Dynamic Responsive Signal Control for Railways:

Lessons from other transport industries

(Results of Literature Review)

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Project Report

Contents

1. Introduction 3

2. Operations of Railway 5

3. Communication 9

4. Recovering from Delay 13

5. A Comparative study: What can the railway industry learn? 17

6. Conclusion 22

References 23

1. Introduction

Railway systems are coming under increasing pressure to serve as a reliable and robust transport system for an increasing number of passengers. In the current financial climate, identifying ways in which to increase the capacity of the railway network without adding extra track is a matter of increasing focus. Railway Stations and Junctions are vital elements that constrain the network capacity. Limitation factors include the railway infrastructure, train schedules, control techniques, passenger flows, information management as well as other human factors and unpredicted variations. Busy stations and junctions are situated in areas of dense population. Core strategies therefore need to maximise the use of the existing infrastructure, with signal control system improvements an important aspect to such as approach. Some systems have been developed to support train operators in making decisions at major stations, but complex operations still rely on manual control and human judgement, and future conflicts and higher levels of optimisations will be demanding on unsupported control officers.

This paper will present ideas that aim to develop the railway industry to operate with dynamic responsive signal control in order to be able to operate more robustly and efficiently whilst improving the capacity of the railway network.

There are three ways in which this project aims to achieve Dynamic Responsive Control:

1. *More responsive operation*

   Current train timetables schedule margins in order to help recovery time to aid service recovery after service perturbations occur so that trains can maintain punctuality. If we remove the margin that has been inserted into train timetables, it is possible to achieve more responsive operations. The resultant loss of robustness in the train timetable could therefore be replaced using a dynamic control methodology.

2. *More efficient operations*

   More efficient operations may be achieved by improving train regulation and having more efficient acceleration and braking profiles. This would enable short headways and regular intervals between trains building capacity into the rail network.

3. *Influence from other dynamic transport modes*

   A key element of this research project which makes our approach different from other railway research projects is the fact that we are not restricted to using traditional railway analysis and methods. Consequently, the operation of other dynamic transport modes such as aviation and taxi despatching influences may influence the future framework and direction of our project.

This paper will focus on the operation of other dynamic transport modes to investigate whether there are operational, communicative or organisational aspects in which can be applied to the railway industry. The aviation and taxi industry are of particular interest to this project due to the dynamic nature of their operations, which the railway industry may be able to benefit from. Despite the obvious differences that exist between these transport industries, there are also many similarities. In particular, the similarities between the aviation and railway industries long term and short term aims in particular show how information sharing between these industries can be beneficial in introducing new ways of thinking to the railway industry. This summary document will initially review relevant literature within the operation, communication as well as the relevant techniques used for recovery from delay within these three dynamic transport modes. Analysis will then be completed comparing the operations, communication and delay recovery of the aviation and taxi industry in turn with the railway industry to review if any techniques or implementation measures can be applicable to the railway industry. This paper will not address each of these industries or operational elements in detail, but will instead focus on key basic decisions that help these dynamic industries operate in order to see if there are any easily implementable ways in which to improve reliability and resilience of the railway industry. This study will support the 'Dynamic Operations at railway junctions and stations research project as shown in the below framework diagram through additional operational observed recommendations.

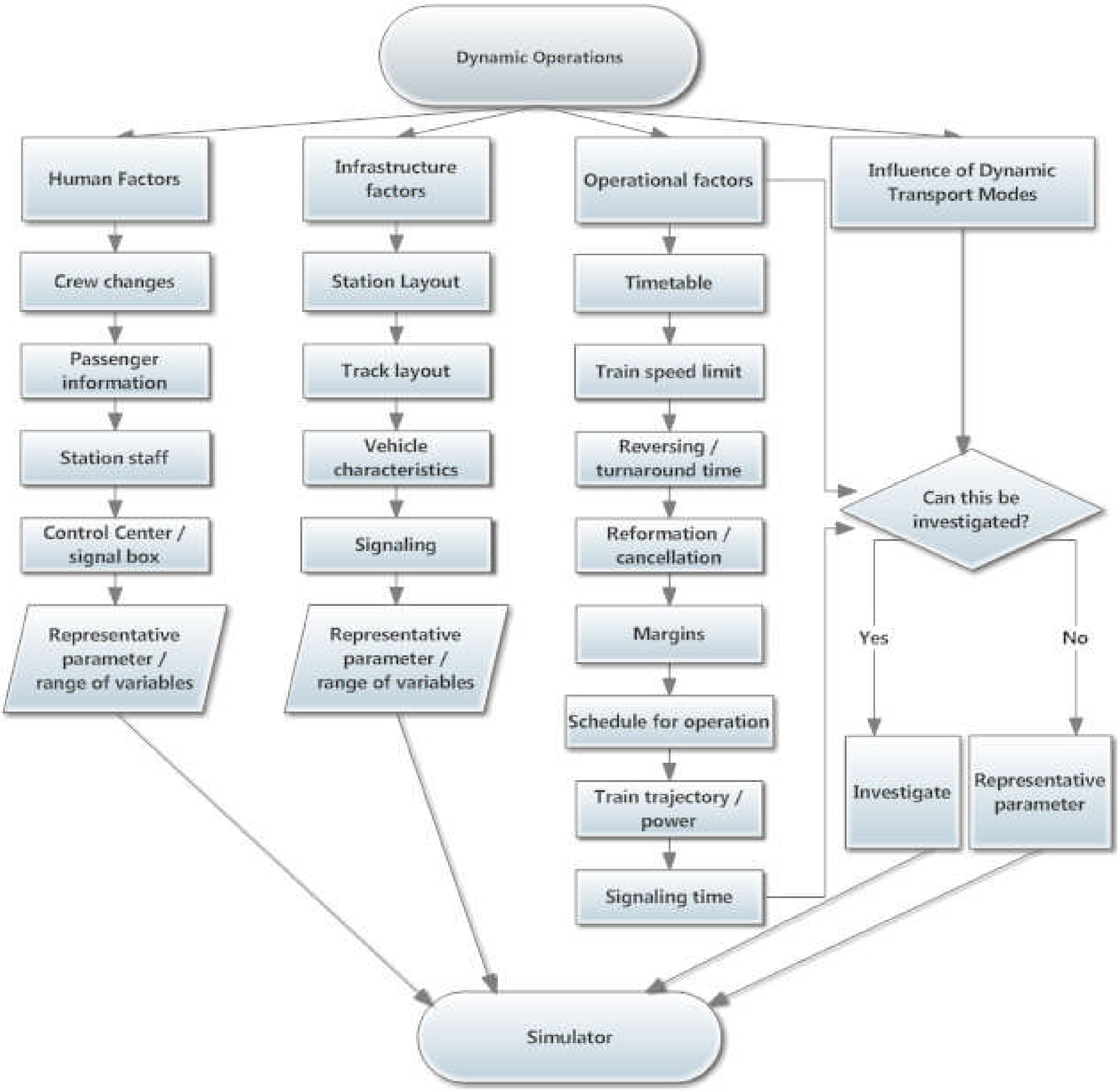

Figure 1. Diagram showing the framework for researching Dynamic Operations at railway junctions and stations

2. Operations of Railway

The railway has two major components; the rolling stock and the infrastructure (Bonnett, 2005). Within the railway system, factors which cause delay include the railway's infrastructure, train schedules, control techniques, passenger flow and information management in addition to other human factors and unpredictable operational problems (Carey & Carville, 2000). Additionally, railway stations and junctions are seen as elements that constrain network capacity. Core strategies are therefore needed to maximise the use of the existing infrastructure, with signal control system improvements an important aspect to such an approach. However, there may also be easily implementable measures that can be adapted from other transport industries.

Within the train operating hierarchy the central control centre ultimately controls and co-ordinates individual train services. The aim of the rail operation control is to ensure that trains run on schedule. These central control centres co – ordinates the operations at several different stations and signal boxes to keep trains to schedule. The signalling system extends between the train and trackside to the central control centre. This allows for the vital control of the railway and also provides operational information to locations, equipment and individuals so that appropriate action can be taken as shown in figure 2 (Bonnett, 2005). Some systems such as Automatic Route Setting (ARS) have been developed to support train operators in making decisions at major stations, but complex operations still rely on manual control, human judgement and foreseeing future conflicts in addition to higher levels of optimisations, which are demanding on unsupported control officers (Mannino & Mascis, 2011).

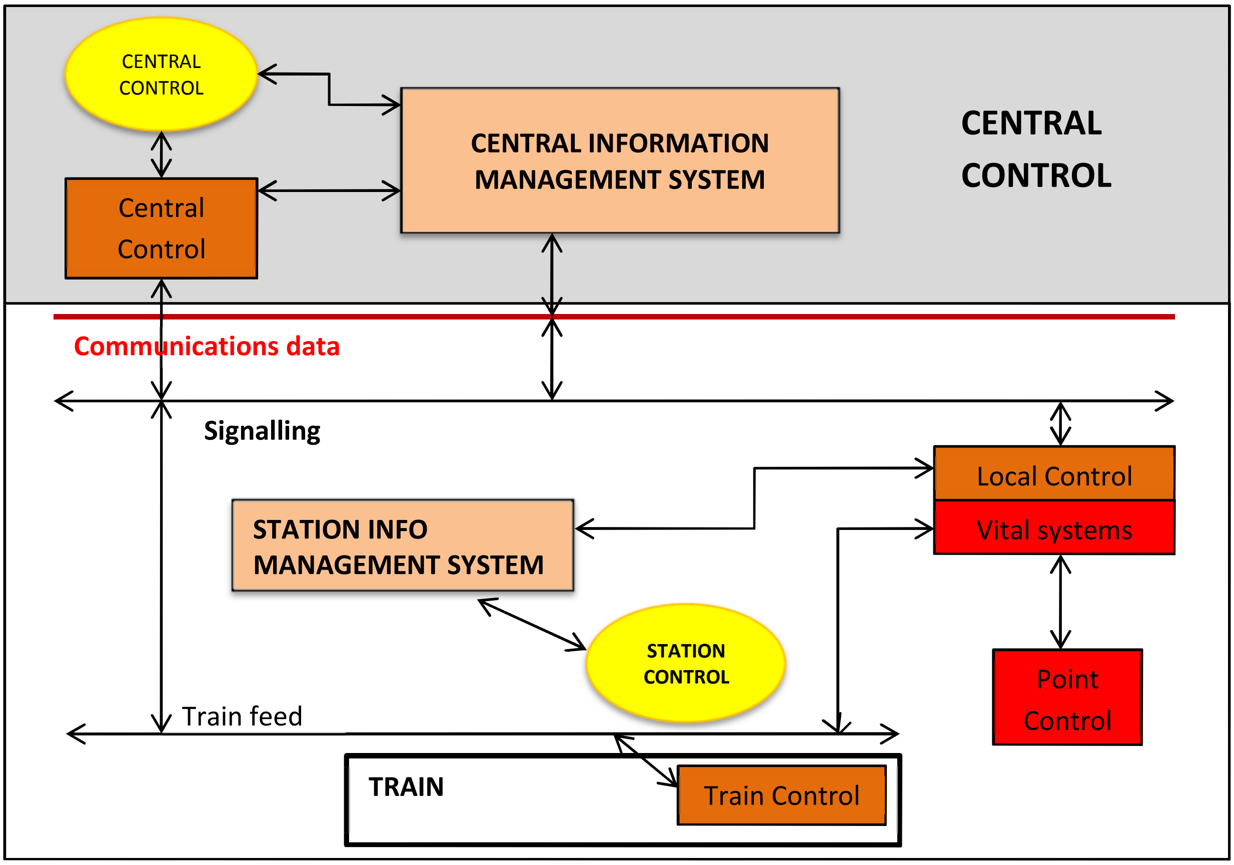

Figure 2. Signalling and Control Systems Diagram (UCL lecture notes, 2009)

The railway industry uses a timetabling system to operate the railway services. Within local stations the controller will take charge of ensuring that trains run normally in terms of clear cut train timetables, rolling stocks, crew and all engineering positions. Passenger railway timetables are usually cyclic, with trains operating regularly and in a cyclical manner (D'Ariano *et al.*, 2006). Traditionally, robust railway services have been built into railway timetables by using margins in between train services in order to design a resilient timetable allowing for service recovery between trains (Abril *et al.* (2008) and Landex, 2006). The UIC (2004, p15) defines these margins as 'Buffer times,' which are "times that are inserted between train paths in addition to the minimum interval between trains that arises depending on the signal system. They serve to reduce transfer delays from one train to the next." Knock-on delays or consecutive delays are caused by the cumulative effect of delay on other train services. This is used to evaluate the degree of robustness of scheduled railway services and the stability of train operations.

This is similar with aviation operations, as buffer times are also vital for effective operation and flight scheduling. Margins are therefore used in a similar purpose to the railway industry. Hassounnah and Steuart (1993) showed that large buffer times could improve the punctuality of flights. Yan and Change (1998) used fixed buffer times between continuous flights and assigned the same gate to absorb stochastic delay. However the best way to calculate buffer times are, many academics alike agree that uniform length possibly results in inferior operating performance.

Figure 3 conceptualises the main factors of airport operations between passenger demand, airport capacity and flight capacity. Even though large scale airport operations are very complex, there are also great similarities between airport operations and railway operations, especially when it is analysed at a more basic level, and this is represented in the below diagram.

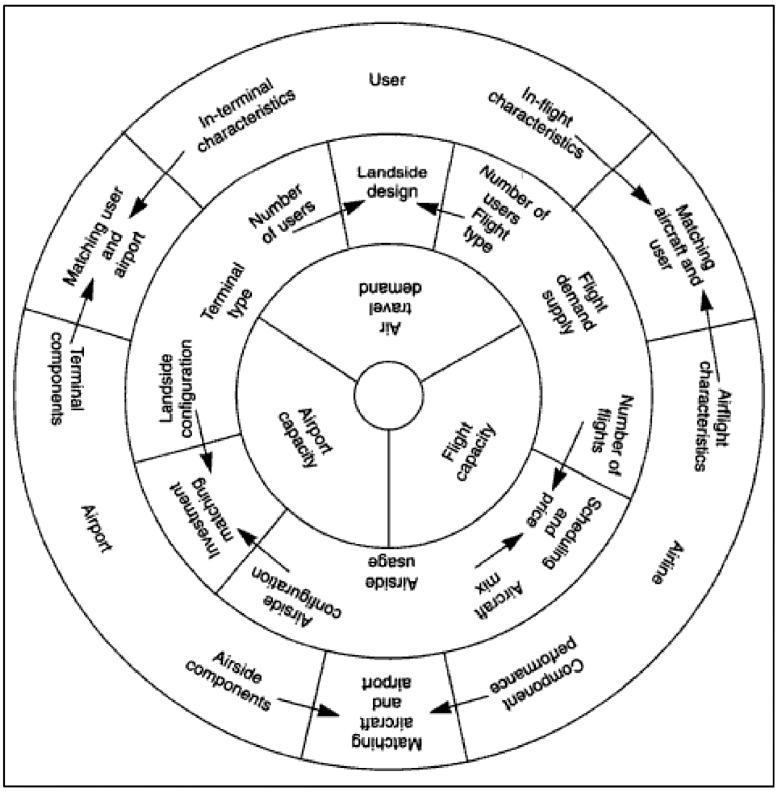

Figure 3. Hierarchical systems diagram of airport relationships (Ashford et al. 1998)

Essentially the aviation industry involves the interplay between the airport, airline and users or passengers. Similarities are apparent with the railway industry as passenger demand and capacity are the key elements, which are central to the aviation system and dictate the timetable, service level, type and price. The level of service and demand is therefore reflected in the flight timetable and is essential to the interplay of different airline companies.

Train journeys usually serve a number of different station, however flights will only land at an intermediate or terminal destination. In this sense, airports provide a change of mode, enable processing and also a change of movement type (Ashford and Wright, 1992). Operations at airports can be simplified into landside and airside functions. These are exemplified in figure 4 from Fricker & Whitford (2004). The system diagram shows how an approaching aircraft uses the runway, taxiway, and apron prior to terminating at a gate position where passengers access or egress from the system. Thus, when air operations are simplified, parallels can be drawn with railway station operations as services are scheduled to approach a stand or platform at a specific time and passengers and crew will wither board or depart accordingly. However, these operations become increasingly complex with the size of the airport.

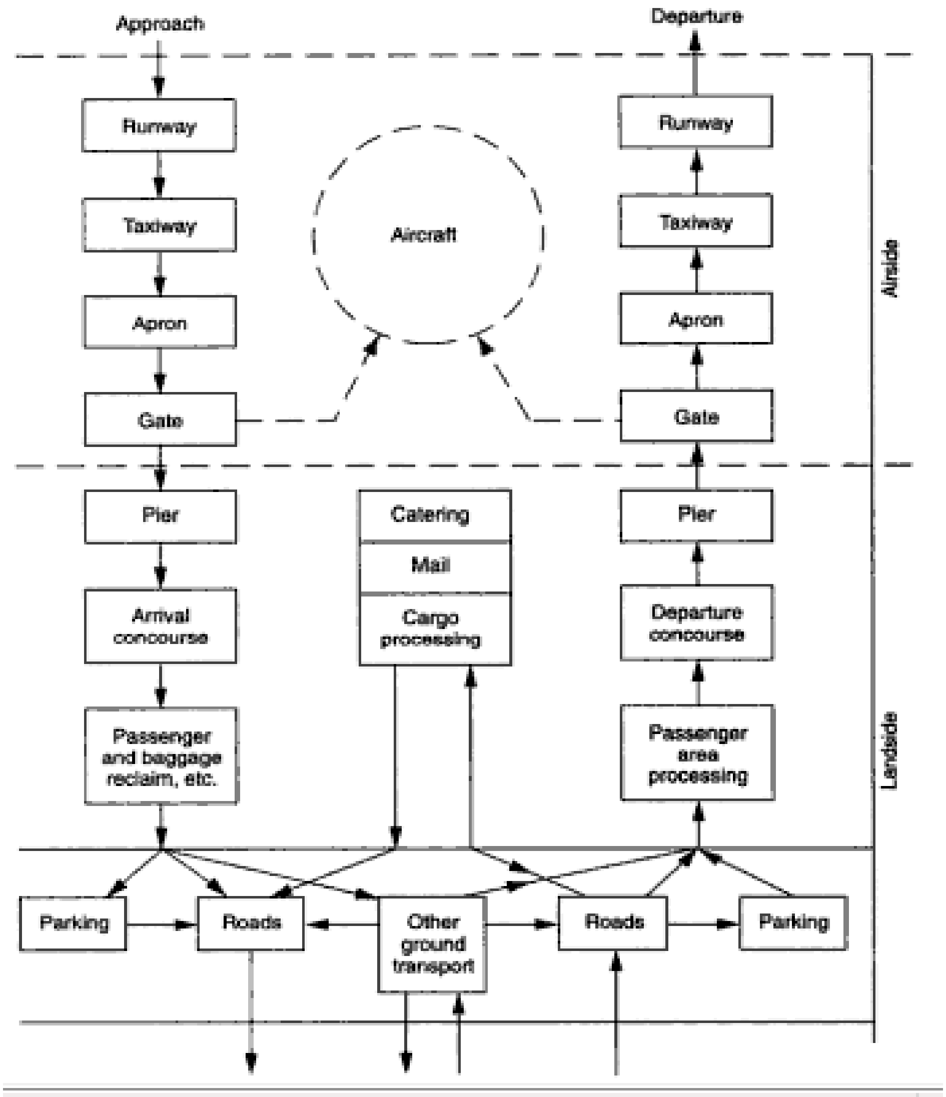

Figure 4. The airport system. (Fricker & Whitford, 2004)

The sequencing of aeroplanes is also very important within operations in the aviation industry. The airport controller decides the landing order and groups the sequencing of planes according to their size and type as far as possible. This enables turbulence to be minimised between services and also increases the efficiency of landing schedules. In contrast, the railway operates based on either the timetable or in some exceptional cases the first-comer-first-served principle.

The Air Traffic control centre also plays a vital part in the safe operation of airports and pilots are expected to listen to the advise air traffic control give who can see the position of other commercial airlines via radar. The close interplay between different levels of crew is also something that the aviation and railway industry share. The airports many parties which include airlines, airport operators, ground handler, air traffic control, Central Flow Management Unit (CFMU) and passengers are all important to the successful co-ordination and inter-play of services.

However, railway and aviation operations vastly contrast with that of the taxi industry as the taxi industry is atomised into a large number of single operators, with no precise organisation, and each taxi unit has the ability to supply at will (Cooper *et al*., 2010). As each taxi is an independent self-sufficient units, the interplay of different parties and departments is not as prominent as in the aviation and railway industry. This is especially the case for licensed Hackney Carriages, which in London are known as 'Black cabs' who operate independently.

However, within the taxi industry, Private Hire vehicle companies (PHVs) are restricted to pre-booked (dispatch) companies, which often also use integrated control centres for operations (Cooper *et al.* 2010). Larger cities will often have a single or small numbers of large dispatch companies, which are sometimes called Radio Rings, with a function to dispatch, but there remains no obligation on the driver to participate or even obey requests. Examples of large rings include Glasgow Taxis, which is a single company for Glasgow, or Radio Taxis in London. In most locations these define zones within a city, of varying sizes. The zones allow for the determination of closest jobs to a radio call, a pre-booked journey, and may be used to encourage supply in a particular area, an example of this is called the magic circle in Edinburgh.

Previously, a dispatcher would simply broadcast the names of locations using radio frequency to all PHVs in and individual drivers would all travel to the required location. PHVs therefore often installed more than one radio chip to pick up calls from other taxi dispatch companies in order to increase work. However, operations have now become far more efficient with improvements to taxi dispatch technology allowing taxi operations to become far more efficient and respond quickly to customer. Computerised dispatching systems now automatically route passenger requests to the closest vehicle as identified by the vehicles on-board GPS device (Cooper *et al.* 2010). Software determines most appropriate vehicle to supply, usually by distance, dispatch call sent by radio, driver receives and responds. Additionally, dispatch centres are able to allocate jobs to taxis that have been in that geographic area the longest using advanced operational rules to receive the next service. The taxi industry does use scheduling software, there are a number of good versions including Taxibook from DDS Mobisoft, and these are more likely to be used in the pre-booked market than for hailed taxis (Erfurth *et al.* 2008). Scheduling and dispatch functions are more associated in allocating the (random) locations of taxis to the determined locations of calls. Thus the passenger is the fixed location, not the vehicle.

Indeed, *Brake et al.* (2006) has noted the rise in flexible transport systems, whereby services for passengers and routes are flexible and are demand responsive. Figure 5 shows the basic level of telematics offered which also forms the base of operations at taxi dispatch centres. In this way, communications can be either fixed or mobile and services are scheduled and dispatched using software, enabling rapid on the day booking (Cooper *et al.* 2010).

3. Communication

Effective communication and operations go almost hand in hand. This is especially the case with taxi services, with regard to Private Hire Vehicles as show in figures 5 & 6. Hackney Carriages are the exception in which effective communication is not required as individual units respond purely to on street customer calls and so do not require communication lines from integrated control centres.

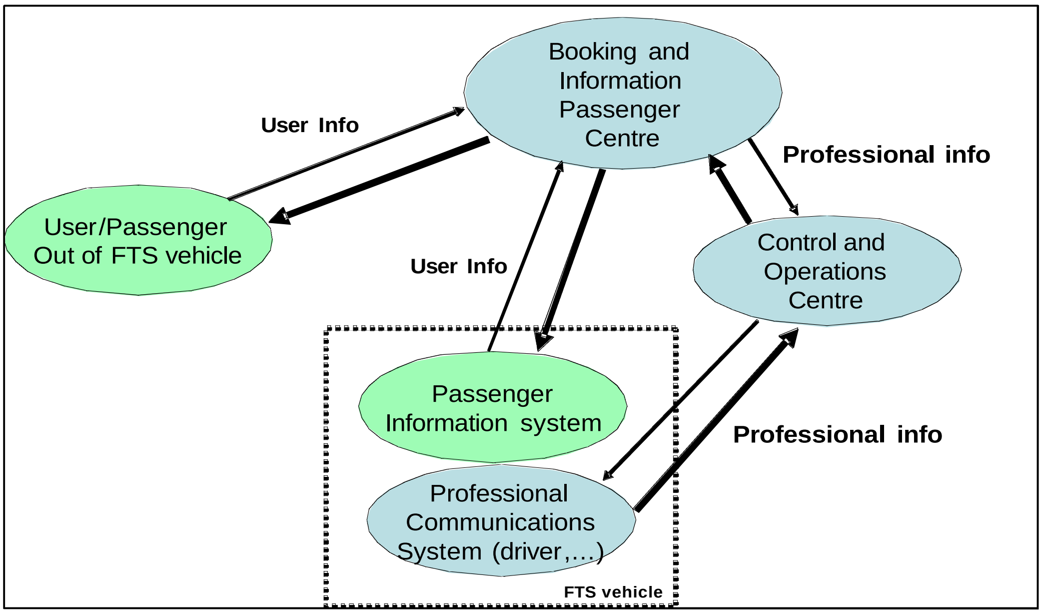

Figure 5. Overall Telecommunications Structure (Cazemier et al. 2011)

Private hire vehicles can be operated via satellites through the One London system. This system allocates the nearest available Private Hire Vehicle via satellite to an on-board GPS unit on-board each vehicle. A simple email or text by the customer identifies the required pick up point and the nearest Private Hire Vehicle is contacted through a digital message. Once the driver accepts the job, the customer receives a message confirming the pick up point and time. This has made taxi operations more dynamic, responsive and efficient. In such way technology has increased flexibility by removing the differentiation between professional or customer links as illustrated in figure 6.

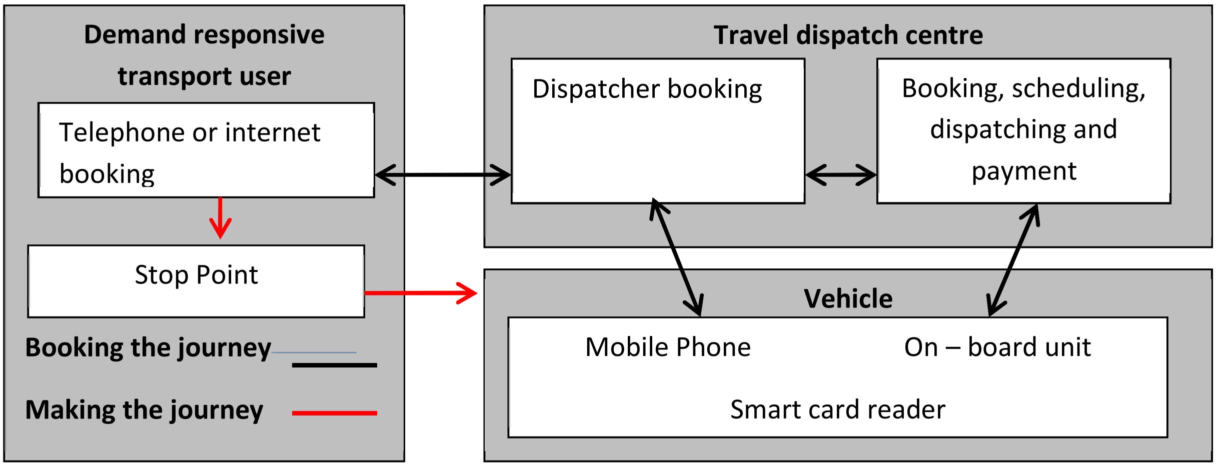

Figure 6. Schematic Representation of telematics- based DRT (based on Brake et al. 2006)

Communication techniques in the railway industry are significantly different from those used in taxi dispatching. Within the railway industry, there are normally there are two types of communication methods. Contacts between drivers and signal boxes have been done via radio, and the major communication method with guards is phone based (Bonnett, 2005). Additionally, pagers or mobile phones are used for contacting key personnel when incidents occur. It is vital that radio systems are compatible so that commands and control strategies can be communicated and implemented.

Network Rail operates various essential telecommunication circuits for signalling and electrification control systems, train radio systems, line side communications, level crossing CCTV, station information and security systems as well as more general IT and business telephony needs. Network Rail operates several analogue radio networks that support mobile communication applications for drivers and line side workers, which consist of base stations, antenna systems and control equipment. The National Radio Network (NRN) was developed specifically for the operational railway; it provides radio coverage for 98% of the rail network through 500 base stations and 21 radio exchanges. Fixed communication at trackside is provided by telephone. These are primarily provided for signallers' to communicate with train-crew, via telephones mounted on signal-posts, and with the public through telephones located at level crossings.

CCTV also plays a vital role within the railway system providing information for the control rooms, train drivers and emergency services to gauge what is happening on the station land platform level. CCTV cameras also enable station controllers to manage the flow of passengers in order to prevent station crowding. They can also provide vital data to help analyse how improvements can be made with regards to station layout and operations.

It is also increasingly important that information is effectively communicated to passengers on the station level. This is often communicated via dot matrix information boards ands PA systems. Figure 7 shows how communication and information is exchanged within the railway system.

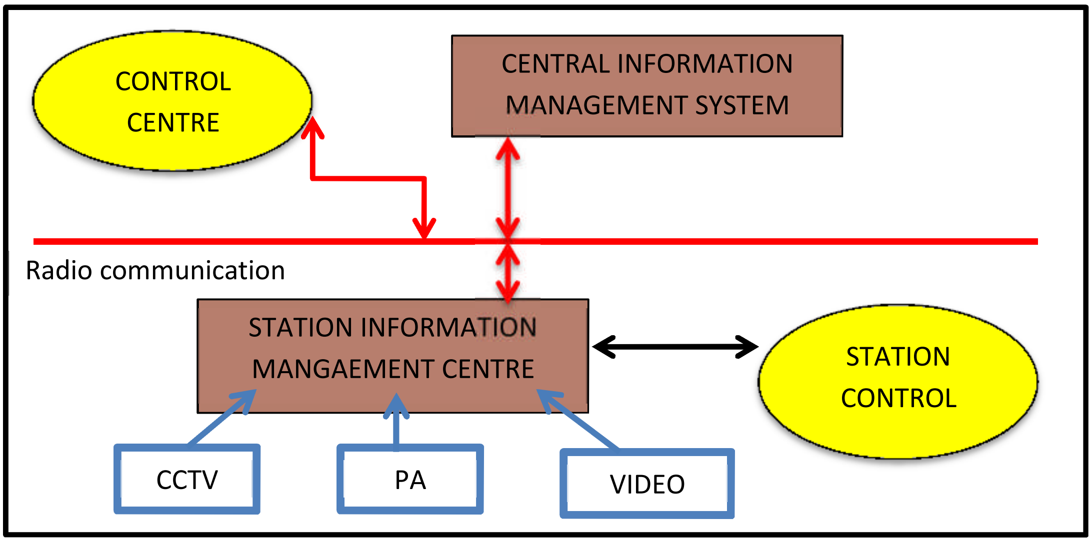

Figure 7. Simplified Railway communication System

Within the aviation industry, Air traffic control (ATC) is ultimately in charge and information sharing occurs on every level producing effective communication, which when done efficiently, produces good aviation operations. Central to the provision of ATC services within the National Airspace System (NAS) are three major functions; these are navigation, surveillance and communications. Navigation delivers important information so that aircrafts are able to navigate along assigned routes. Surveillance allows for the collection of information of aircraft positions. Air-ground communication facilitates ATC to air-bourne pilots and allows data requests from pilots. The NAS extensive existing infrastructure supports ATC functions. The below diagram illustrates the complex transfer of communication between the air and ground within the aviation industry.

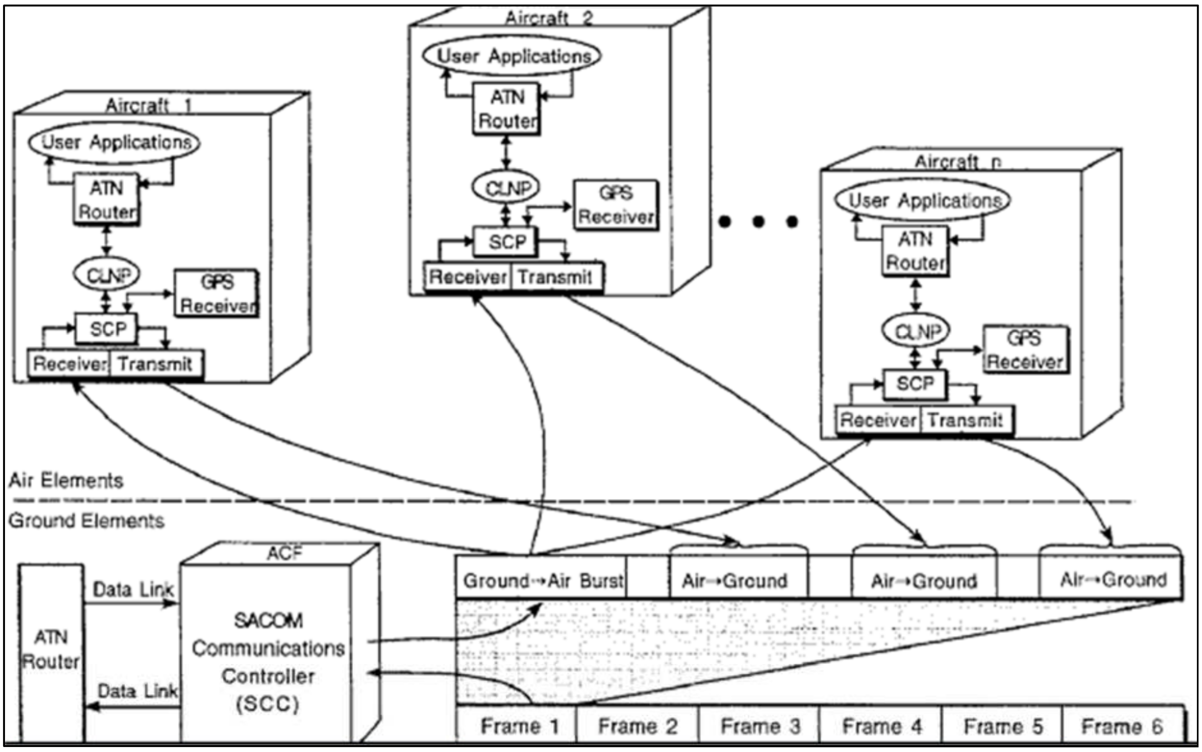

Figure 8. Communication structure within the aviation industry (Schuchman et al.1995)

Air ground communication function is supported through a network of radios with which allow direct communication enroute, at terminals, tower and flight service station control positions which allows direct communication with pilots at each point on the ground and in the air. The ATC is system supported by the navigation, surveillance and communications infrastructure is the primary system used to establish and maintain safe separations between aircrafts in the ATC system and between aircrafts on the ground. Traffic Alert and Collision Avoidance system (TCAS) uses data received from air-bourne transponders responding to secondary radar interrogations and is the last line of defence against unsafe air traffic situations. The SCCOM Communications Control (SCC) employs dependent surveillance to provide data required for surveillance using GPS. This system is consistent with the Aeronautical Telecommunications Network, air-ground radios and Air Traffic Control. Voice communication is still one of the most important forms of communication within the aviation communication system as in the railway and taxi dispatching system. This is important so that a single pilot can have direct communication with a single Air Traffic Controller via radio transmission (Schuchman *et al.*1995).

However, it is also important to look at team communication within the aviation industry to see if lessons can be learnt. Katz et al. (2003) argues that human error is the main reason for communication break downs within the aviation industry and instead believes that communication links need to be improved within the cockpit and in crew co-ordination through better non-verbal communication. Indeed, many other academics agree as shown by the wealth of research regarding how to improve human communication in order to improve information sharing within every level of operations (Trenholm, 1995).

4. Recovering from Delay

As Private Hire Vehicles and Hackney Carriages do not operate to a schedule, service recovery after disruption is not applicable. If private Hire vehicle is going to be late for a customer pick up point, another taxi in a nearby location will be called instead. However, the railway and aviation industry both have individual techniques for bringing services back to normal operations after perturbation.

Within the railway industry, timetables and schedules are planned approximately six months in advance and are analysed and improved periodically in order to continuously improve railway timetables, aiming to make timetabled services to be more robust and efficient. Services are planned in detail such as co-ordination of trains at crossings, junctions and platforms as well as the train order. Reasons as to why trains are not running to schedule range from serious engineering failures delay, human error such as a new guard operating at a station, passenger delays such as wheelchair passengers and minor and serious signal failures. Good timetable planning and scheduling may not be badly affected by minor delays. However, even the most robust scheduling will not be able to prevent delay from major railway or blocked tracks (Vromans *et al*., 2006).

Currently when trains do not run to schedule, there are several ways in which the railway industry aim to bring services back to timetabled services. Managing railways in real-time traffic in order to recover services from delay include modifying timetables, minimising delay between consecutive train services and reforming train services by changing the final destination or stopping points. Often decisions have to be made by rule of thumb when perturbation exists and trains run off schedule. Factors need to be considered in decision making when a train is delayed are:

i. Next train' arriving time
ii. Time taken for decision making,
iii. Needs of passengers
iv. Time needed to carry out the decision
v. Crew (Changes / required),
vi. Rolling stock
vii. Others

Knock-on delays or consecutive delays are caused by the cumulative effect of delay on other train services. This is used to evaluate the degree of robustness of scheduled railway services and the stability of train operations. This had led to a wealth of research by many academics including Ho *et al.* (1997), Adenso-Diaz *et al.* (1999), Tornquist *et al.* (2007) and D'Ariano *et al.* (2006) who aim to minimise delay using a range of simulation tools and control methods ranging from minimising margins between services and reschedule trains.

During real-time train rescheduling, the dispatcher has to modify the timetables, introduce new train routes, short-run train trips in case of track blockage or even cancel train services at some stations. Given the timetable and the infrastructure alternative routes are found by the real-time optimisation model considers default routes as shown in figure 9. However, if no suitable alternatives are found, the dispatcher will be in charge of manually finding better alternative routings.

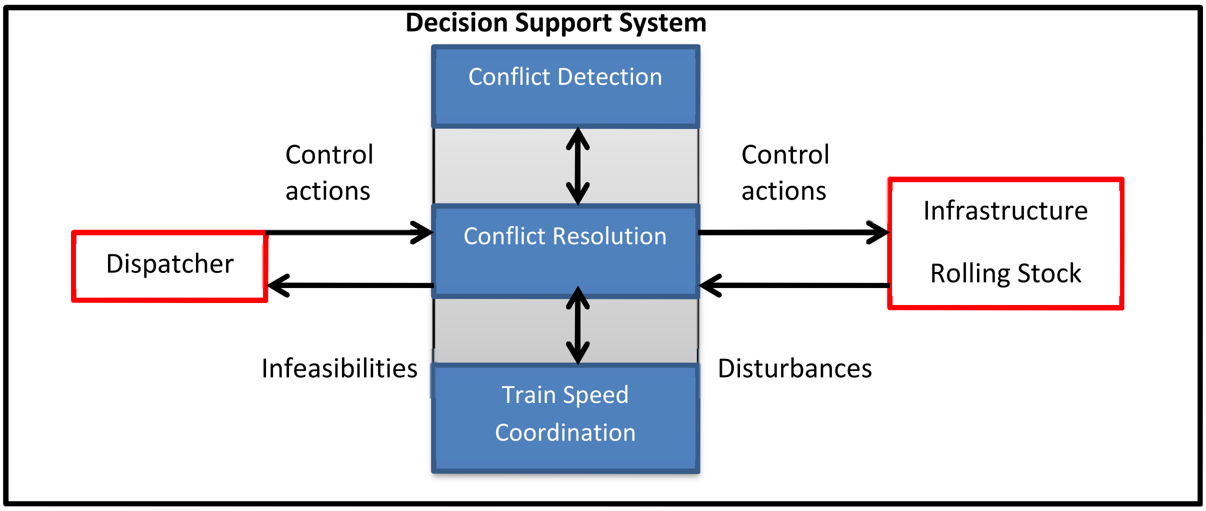

Figure 9. Real-time train rerouting procedure D'Ariano (2008)

Real- time train Dispatching Support System (DSS) have been developed by Shoji and Igarashi (1997) Kawakami (1997), Konig and Schnieder (2001) and Giannettoni and Savio (2004) to help dispatchers to aid the decision making process which is shown in figure 10. This system is designed to quickly reschedule train movements during real-time disruptions using components for conflict detection, conflict resolution and train speed coordination within the decision support system process.

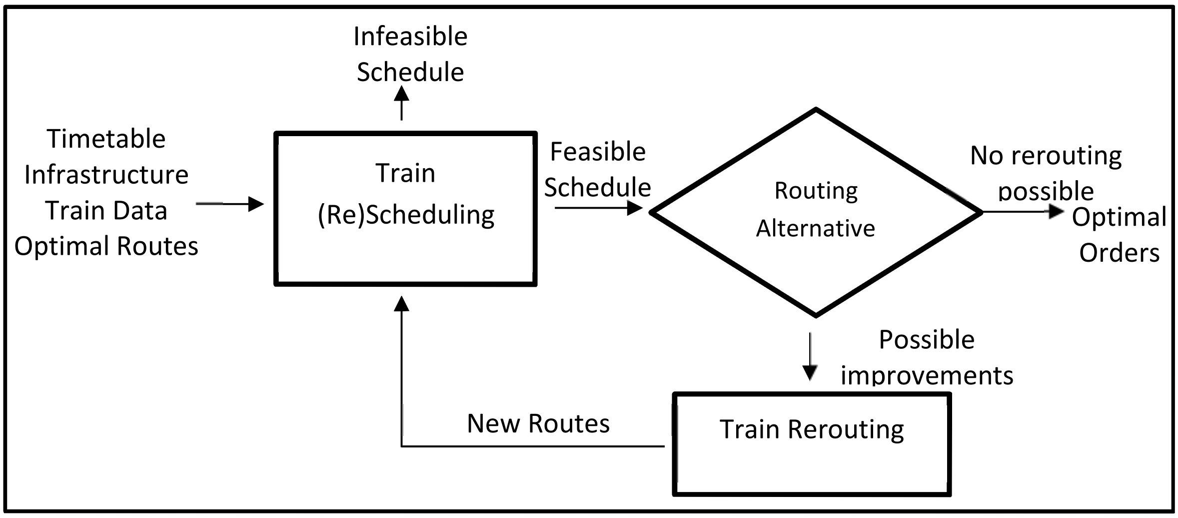

Figure 10. Components of a proactive train dispatching support system

Conflict detection involves finding potential conflicts in train routes using pre-established traffic predictions, according to real time timetable status, infrastructure information and position and speed running time. Conflict resolution is the proposal of the most suitable and robust dispatching options. According to Takeuchi & Tomii, (2005), this can involve train rescheduling, rerouting and removing train journeys or connection services. Train speed coordination finally creates new target times based on real time information and headway information to minimise delay to the system. This shows how computational systems can help produce solutions for real-time train operations.

There are many reasons as to why delays can occur within aviation operations. According to Zhang and Hansen (2008) shortages of airline resources and airspace capacities are two major causes of airline operations disruptions. Bratu and Barnhart (2006) describe airline disruptions in great detail. The rescheduling procedure in aviation operations s very complex and involves a lot of different departments and people within the aviation industry. This is simplified by Ashford *et al.* (1998) in the figure 11 below.

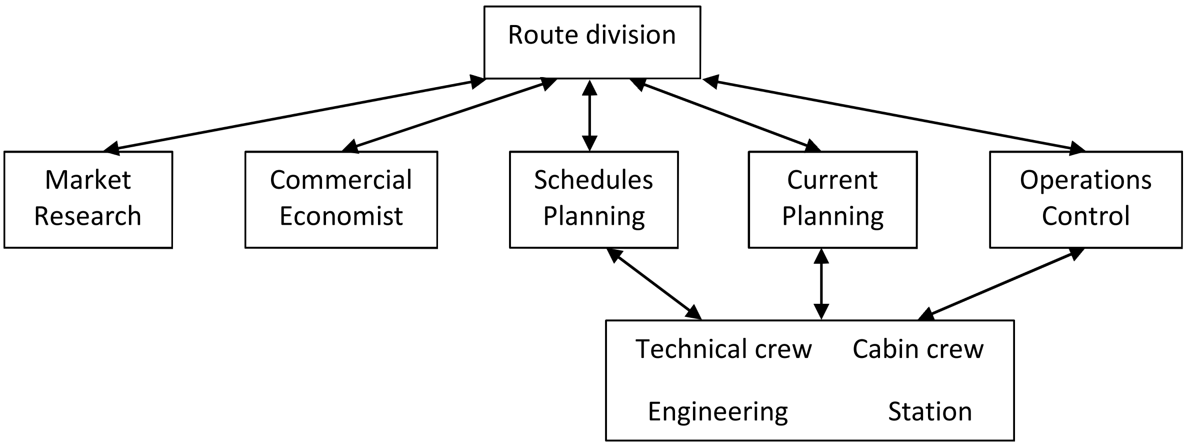

Figure 11. Organisation of scheduling within a typical airline (Ashford et al. 1998)

Figure 11 shows the commercial economist takes advice from market research and interacts with the various route divisions, which control the operations and various groupings of the airline routes. In some airlines there are no route divisions, the commercial economist and route divisions are both part of the commercial department. Within the rescheduling procedure the commercial economist will additionally analyse factors such as current route capacity, past data of the route, aircraft type and fare structure and time of day (Ashford *et al.*, 1998).

Shortages of airspace can be caused by bad weather, air traffic control malfunctions and security threats to name a few. Similarly, ground disruptions can happen for numerous reasons, mostly including bad weather and technical failures on aircraft. Under the current system of collaborative decision-making (CDM), once an imbalance between demand and supply is detected, a ground delay programme (GDP) is raised. This assigns flights an estimated later arrival time. Depending on the time when the failure has been detected, airlines consider different scenarios. If this brings flights back to schedule, GDP ends. However, if operations are still delayed ATC issues each scheduled flight an estimated departure and clearance time and a controlled time of arrival. Airlines manage their controlled arrival slots themselves and will organise them in their best business interests (Zhang and Hansen, 2008).

The scenarios that the airlines decide to follow may vary. Some may try to minimise the costs and or delays, for the others it is important to get to the destinations due to next connecting flight and so on. Each airline will analyse the effects of each scenario and when this is chosen they will communicate it to the ATC by sending a modified flight plan. The flight plan is updated and then being sent back to the CFMU (Central Flow Management Unit) who then compares demand with the available capacity of the system. If there is no shortfall in capacity, every flight is being operated according to previously submitted flight plans on the “first come, first served” principle. In case of disruption, the CFMU identifies the location and the duration of that disruption and tries to solve it. The solution to disruption is mostly based on re-routings to avoid the congested areas or assignment of ground delays. Based on this, the CFMU assigns windows of -5/+10 min within which each flight has to depart. Those are then communicated back to the air traffic control, airline and aircraft operators who together have to act in order to meet the given timeframes. The parties mentioned above communicate via telephone, fax, radio or data exchange. If some further changes are needed, these are sent to the CFMU who then re-calculates the disruptions and assigns time slots and resends them to the air traffic control, airline and aircraft operators.

Handling the disruptions in the air involves fewer parties. Airspace is organised in the elementary sectors which each have their own capacity. The sector is often controlled by a team of two controllers. When the amount of traffic in a particular sector exceeds the capacity, this may cause a disruption. There are many options to resolve this problem. The particular air traffic control centre may ask from CFMU to regulate a particular portion of their airspace by making aircraft go around rather than through the particular part of airspace. Or if they have enough staff, the air traffic control centre can split a sector into two and allow handling more flights. Those changes are then communicated to the CFMU and the pilot via telephone, fax, radio or data exchange.

Crucial to the aviation industry is an interoperable system so as to allow efficient information sharing between the airlines as well as different departments within the aviation industry. The reasoning mechanism also needs to be easy to understand so the system used should be able to give explanation on its actions to improve transparency between departments. This allows all departments to share updated information from one simple server, creating efficient communication throughout all departments helping flights to get back to schedule (Chun *et al*., 2000).

5. A Comparative study: What can the railway industry learn?

From looking at the operations, communication and delay recovery between rail, air and taxi operations, many similarities and differences have become apparent. Similarities are especially apparent when comparing railway and airport operations. It becomes apparent the number of operational similarities that exist, especially between the aviation and railway industry in regards to long and short-term goals. The basic structure of the aviation industry can be correlated with that of the railway industry. Both industries use a central control centre, which in the aviation industry is comparable to the air traffic control centre. Flights and train services are also scheduled with buffer times built in for service recovery and stands or platforms are sent to accordingly. The sequencing of trains and aircrafts are also vital components within rail and air operations and the methods for service recovery both involve cancelling or changing the destination of a service. Therefore, the short-term similarities between the operations of the two industries reveal how techniques and lessons can be learnt and shared between the two industries.

However, there are not only similarities in current operations and delay recovery strategies, but similarities in the long term plans and aspirations of both transport facilities. Both industries plan on improving the integration of services in order to improve the efficiency of their operations. The railway industry wants to create a larger Integrated Control Centre for Network Rail operations and the aviation industry wants to create one European sky, through the SESAR project enabling all airports and flights across Europe to be intrinsically operated. This shows that the long term intermodal information sharing and collaboration could be beneficial for both industries as information and techniques can be shared and improved.

For instance, as previously mentioned, the sequencing of aeroplanes is very important within operations in the aviation industry. The airport controller decides the landing order and groups the sequencing of planes according to their size and type as far as possible. This enables turbulence to be minimised between services and also increases the efficiency of landing schedules. In contrast, the railway operates based on either the timetable or in some exceptional cases the first-comer-first-served principle. A grouping could be introduced within the railway industry in order to minimise the delay. This will be increasingly important as new trains are rolled out into service, which have improved capabilities compared with older trains.

Another aspect which railway and aviation industry share is the operation of both freight and passenger services. This has not been investigated in this document, but the interplay between these services is also another key aspect that will help improve railway operations. Analysis and evaluation of how the aviation industry balances these services would be beneficial for the railway operators and controllers.

Indeed, maybe the most important factor that the railway industry can learn from the aviation industry is how they share all information and use an interoperable simple system so to improve information sharing and team work. According to (Chun *et al.*, 2000), the system that is currently used in Hong Kong Airport (HKA) that has shown to be extremely effective is one which in interoperable between all departments and allows for open information sharing, allowing schedules and plans to be updated easily by all users, which is automatically fed into the system for all to view.

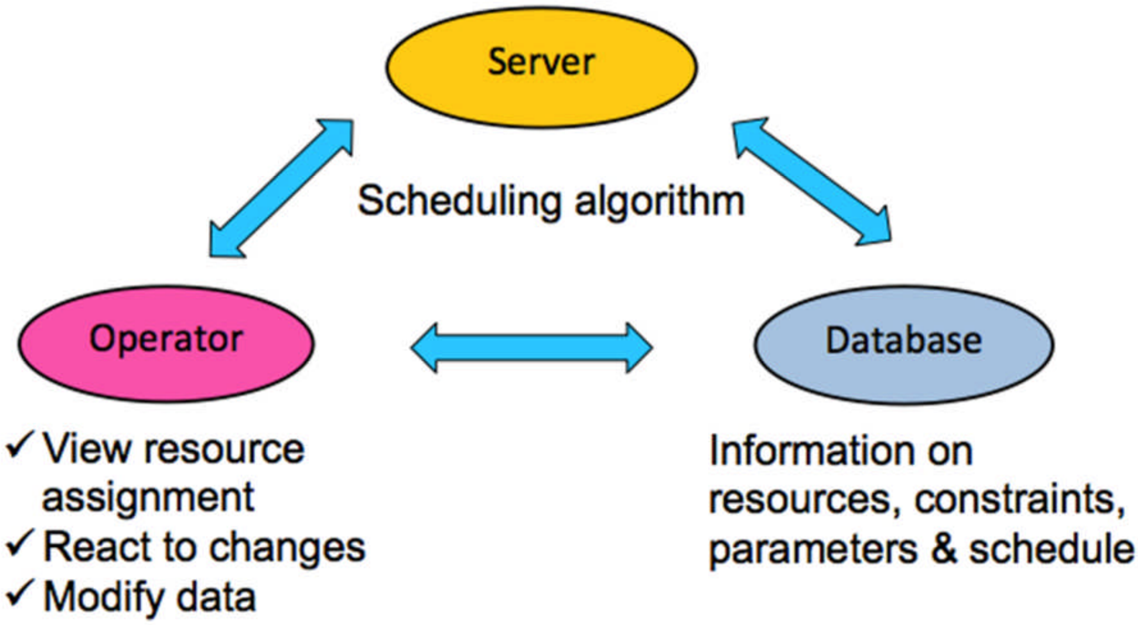

Figure 12. Simplified version of the tiered software used in HKA (Chun et al., 2000)

As previously stated, the taxi industry is very different from the railway industry as their services are not scheduled or planned and so they do not need to reschedule or change their services if delay is encountered. The taxi units are also fully independent and so the driver will ultimately have control over the jobs he takes and which routes he uses. The only similarities that exist within these services are the use of the integrated control centre to calculate the nearest taxi to a call and the use of live to live information. However, the communication structure within the taxi and demand responsive transport industry has proved to be extremely efficient, some of which may be transferable to the railway industry.

Each individual Private Hire Vehicle is fitted with a GPS unit so that the integrated Control Centre can easily allocate the nearest taxi to a call so to dispatch taxis quickly and efficiently. This may be transferred to the railway industry to be used by individual train units as well as possibly even station staff. This way live information would be able to indicate where each specific train unit is which can be used in conjunction with the traditional signalling and live to live communication. Similarly, station staffs in large terminal railway stations like Waterloo or Clapham Junction may be able carry individual GPS units. In this way, if an incident occurs at a train station, the Integrated Control Centre can allocate the nearest staff member to the incident in order to deal with station incidents quickly and effectively so to avoid causing delay to train services.

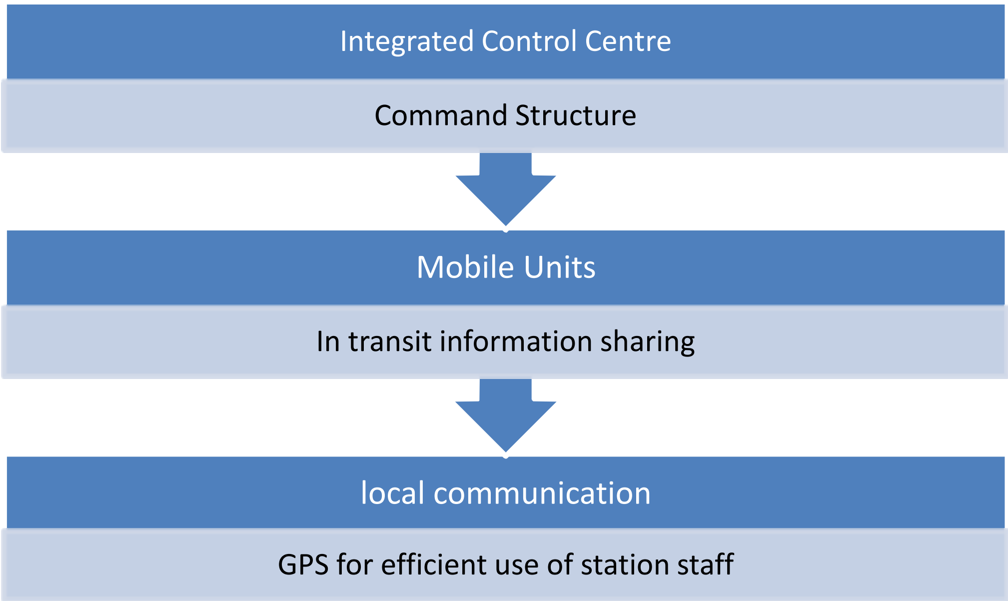

Figure 13. Possible improvements for Railway Communication

The taxi industry is very different by nature from the railway industry and this is reflected in their operations. However, this does not mean that nothing can be learnt from the organisation and communication structure of dynamic taxi operations. From the taxi and aviation operation, a key is that they have a far better real-time position identification system as the air traffic control centre and taxi dispatching centre both know exactly where each unit is, which enables more efficient dynamic operation. The current railway system does not have such accuracy, as train controllers only know which block a train is in. Although the railway system is moving towards this level of operation through in the future with the use of GPS, until detailed positioning showing the exact location of each train is available, improving efficient and robust dynamic operations will be difficult.

From looking at the communication system in the private hire vehicle operations in figure 5, shows how real-time staff and customer locations are fed into the booking passenger information centre and operation control centre allow for up to date efficient dynamic operations. However, this is not possible in railway operations as an estimation of passenger demand is only analysed during the timetable preparations stage. Therefore, real-time demand is not taken into account during real-time control. A key element in creating successful railway dynamic operations would be for real-time train control to understand passenger demand and implement this in optimising train operations. Real time passenger demand Information collected at ticket barriers couch be used. Passenger information can be gained from season tickets sales so that we can understand the demand for certain routes at particular times of the day. Oyster card data can also be used to gather passenger demand, travel history and frequency. Data of passenger load within each train can additionally be used so that transport services correspond with the level of passenger demand and growth of certain routes.

Airport communication as shown in figure 8 is also much more centralised than railway communications. Communication and information generated is directed to the central system. However, in comparison, figure 7 shows that the information hub within the railway system is predominantly gathered in railway stations. The railway is moving towards a more centralised control system and this will improve the dynamic response of railway systems. Centralising communication and operations will enable

Human error in the aviation is an interesting issue. The communication contents can be categorised into the following two categories:

i. *Safety-critical issues* – such as when a airplane can go into the runway or when it is safe to descend and land etc.
ii. *Additional information* - such as weather conditions at the origin or destination of flights, crew delays or even technical problems etc.

These are communicated via live to live information within the control room or between one air controller and one pilot. In the current railway, safety crucial issues are communicated via signal system, not radio communication. Even though a train driver does not listen to the radio communication, as long as he follows the signals, no collision will occur. However, as the railway moves towards dynamic operation moving away from the traditional railway signals, safety-critical issues may start to occur. It is therefore reasonable that human error may become more prominent in railway operations as staff and drivers may need to develop different operating and signalling techniques and knowledge for the new system. Safety precautions for this stage of operations will need to be developed to safeguard from these kind of human error decision making, and these can be developed in line with those used in aviation technology. For example, the use of different voice and radio control facilities.

Other communication improvements that may be able to be developed within the railway industry is the interplay between navigation, surveillance and communication. Within current railway operations, these factors are used within the operating system. However, they may not be used in conjunction at all control centres and stations. Improved navigation will develop train control; more efficient surveillance could be beneficial in staff and train positioning, better understanding of passenger demand and movements and prediction of possible delays; and better communication could integrate all levels of staff and decision making as well as making customers able to make more informed decisions.

From looking at how the aviation and railway industry recover from delay, there are aspects that the aviation industry use, that the railway sector may be able to develop. From looking at figure 11 commercial economics as well as market research is used to update flight schedules. In the railway industry, market research is not implemented when trains move away from schedule and there is also no commercial economist role involved within the decision-making delay recovery process. This is an interesting aspect that might be able to enhance the decision making process within the railway integrated control centre.

Information sharing available through the interoperable system as used in Hong Kong Airport may also be a useful aspect for railway industry members to look into. In the railway, it is often the case that the case that the signal controller may be the predominant person who knows about every aspect of the current operating system, divulging this information within a small team who will support him in the decision making process if trains run off schedule. However, in the aviation industry a large team of players are involved in the alteration of flight schedules. This may overcomplicate the procedures necessary to enable rapid recovery delay and there are also many adverse reasons as to why this may not be ever implemented in the railway industry. However, if this process is finely tuned, better information sharing within teams and departments may allow for more efficient operations operating at a larger capacity.

6. Conclusion

In conclusion, there are many aspects related to operations, communication and recovery from delay that can be learnt from the aviation and taxi industry. These improvements will optimise capacity and efficiency by centralising control, integrating communication, navigation and surveillance. Introducing more efficient use of current information in sequencing of services and passenger demand estimation and use of GPS in trains and also stations may also even help delay recovery or even prevent delays from occurring in the first time. A more interoperation system with effective information sharing methods may also help crew and passengers alike. However, most importantly the opportunity to learn from other industries, not only aviation and the taxi industry is vital. Railway systems and operations are making vast improvements technologically and physically and it is important that techniques and knowledge already in practically in other industries and countries are fully investigated in order to operate at their full potential. This is said especially with the development of the SESAR aviation programme and the move for railways towards a more centralised and dynamic system. Indeed, aviation, railway and taxi industries may be missing a trick by not exploring other industrial practices and knowledge.

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