-link Broadcast only

  Radio and Data-link Directed

  Radio and Data-link Broadcast
- Would any environment be good for training? Why?
- Any suggestions to make the system better. Improvements. Any comment is welcome. Feel free to write anything, especially critics!

5.4 Appendix D – Documents for the dispatcher

Appendix D contains all the documents provided to the dispatcher during the two one-hour experiments, except the train schedules and the message tree structure. Train schedules for the experiments can be found in Appendix B and the message tree structure can be found in Appendix A. In order, we have the explanatory text for the use of the simulator, the train schedule for the training scenario, the transfer sheets, the Form D sheets and the foul time sheets.

The simulator quick user's manual

About the routing:

1. A red track is a track occupied by a train. When there is no train, the track is white.

2. Every train leaving the terminal has to be sent a bulletin before he can leave. Assume that, in any other station, the train has already started the ride and received a TSRB.

3. To clear the route, click first on the "clear route" button at the bottom of the screen. Then click on the entry and exit signals of the interlocking according to the route you want the train to take. The color of the track changes to green.

4. To unclear a route, click first on the "unclear" button at the bottom of the screen. Then click on entry or exit signal of the interlocking according to the route you want the train to take. The color of the track changes back to white.

5. The route will unclear automatically if a train has used it. The color of the track will change back to white.

6. To block a route for MOW activity, click first on the "block" button at the bottom of the screen. Then click on the part of the track you are giving away. You have to repeat the process if you want to block more track.

7. To unblock a route, click first on the "unblock" button at the bottom of the screen. Then click on the part of the track you want to unblock. You have to repeat the process if you want to unblock more track.

Names:

The territory has four main branches, respectively named A, B, C and D. Stations on these branches have the name of the branch. There are four stations: station A, station BR, station BL and station D.

Interlockings have names composed of a letter (the branch) and a number, the number representing the order of the interlocking from left to right.

To identify blocks during communications, we use a set of three elements. First the general position i.e. the interlocking, the station or interlockings on the left and on the right; second the number of the track knowing that tracks are numbered from top to bottom and third, the number of the block.

About the messaging system:

1. The message console is divided in two parts: the left window handles received messages and the right window shows the messages that were sent-out. In each of these windows, there are two elements: a list of all appropriate messages and the message, currently highlighted in the list, displayed at the bottom of the window.

2. To answer the messages: by pressing the send message or the reply button, a list of pre-programmed messages pops up. These messages are sorted into a message tree. The tree has four levels: the priority, the recipient, the subject of the message and the pre-programmed message itself. A layout of the tree will be provided and explained to you.

3. To fill in the blanks in the messages, you can use either the keyboard or the mouse. Most blanks can be specified by double clicking on the adequate field and by clicking the target train or by using the keyboard directly (without double-click). This is valid for train numbers, MOW crew identifiers, name of block to be worked on. The cursor automatically moves from one field to the next. When a message is highlighted, i.e. read, the blocks specified in the text of the message turn yellow on the routing screen.

About the work allocation:

There are two groups of messages related to work request. We are going to describe each group.

1. First, the track work. Track Cars or Repair Crew usually perform track work. We expect the dispatcher to answer their request using the correct branch of the message tree. The type of work will be indicated in the work request message.

2. Second, the signal work. Signal Workers usually perform repairs on signal. They expect to receive answers from the signal work subtree. Here again the type of work in the request message will help decide which branch of the tree to use.

About the message "replying", sending and forwarding requirements:

1. Any update about hazards has to be transmitted to all other train scheduled to ride the branch on which the hazard is located. These messages include: trespasser on the track and trespasser are gone, kids throwing stones and kids are gone and finally, bad weather zone and bad weather zone is gone.

2. Overweight events and engine state messages are for your personal information.

Training scenario train schedule

Br.	Dir.	Train #	Ptf.	Terminal		Interlocking		Interlocking		Interlocking		Interlocking		Interlocking	
Br. A	IN		1	1:26 PM	A1	1:23 PM	A2	1:21 PM	A3	1:14 PM	A4	1:07 PM	A5	1:00 PM	A-t2
	OUT	111	2	1:04 PM	A1	1:07 PM	A2	1:09 PM	A3	1:16 PM	A4	1:23 PM	A5	1:30 PM	A-t3
Br. B	IN		4	1:30 PM	B1	1:26 PM	B2	1:20 PM	B3	1:15 PM					NS
	OUT	221	5	1:07 PM	B1	1:11 PM	B2	1:17 PM					B4	1:22 PM	BL-t1
Br. C	IN		6	1:21 PM	C1	1:17 PM	C2	1:13 PM	C3	1:10 PM	C4	1:05 PM	C5	1:01 PM	No
	OUT	331	7	1:15 PM	C1	1:19 PM	C2	1:23 PM	C3	1:26 PM	C4	1:31 PM	C5	1:35 PM	No
Br. D	IN		9	1:35 PM	D1	1:33 PM	D2	1:25 PM	D3	1:21 PM	D4	1:17 PM	D5	1:10 PM	D-t2
	OUT	441	8	1:08 PM	D1	1:10 PM	D2	1:18 PM	D3	1:22 PM	D4	1:26 PM	D5	1:33 PM	D-t1
Yard	IN	331EQ	7	ar. 1:00 PM											

Station		Interlocking		Interlocking		Interlocking		Station		Interlocking	F.D.	Train #	Dir.	Br.
12:59 PM	A6	12:56 AM	A7	12:49 AM							1	100	IN	Br. A
1:34 PM	A6	1:36 PM	A7	1:43 PM									OUT	
			B6	1:14 PM	B7	1:07 PM	BR-t3	1:05 PM	B8	12:50 PM	4	200	IN	Br. B
1:27 PM	B5	1:28 PM	B6	1:30 PM	B7	1:37 PM	NS-t3	1:39 PM	B8	1:41 PM			OUT	
											6	300	IN	Br. C
													OUT	
1:09 PM	D6	1:04 PM	D7	1:01 PM	D8	12:58 PM					9	400	IN	Br. D
1:40 PM	D6	1:40 PM	D7	1:43 PM	D8	1:46 PM							OUT	
										ar. 1:00 PM	7	331EQ	IN	Yard

Transfer sheet for scenario #1 and scenario #2

Dispatchers take over the track given away by the previous dispatcher on the shift when they start their experiment. Dispatchers also get written information about the scheduled work during their shift. This information is usual found on a transfer sheet. The following are our transfer sheets (Note that the only similarity with the real world is the name and the type of information. The same is true for the Form Ds that follow.).

Transfer Sheet for scenario #1

Scheduled work information (provided when the dispatcher start the experiment):

1. Track outage is scheduled at 1:30 PM between interlocking B1 and B2 on track 1 and track 2 block 2, at interlocking B2 T11, at interlocking B2 T12 and at interlocking B2 T22 block 1. Repair Crew #3 will ask for protection around 1:25 PM. Form D required
2. Track outage is scheduled at 1:30 PM between interlocking C4 and C5 on track 3 block 1 and at interlocking C5 T33 block 1. The MOW crew will ask for protection around 1:25 PM. Form D required

Please follow the platform indications as closely as possible. As at South Station, some trains have a longer consist and might not fit everywhere. The schedule has been drafted accordingly.
Also, you might want to pay particular attention to the incoming train appearing during the simulation given that you don't have a big overview display.

Transfer Sheet for scenario #2

Scheduled work information (provided when the dispatcher start the experiment):

1. Track outage is scheduled at 4:38 PM at interlocking C4 T32, interlocking C4 T22, block 2 and interlocking C4 T33, block 2. Repair Crew #8 will ask protection around 4:33 PM. Form D is required in the radio environment.
2. Track outage is scheduled at 4:19 PM between interlocking B1 and B2 on track 3 block 1 and 2 and on track 4 block 1 and 2. Repair Crew will ask for protection around 4:15 PM. Form D is required in the radio environment.

Please follow the platform indications as closely as possible. As at South Station, some trains have a longer consist and might not fit everywhere. The schedule has been drafted accordingly.
Also, you might want to pay particular attention to the incoming train appearing during the simulation given that you don't have a big overview display.

Form D's, (their use was required twice for each radio experiment)

Form D

Work Crew # ____________________

Date ______________________________ Dispatcher's name ____________________

Starting Time ______________________ Ending Time ______________________

Location ____

____

____

Form D

Work Crew # ____________________

Date ______________________________ Dispatcher's name ____________________

Starting Time ______________________ Ending Time ______________________

Location ____

____

____

Foul time forms (optional use)

Foul Time Request

Work Crew # ______________________

Date ______________________________ Dispatcher's name ___________________

Starting Time _______________________ Ending Time________________________

Location ____

____

____

- -

Foul Time Request

Work Crew # ______________________

Date ______________________________ Dispatcher's name ___________________

Starting Time _______________________ Ending Time________________________

Location ____

____

____

5.5 Appendix E – Raw data

Appendix E mainly consists of the raw data in a readable form. One will find: the "summarizing" table for each of the twelve experiments (two per dispatcher), the productivity "basic information" table, the train safety table, the situation awareness evaluation for each environment (with the grades for each question), the closed question answer table for the post-experiment and for the debriefing questionnaires and finally the means for communication efficiency for the T1 and T2 type messages for each experiment.

Disp #1 - Scenario #1 – Summary table

Total Mess.		Protected	Comments	waiting time	processing time	answering time	cycle
1	SW #1	y	granted	41	26	115	182
2	Tresp #1 on track		Train #113	22	1	15	38
3	Bridge	y	granted	19	21	29	69
4	RC #5	n	granted	44	436	277	757
5	SW #1 clearing			96			
6	Kids #2 on track		Train #400	19	3	37	59
7	SW #3	n	granted	31	600	89	720
8	Tresp #2 on track		Train #223!?	27	0	22	49
9	RC #1 clearing			29			
10	Kids #2 gone		no train	27			
11	RC #6	y	granted	36	1031	455	1522
12	RC #2 clearing			41			
15	RC #3	n	granted	6	0	118	124
17	TC #2	n	granted	39	574	111	724
18	SW #4		not answered	20			
19	Tresp #1 again		Train #117	26	3	15	44
20	TC #3		not answered	36			
21	RC #4		denied	4	0	30	34
22	Kids #1 on track		not forwarded	51			
23	Bridge	y	granted	190			
24	SW #5	y	granted	23	0	47	70
	Train #115			3	0	12	15
	Train #117			7	0	8	15
	Train #223			13	0	6	19
	Train #331			5	0	14	19
	Train #333			4	0	12	16
	Train #443			5	0	8	13

Disp #1 - Scenario #2 – Summary table

Total Mess.		Protected	Comments	waiting time	reading time	writing time	cycle
1	SW #1	y	granted	6	26	94	132
2	Kids #2 on track		Train 480	25	13	63	130
	Kids #2 on track		Train 493			33	
3	RC #2		denied	60	8	20	100
4	RC #1 clearing			132			
5	Bridge		denied	185			
6	RC #5	y	granted	63	68	55	190
7	Tresp #1 on track		Train 191	58	23	29	126
	Tresp #1 on track		Train 122			23	
8	RC #3	y	granted	117	86	57	263
9	Kids #1 on track		Train 362	8	8	38	75
10	Kids #2 gone		not ff	15			
12	RC #6 clearing			153			
13	TC #2	y	granted	98	11	138	255
14	Tresp #2 on track		Train 293	162	79	66	357
15	RC #8		denied	187	12	14	219
16	TC #1		denied	29	82	11	130
18	RC #7	y	granted	129	39	64	239
19	RC #4	y	granted	78	24	42	167
22	RC #5 clearing			60			
23	Bridge		denied	160			
24	TC#3	y	granted	16	17	51	93
25	TC #2 clearing			70			
	Train #291			22	4	9	78
	Train #391			19	3	9	38
	Train #293			79	4	7	92
	Train #493			193	5	9	212
	Train #193			65	2	9	81
	Train #393			127	9	8	148

Disp #2 - Scenario #1 – Summary table

Total Mess.		Protected		waiting time	reading time	writing time	cycle
1	SW #1	y	granted	11	88	62	168
2	Tresp #1 on track		Train #113	3	7	28	115
	Tresp #1 on track		Train #115			23	
3	Bridge	y	granted	15	15	26	
4	RC #5	y	granted	29	20	73	154
5	SW #1 clearing			111			
6	Kids #2 on track		Train #400	70	86	23	251
7	SW #3		not answered	6			
8	Tresp #2 on track		Train #200	14	5	45	337
9	RC #1 clearing			167			
10	Kids #2 gone		no train	2			
11	RC #6	y	granted	13	26	52	109
12	RC #2 clearing			36			
15	RC #3	y	asked first at 1875	17	8	61	97
17	TC #2	n	granted	64	113	60	247
18	SW #4		denied	301	7	17	335
19	Tresp #1 again		Train #117	1	10	21	57
20	TC #3		denied	11	7	10	47
21	RC #4	y	granted	48	8	60	127
22	Kids #1 on track		Train #333	13	46	38	121
23	Bridge	y	granted	80	9	17	
24	SW #5		denied	52	7	17	86
25	TC #2 clearing			21			
	Train #115			44	13	13	80
	Train #117			10	5	6	31
	Train #223			35	2	6	48
	Train #331			46	6	8	68
	Train #333			4	3	7	39
	Train #443			45	4	9	62

Disp #2 - Scenario #2 – Summary table

Total Mess.		Protected		waiting time	processing time	answering time	cycle
1	SW #1		granted	94	447	308	849
2	Kids #2 on track		Train 480	17	0	19	36
3	RC #2		not answered	24			
4	RC #1 clearing			67			
5	Bridge	y	granted	33			
6	RC #5	y	granted	899	789	87	1775
7	Tresp #1 on track		Train 191	29	0	19	48
8	RC #3	y	granted	287	39	44	370
9	Kids #1 on track		Train 362	23	3	21	47
10	Kids #2 gone		not ff	16			
11	SW #1 clearing			13	0	41	54
12	RC #6 clearing			190			
13	TC #2	y	granted	20	959	138	1117
14	Tresp #2 on track		Train 242	42	4	20	66
	Tresp #2 on track		Train 244	0	2556	24	2580
	Tresp #2 on track		Train 293	0	2580	10	2590
15	RC #8	n	granted	118	530	96	744
16	TC #1		denied	7	0	72	79
18	RC #7	n	not answered	625			
19	RC #4	n	granted	10	117	110	237
20	Kids #1 gone		not forwarded	4	0	17	21
23	Bridge	y	granted	15			
	Train #291			11	0	18	29
	Train #391			5	0	10	15
	Train #293			4	0	6	10
	Train #493			6	0	10	16
	Train #193			8	0	6	14
	Train #393			122	0	12	134

Disp #3 - Scenario #1 – Summary table

Total Mess.		Protected	Comments	waiting time	processing time	answering time	cycle
1	SW #1	y	granted	80	124	116	320
2	Tresp #1 on track		Train #113	21	0	14	35
3	Bridge	y	granted	22	0	2	24
4	RC #5	n	granted	42	283	112	437
5	SW #1 clearing			39			
6	Kids #2 on track		Train #400	15	19	20	54
7	SW #3	n	granted	174	115	55	344
8	Tresp #2 on track		Train #200	46	2	15	63
9	RC #1 clearing			53			
10	Kids #2 gone		no train	24			
11	RC #6	y	granted	76	20	94	190
12	RC #2 clearing			38			
14	Tresp #2 gone		not ff to other trains	15			
15	RC #3	y	granted	21	159	292	472
16	SW #3 clearing			25			
17	TC #2	n	granted	18	224	142	384
18	SW #4	y	granted	29	165	331	525
19	Tresp #1 again		Train #117	20	0	13	33
	Tresp #1 again		Train #104			29	
20	TC #3	y	granted	217	115	49	381
21	RC #4	y	granted	49	143	47	239
22	Kids #1 on track		Train #333	14	0	17	31
23	Bridge	y	granted	25			
24	SW #5		denied	47	81	180	308
25	TC #2 clearing			27			
	Train #115			7	0	13	20
	Train #117			5	0	7	12
	Train #223			3	3	4	10
	Train #331			7	0	8	15
	Train #333			4	0	4	8
	Train #443			3	2	5	10

Disp #3 - Scenario #2 – Summary table

Total Mess.		Protected		waiting time	reading time	writing time	cycle time
			granted later				
1	SW #1	y	denied first	96	37	11	153
2	Kids #2 on track		Trains D	10	14	36	73
3	RC #2	y	granted	117	98	53	285
4	RC #1 clearing			14			
5	bridge		denied	4	5	47	
6	RC #5	y	granted	7	51	32	108
7	Tresp #1 on track		Trains A	21	11	33	87
8	RC #3		denied	8	15	-943	
9	Kids #1 on track		Trains C	7	10	30	67
10	Kids #2 gone		not ff right	10	31	52	138
11	SW #1 clearing			8			
12	RC #6 clearing			2			
13	TC #2	y	granted	8	11	66	154
14	Tresp #2 on track		Trains B	21	5	19	75
15	RC #8	y	granted	50	238	41	344
	Kids #2 gone		Trains D	100			355
	Kids #1 gone		Trains C	63	10	34	
16	TC #1	y	granted	14	361	26	432
17	RC #2 clearing			3			
18	RC #7	y	granted	1	37	40	92
19	RC #4		not responded	36			
20	Tresp #1 gone		Trains A	16	32	22	87
21	RC #5 clearing			55			
23	bridge	y	granted	3	10	14	
24	TC#3	n	granted	1	32	37	105
25	TC #2 clearing			13		0	
	Train #291			31	1	10	47
	Train #391			4	2	6	26
	Train #293			28	3	7	44
	Train #493			6	2	7	21
	Train #193			0		15	
	Train #393			2	2	9	26

Disp #4 - Scenario #1 – Summary table

Total Mess.		Protected	Comments	waiting time	reading time	writing time	cycle
1	SW #1		denied	21	88	45	162
2	Tresp #1 on track		Trains A	61	13	135	236
3	Bridge	y	granted	43	22	30	
4	RC #5		denied	63	86	33	201
6	Kids #2 on track		Trains D	1	13	47	77
7	SW #3		denied	124	23	24	181
8	Tresp #2 on track		Not forwarded	247			
9	RC #1 clearing			392			
10	Kids #2 gone		mistake ff to #400	207	16	44	
11	RC #6	y	granted	30	49	74	167
12	RC #2 clearing			335			
13	Tresp #1 gone		Trains A	393	7	45	464
15	RC #3		denied	144	35	22	210
17	TC #2		never answered				
18	SW #4	y	granted	124	41	65	245
19	Tresp #1 again		Trains A	35	9	32	111
20	TC #3		denied	167	13	22	211
21	RC #4	y	granted	187	22	48	282
22	Kids #1 on track		Trains C	3	10	36	91
23	Bridge		denied	30	5		
24	SW #5		never answered				
	Train #115			498	4	10	526
	Train #117		sent twice	91	3	11	116
	Train #223			9	4	8	43
	Train #331			175	2	8	202
	Train #333			20	2	5	86
	Train #443			16	3	14	39

Disp #4 - Scenario #2 – Summary table

Total Mess.		Protected	Comments	waiting time	processing time	answering time	cycle
1	SW #1	n	granted	75	36	54	165
2	Kids #2 on track		Train 480	110	6	30	146
3	RC #2		denied	12	280	105	397
4	RC #1clearing		granted	69			
5	Bridge		granted	4	0	31	35
7	Tresp #1 on track		Train 191	30	0	18	48
8	RC #3	y	granted	139	369	84	592
14	Tresp #2 on track		Train 244	106	10	19	135
9	Kids #1 on track		not ff	31			
11	SW #1 clearing			42			
12	RC #6 clearing			301			
13	TC #2	y	granted	75	121	70	266
15	RC #8	n	granted	80	64	61	205
10	Tresp #2 gone		not ff	10	0	18	28
16	TC #1	y	granted	79	605	112	796
18	RC #7	n	granted	26	0	122	148
19	RC #4	y	granted	10	92	20	122
23	Bridge	y	granted	45			
24	TC #3	y	granted	220	113	31	364
	Train #291			8	0	18	26
	Train #391			4	0	13	17
	Train #293			4	0	7	11
	Train #493			485	0	13	498
	Train #193			77	0	15	92
	Train #393			8	0	13	21

Disp #5 - Scenario #1 – Summary table

Total Mess.		Protected	Comments	waiting time	reading time	writing time	cycle
1	SW #1	y	granted	10	31	49	100
2	Tresp #1 on track		Train #113	6	11	44	71
	Tresp #1 on track		Train #102			33	
3	Bridge	y	granted	8	13		
4	RC #5		denied	20	9	10	49
5	SW #1 clearing			17			
6	Kids #2 on track		Train #400	34	2	73	119
7	SW #3		denied	42	13	6	71
8	Tresp #2 on track		Train #200	39	24	54	127
9	RC #1 clearing		1087	8			
10	Kids #2 gone		no train	11			
11	RC #6	y	granted	37	72	224	343
12	RC #2 clearing		1506	23			
13	Tresp #2 gone		others missed	14			
14	Tresp #2 gone		225 gone	17			
15	RC #3	y	granted	17	32	228	287
17	TC #2	n	granted	23	23	45	101
	Kids #1 caught by #225		Train #302			42	
	Kids #1 caught by #225		Train #333	24	368	275	677
18	SW #4		denied	39	28	10	87
19	Tresp #1 again		Train #117	56	57	27	150
	Tresp #1 again		Train #104			38	
20	TC #3	y	granted	137	26	30	203
21	RC #4	y	granted	39	19	33	101
23	Bridge	y	granted	6	16		
24	SW #5	y	granted	15	31	34	90
25	TC #2 clearing			54			
	Train #115					10	
	Train #117			11	4	6	31
	Train #223					22	
	Train #331					6	
	Train #333					16	
	Train #443					9	

Disp #5 - Scenario #2 – Summary table

Total Mess.		Protected	Comments	waiting time	reading time	writing time	cycle time
1	SW #1	y	granted	35	13	40	88
2	Kids #2 on track		Trains D	29	17	21	67
3	RC #2	y	granted	55	18	32	105
4	RC #1 clearing			20			
5	Bridge		denied	15			
6	RC #5	y	granted	14	17	36	67
7	Tresp #1 on track		Trains A	12	2	96	110
8	RC #3		denied	2	4	18	24
9	Kids #1 on track		Trains C	19	11	41	71
10	Kids #2 gone		Trains D	52	15		
11	SW #1 clearing			74			
12	RC #6 clearing			9			
13	TC #2	y	granted	7	20	39	66
14	Tresp #2 on track		Trains B	46	21	45	112
15	RC #8		denied	108	13	8	129
	Kids #1 gone		no train	31			
16	TC #1		denied	18	19	14	51
17	RC #2 clearing			17			
18	RC #7	y	granted	111	17	46	174
19	RC #4		denied	4	25	29	58
20	Tresp #1 gone		Trains A	43	9	41	93
21	RC #5 clearing			53			
23	Bridge		denied	56			
24	TC#3	y	granted	24	28	38	90
25	TC #2 clearing						
Train #291	Train #291			4	2	2	8
Train #391	Train #391			0		24	
Train #293	Train #293			0		12	
Train #493	Train #493			0		8	
Train #193	Train #193			0		7	
Train #393	Train #393			9	4	63	76

Disp #6 - Scenario #1 – Summary table

Total Mess.		Protected	Comments	waiting time	reading time	writing time	cycle
1	SW #1		denied	48	16	23	98
2	Tresp #1 on track		Trains A	17	15	38	99
3	Bridge	y	granted	39	33	29	
4	RC #5		denied	36	7	17	66
6	Kids #2 on track		Trains D	55	15	22	99
7	SW #3		denied	118	35	22	189
8	Tresp #2 on track		Trains B	4	20	25	94
9	RC #1 clearing			92			
10	Kids #2 gone		mistake sent to #400	38	28	31	
11	RC #6	y	granted	67	196	61	335
12	RC #2 clearing			8			
13	Tresp #2 gone		Trains B	13	12	27	
14	Tresp #1 gone		Trains A	74	10	23	
15	RC #3	y	granted	6	10	70	118
17	TC #2	y	granted	49	16	52	228
18	SW #4		denied	51	14	15	90
19	Tresp #1 again		Trains A	12	15	21	78
20	TC #3	y	granted	270	9	49	346
21	RC #4	y	granted	235	47	60	356
22	Kids #1 on track		Trains C	30	16	22	137
23	Bridge	y	granted	90	6	36	
24	SW #5		denied	78	7	7	105
25	TC #2 clearing			2			
	Train #115			56	2	5	72
	Train #117			19	3	6	37
	Train #223			4	2	5	17
	Train #331			35	3	5	48
	Train #333			9	2	5	34
	Train #443			3	1	6	15

Disp #6 - Scenario #2 – Summary table

Total Mess.		Protected		waiting time	reading time	writing time	cycle time
1	SW #1	y	granted	54	28	43	137
2	Kids #2 on track		Train #480	12	22	50	109
3	RC #2	y	granted	118	77	87	300
4	RC #1 clearing			98			
5	Bridge	y	granted	30	18	32	
6	RC #5		not answered	26			
7	Tresp #1 on track		Train #191	53	16	29	123
8	RC #3		not answered	415			
9	Kids #1 on track		Train #362	3	38	26	85
10	Kids #2 gone		not ff	62			
11	SW #1 clearing			490			
12	RC #6 clearing			44			
13	TC #2		not answered	14			
14	Tresp #2 on track		Train #293	196	67	20	394
15	RC #8	y	denied	581	11	16	631
16	TC #1	y	granted	445	35	38	528
17	RC #2 clearing			358			
18	RC #7		not answered	370			
19	RC #4		granted	232	39	38	322
20	Tresp #1 gone		nothing to do	181			
23	Bridge	y	granted	9	38	20	
24	TC#3	y	granted	24	31	41	110
	Train #291			50	4	7	65
	Train #391			18	14	9	52
	Train #293			12			
	Train #493			8			
	Train #193		2791	230	607	8	853
	Train #393			25			

Productivity Basic Information Table for scenario #1

	Position	Disp #5	Disp #2	Disp #4	Disp #6	Disp #3	Disp #1
	delays >5 min.	DD	DD	DB	DB	Radio	Radio
Train #100	terminal	0	503	0	0	0	0
Train #102	terminal	0	782	459	0	0	0
Train #115	terminal	0	592	530	0	0	0
Train #117	terminal	0	0	0	0	0	0
Train #200	terminal	0	0	0	0	0	571
Train #223	terminal	0	0	0	0	0	0
Train #225	terminal	0	0	0	0	0	0
Train #300	terminal	0	0	858	0	0	526
Train #302	terminal	0	0	0	0	0	0
Train #331	terminal	0	334	332	0	0	0
Train #333	terminal	0	0	0	0	0	0
Train #400	terminal	0	0	0	0	0	0
Train #443	terminal	0	0	0	0	0	328
Train #400	station D	0	418	339	0	0	605
Train #402	station D	0	0	442	0	0	311
Train #441	station D	0	0	0	0	0	0
Train #443	station D	0	0	0	0	0	0
Train #202	station BR	0	0	0	0	0	0
Train #221	station BR	0	0	0	0	0	0
Train #223	station BR	0	0	0	0	0	514
Train #221	station BL	0	0	0	0	0	0
Train #223	station BL	0	0	0	0	0	309
Train #225	station BL	wrong B	0	0	486	0	414
Train #102	station A	0	0	0	0	0	0
Train #104	station A	0	0	0	0	0	0
Train #111	station A	0	0	0	0	0	434
Train #113	station A	0	338	0	0	0	473
Train #115	station A	0	0	501	0	0	0
TOTAL		**1**	**6**	**7**	**1**	**0**	**10**

Signal Worker #1	at B3	1	1	0	0	1/0	1
Bridge @ 10	bet. D7 and D8	1	1	1	1	1	1
Repair Crew #5	before C2 and at C2	0	1	0	0	1	1/0
Signal Worker #3	bet. D3 and D4	0	0	0	0	1/0	1/0
Repair Crew #6	bet. C4 and C5	1	1	1	1	1	1
Repair Crew #3	bet. B1and B2	1	1	0	1	1	1
Track Car #2	before D2 and at D2	1	1	0	1	1	1
Signal Worker #4	at C3	0	0	1	0	1/0	0
Track Car #3	at D6	1	0	0	1	1	0
Repair Crew #4	bet. B3 and B6	1	1	1	1	1	0
Bridge @ 50	bet. D7 and D8	1	1	0	1	1	1
Signal Worker #5	at B7	1	0	0	0	0	1
TOTAL (/12)		**9**	**8**	**4**	**7**	**11/8**	**9/7**

Productivity Basic Information Table for Scenario #2

	Position **delays > 5 min.**	Disp #5 DB	Disp #3 DB	Disp#6 DD	Disp #1 DD	Disp #4 Radio	Disp #2 Radio
Train #120	terminal	0	0	0	0	0	0
Train #191	terminal	0	0	0	0	0	0
Train #193	terminal	0	0	887	0	695	0
Train #240	terminal	0	0	0	0	0	0
Train #242	terminal	1096	0	593	332	0	late
Train #244	terminal	349	0	0	0	678	late
Train #291	terminal	0	0	0	0	0	0
Train #293	terminal	355	0	535	0	0	470
Train #360	terminal	0	0	0	346	1196	0
Train #362	terminal	0	0	0	0	802	1251
Train #364	terminal	0	0	0	late	0	late
Train #391	terminal	0	0	0	0	0	0
Train #393	terminal	0	0	477	0	1153	0
Train #480	terminal	0	0	0	934	0	0
Train #482	terminal	0	0	late	late	0	0
Train #493	terminal	0	0	609	0	639	1329
Train #482	station D	0	0	1229	338	0	976
Train #484	station D	0	616	0	0	0	0
Train #491	station D	0	0	0	414	0	318
Train #493	station D	0	0	670	0	589	600
Train #244	station BR	0	0	0	0	0	0
Train #291	station BR	0	0	0	0	0	late
Train #293	station BR	0	338	488	0	0	late
Train #242	station BL	0	0	576	0	0	0
Train #293	station BL	306	468	618	0	0	1200
Train #122	station A	0	0	0	0	0	583
Train #124	station A	0	0	0	0	0	0
Train #191	station A	0	0	344	446	0	0
TOTAL		**4**	**3**	**12**	**8**	**7**	**13**
Signal Worker #1	before station A	1	1	1	1	1	1
Repair Crew #2	bet. term and B1	1	1	1	0	0	0
Bridge @ 10	bet. D7 and D8	0	0	1	0	0	1
Repair Crew #5	bet. C1 and C2	1	1	0	1	0	1/0
Repair Crew #3	bet. B1and B2	0	0	0	1	1	1
Track Car #2	bet. D6 and D7	1	1	0	1	1	1
Repair Crew #8	at C4	0	1	0	0	1	1
Track Car #1	bet. D4 and D5	0	1	1	0	1/0	0
Repair Crew #7	bet. D1 and D2	1	1	0	1	1	0
Repair Crew #4	bet. B2 and B3	0	0	1	1	1	1
Bridge @ 50	bet. D7 and D8	0	1	1	0	1	1
Track Car #3	at B7	1	1	1	1	1	0
TOTAL (/12)		**6**	**9**	**7**	**7**	**9/8**	**8/7**

Safety evaluation results

For each hazard, we mentioned the number of trains to be alerted and the number of trains eventually alerted.

Scenario #1

To be	Disp #6	Disp #4	Disp #5	Disp #2	Disp #3	Disp #1
alerted	DB	DB	DD	DD	Radio	Radio
/5	5	5	2	2	1	1
/3	3	3	0	0	0	0
/2	2	2	2	1	2	1
/2	2	0	2	1	1	0
/1	1	0	0	0	0	0
/1	1	1	1	1	1	0
/1	1	1	1	1	1	1
/15	100.00	80.00	53.33	40.00	40.00	20.00

Scenario #2

To be	Disp #5	Disp #3	Disp #6	Disp #1	Disp #2	Disp #4
alerted	DB	DB	DD	DD	Radio	Radio
/3	3	3	1	2	1	1
/1	1	1	0	0	0	0
/1	1	1	1	1	1	0
/3	3	3	1	2	2	1
/1	1	1	0	0	0	0
/3	3	3	1	3	1	1
/2	2	1	0	0	0	2
/14	100.00	92.86	28.57	57.14	35.71	35.71

Train Safety	**Radio**	**DD**	**DB**
Disp #1	0.20	0.57	
Disp #2	0.36	0.40	
Disp #3	0.40		0.93
Disp #4	0.36		0.80
Disp #5		0.53	1.00
Disp #6		0.29	1.00
Mean	**0.33**	**0.45**	**0.93**

Situation awareness “grades” – Radio environment

Situat. Aware	Disp #1	Disp #2	Disp #3	Disp #4	Disp #5	Disp #6
Question 1	1	1	0	0		
Question 2	1	0	0	0		
Question 3	1	0	0	0		
Question 4	1	0	0	0		
Question 5	0.5	1	1	1		
RADIO-Routing	**0.90**	**0.40**	**0.20**	**0.20**		
Question 6	1	0	1	1		
Question 7	0.33	0	1	0.5		
Question 8	0	0	0	0.25		
Question 9	1	1	1	1		
RADIO-Hazards	**0.58**	**0.25**	**0.75**	**0.69**		
Question 10	0.66	1	0.66	1		
Question 11	1	0	1	1		
Question 12	1	0.5	1	1		
RADIO-MOW	**0.89**	**0.50**	**0.89**	**1.00**		
Question 13	0	1	1	0.5		
Question 14	1	0.5	1	1		
Question 15	0	1	1	1		
Question 16	0	0	0	0		
RADIO-Mess.	**0.25**	**0.625**	**0.75**	**0.625**		

Situation awareness "grades" – Data-link Directed

Situat. Awareness	Disp #1	Disp #2	Disp #3	Disp #4	Disp #5	Disp #6
Question 1	1	0			1	1
Question 2	0	0			1	1
Question 3	1	1			1	0
Question 4	1	0			1	0
Question 5	1	1			0	0.5
DD-Routing	**0.80**	**0.40**			**0.80**	**0.50**
Question 6	1	1			1	1
Question 7	1	0.5			1	1
Question 8	0.33	0.5			1	0.25
Question 9	1	1			1	1
DD-Hazards	**0.83**	**0.75**			**1.00**	**0.81**
Question 10	1	0.5			1	1
Question 11	0.66	0.5			0.5	1
Question 12	1	1			1	1
DD-MOW	**0.89**	**0.67**			**0.83**	**1.00**
Question 13	0.5	1			1	0
Question 14	0	1			1	1
Question 15	0.5	1			1	0.5
DD-Messages	**0.33**	**1.00**			**1.00**	**0.50**

Situation awareness "grades" – Data-link Broadcast

Situat. Awareness	Disp #1	Disp #2	Disp #3	Disp #4	Disp #5	Disp #6
Question 1			1	1	0	1
Question 2			1	0.5	0	1
Question 3			0	0.5	1	1
Question 4			0	0	1	1
Question 5			1	0.5	1	0
DB-Routing			**0.60**	**0.50**	**0.60**	**0.80**
Question 6			1	1	1	1
Question 7			1	0.25	0	1
Question 8			0.33	0.25	0	1
Question 9			1	1	1	1
DB-Hazards			**0.83**	**0.63**	**0.50**	**1.00**
Question 10			0.66	1	0	1
Question 11			0	1	0	1
Question 12			1	1	1	1
DB-MOW			**0.55**	**1.00**	**0.33**	**1.00**
Question 13			1	1	0	0
Question 14			1	1	1	0
Question 15			0	1	1	1
Question 16			0	1	1	0.5
DB-Messages			**0.5**	**1**	**0.75**	**0.375**

Closed questions table for post-experiment questionnaires and for the debriefing questionnaire

Questionnaire	Disp #1	Disp #2	Disp #3	Disp #4	Disp #5	Disp #6	Average
Workload radio	6	7	5	7			**6.3**
Workload DD	6	7			6	5	**6**
Workload DB			5	7	6	5	**5.8**
Comfortable radio	6.5	5	5	7			**5.9**
Comfortable DD	5	5			6	4	**5**
Comfortable DB			2	4	5	6	**4.3**
Realistic radio	3	1	2	2.5			**2.1**
Helpful DD	4.5	5			6	6	**5.4**
Helpful DB			4	4	5	6	**4.8**
what first radio	message	depends	depends	routing			**depends**
what first DD	depends	depends			routing	depends	**depends**
what first DB			depends	routing	routing	depends	**depends**
DD in addition?	yes	yes			yes	yes	**yes**
DB in addition?			yes	yes	yes	yes	**yes**
you liked most…	Radio fam	DD	Radio fam	DB	DB	both	**datalink**
first in ranking	R	R+DD	R+DB	R+DB	R+DB	R+DB	**R+DB**
second in ranking	R+DD	DD	R	DB	R+DD	R+DD	**N/A**
third in ranking	DD	R	DB	R	R	R	**N/A**
fourth in ranking					DB	DB	**N/A**
fifth in ranking					DD	DD	**N/A**

Means for each experiment of the various communication times for T1 and T2 type messages

waiting time	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
Disp #1	24.17	47.67	90.45	72.43		
Disp #2	70.94	184.50	48.05	37.14		
Disp #3	21.74	68.45			22.50	33.00
Disp #4	87.71	74.73			144.38	96.00
Disp #5			25.94	32.44	31.05	41.00
Disp #6			154.57	130.29	36.45	108.00
Mean - Environ.	51.14	93.84	79.75	68.08	58.60	69.50

processing time	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
Disp #1	0.64	336.00	19.38	38.71		
Disp #2	0.58	480.17	14.40	39.86		
Disp #3	8.92	134.80			10.25	97.22
Disp #4	26.91	155.56			18.67	33.50
Disp #5			57.33	29.22	11.83	18.83
Disp #6			22.50	38.00	11.74	45.29
Mean - Environ.	9.26	276.63	28.40	36.45	13.12	48.71

answering time	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
Disp #1	16.27	155.13	23.20	71.57		
Disp #2	16.64	130.50	20.75	50.00		
Disp #3	25.31	124.00			20.00	35.56
Disp #4	24.45	65.00			31.82	54.25
Disp #5			40.06	91.86	28.60	38.50
Disp #6			20.63	42.71	17.11	51.00
Mean - Environ.	20.67	118.66	26.16	64.04	24.38	44.83

cycle	Radio T1	Radio T2	DD T1	DD T2	DB T1	DB T2
Disp #1	29.18	521.00	137.38	191.29		
Disp #2	40.83	848.67	118.27	161.00		
Disp #3	49.92	331.60			87.17	209.13
Disp #4	129.00	299.22			184.75	231.33
Disp #5			153.56	175.00	72.64	98.33
Disp #6			214.13	279.40	79.88	276.60
Mean - Environ.	62.23	500.12	155.83	201.67	106.11	203.85

6 Glossary

Block. A length of track with defined limits on which train movements are governed by block signals, cab signals, or Form D.

BIBD. Balanced incomplete block design. Typical experimental design when data points are difficult to obtain and treatment levels are numerous.

Cognitive Task Analysis (CTA). Analysis of the cognitive demands of a complex task. This includes the knowledge, mental processes, and decisions that are required to perform the task. The goals of a CTA are (1) to identify what factors contribute to cognitive performance difficulty; (2) to uncover the knowledge and skills that expert practitioners have developed to cope with task demands; and (3) to specify ways to improve individual and team cognitive performance in a domain through new forms of training, user interfaces, or decision-aids.

Consist. The makeup of a train, including locomotives and cars, and described by its locomotive power, tonnage, number and type of cars, and location and type of hazardous materials.

Crossover. A combination of two switches connecting two adjacent tracks. When aligned, this switch combination allows movements to cross from one track to the other.

CETC. Centralized Electrification and Traffic Control Center

Data-link. High bandwidth digital communication systems. Data-link technology enables information that is now passed in speech form over the audio radio to be passed over wire or wireless data lines. One implication is that information that is currently communicated orally over the radio could be buffered and presented visually on a computer display instead.

FedEx. Federal Express

Form D. A track usage authority form that is issued by a train dispatcher. Form D's permit trains and other track users to occupy specific segments of track identified by the train dispatcher.

Foul time. Time during which track is taken out of service for MOW work on or around the track.

GPWS. Ground Proximity Warning System. Data-link systems providing alerts to pilot if they fly into terrain.

Interlocking. A configuration of switches and signals interconnected to direct trains along different routes, the limits of which are governed by interlocking signals.

Maintenance-of-Way (MOW). On-track maintenance for repairing, testing, and inspecting track or wayside apparatus such as signals and communication devices.

NORAC. Northeast Operating Rules Advisory Committee.

Operating Rules. A book of rules that govern a particular railroad's operating procedures and practices.

Shunt. Activate automatic block or interlocking signals when present on track.

TCAS. Traffic Alert and Collision Avoidance System. Data-link system providing onboard protection from midair collisions.

TGV. Train à Grande Vitesse, the French high speed train.

Territory. A section of railroad for which a dispatcher is responsible for the safe and efficient movement of trains and other on-track equipment.

Track Car. Equipment, other than trains, operated on a track for inspection or maintenance. Track cars might not shunt track circuits.

UPS. United Parcel Service

VDU. Visual Display Unit

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