New ticketing technologies and solutions

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2 NEW TICKETING TECHNOLOGIES & SOLUTIONS

2.1 EXECUTIVE SUMMARY

This report documents the application of a six-step Horizon Scanning process to the rail industry to identify technologies and solutions for ticketless travel – see figure 1.

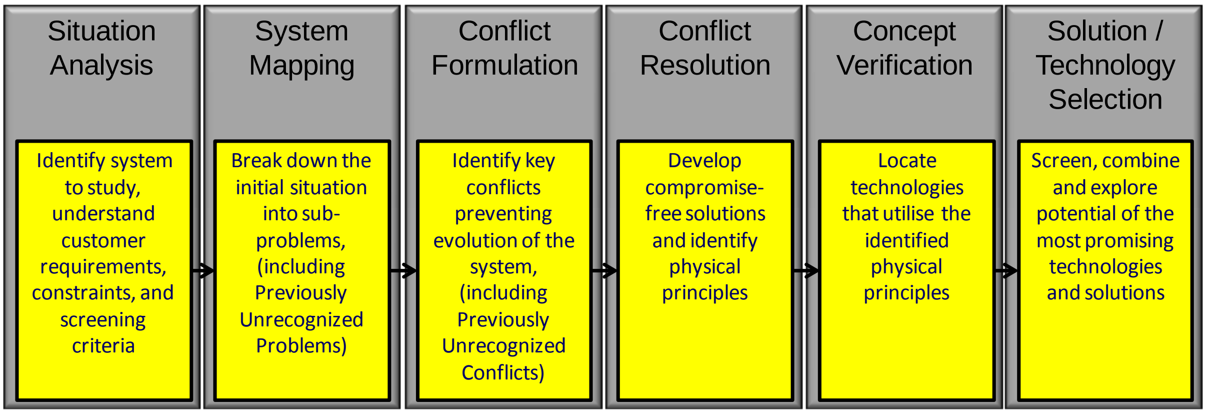


Figure 1: Six-step Horizon Scanning process

The report details the process that was followed as the project progressed and presents the outputs of the analysis conducted.

The study produced a number of findings:

- The rail ticket is in effect an information system, providing data to the rail company and to the passenger. A measure of the effectiveness of any information system is the rate of data exchange.
- Many of the solutions listed in this report support far higher levels of data transfer than is currently possible. This increased richness of data will mean that the rail company can build a much better understanding of passenger behaviour and system utilisation while providing the passenger with greatly enhanced information and services.
- The core “revenue protection” function of the ticketing system can be enhanced through the analysis of the increased amount of data available
- Security and privacy will become far greater concerns. Technologies such as encryption and digital signature will be crucial to the smooth operation of the rail industry.

Due to the broad scope of the technology areas discussed in this report, and the need for multiple solutions, it is impractical (and would be misleading) to present a shortlist of the most promising solutions. A key aim of this document is to stimulate further discussion in the rail industry on future travel payment, authorisation and information sharing methods. Depending on input from the rail industry, many of the technology areas reviewed might warrant further research.

2.2 BACKGROUND

Since the birth of the railway there has been a need to check that the people using the service have paid. The railway ticket provided a means to check payment before, during and after the train journey. Until recently the format of the rail ticket has remained relatively unchanged despite rapid technological change in other sectors. Rail companies are looking for ways to reduce cost – ticketing currently costs the rail industry £500m per year while many rail users would prefer more convenient travel solutions. There is also a desire on the part of the UK Government to encourage a more integrated transport system offering seamless travel between different modes of travel. As a result of these drivers a number of new technology options such as e-tickets, smart tickets and mobile payment are starting to be used in the rail industry. This report sets out to study a range of technologies and solutions which might enable the UK rail industry to provide low-cost proof of payment, replacing and enhancing the functionality of the existing rail ticket. In addition, consideration is given to how these new technologies could help deliver improved operational efficiency and an enhanced service to rail users.

2.3 STEP 1: SITUATION ANALYSIS

2.3.1 PROJECT SCOPE

Figure 2 shows the areas of the rail system which were included within the scope of the study.

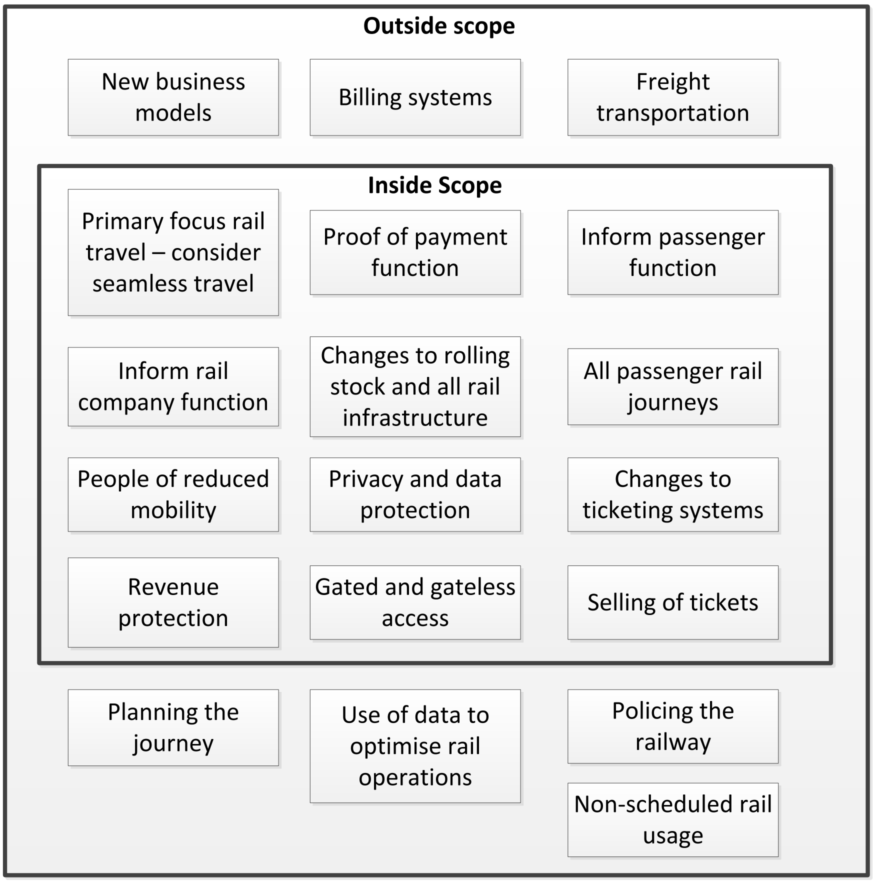


Figure 2: Project Scope diagram

We will focus our efforts on researching items inside scope. We will consider the impact of the technologies and solutions found on all areas, including those defined as outside of scope.

2.3.2 PROBLEM MAPPING

The problem situation was analysed to create a problem map (shown in figure 3). The problem map provided a high level summary of the different aspects of the initial situation and enabled the context of the problem to be reviewed. Sometimes during problem mapping a new problem is identified for study. In this case, the original problem statement was selected for further analysis.

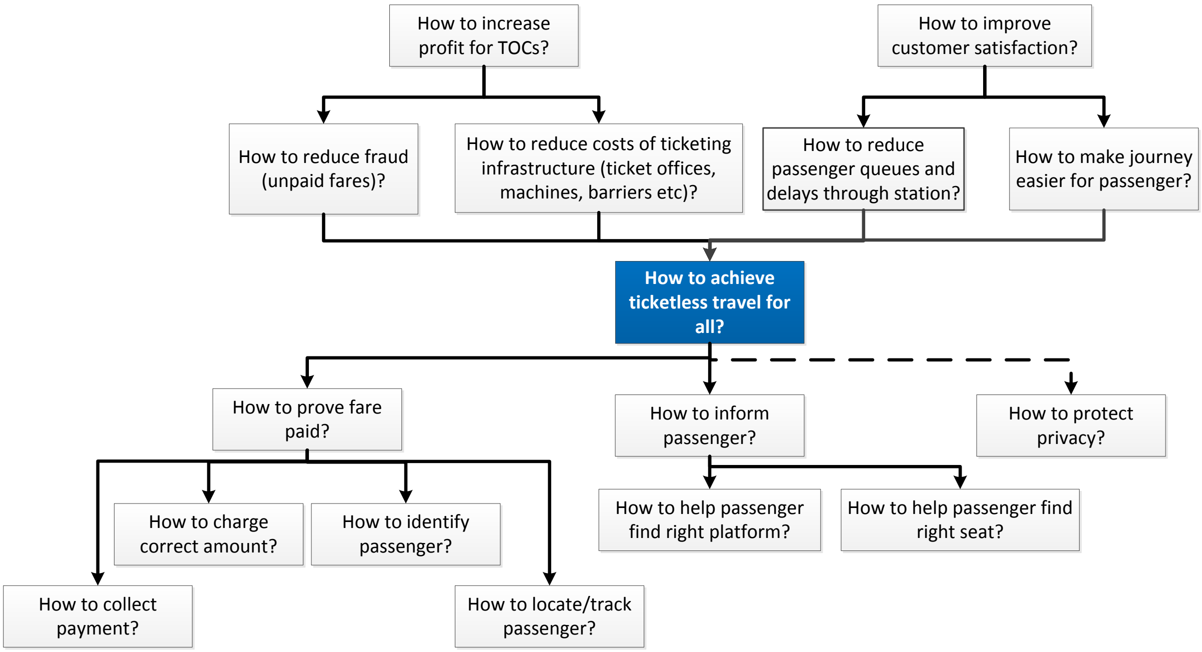


Figure 3: Problem Map – ticketless travel for all

2.3.3 FUNCTION TREE FOR TICKET

The following function tree was prepared to identify the functions performed by or related to the ticket (highlighted in blue boxes) – see figure 4. The function tree shows that the presence of a ticket is currently crucial to a number of higher level information-related functions. In order to achieve ticketless travel, it will be important to consider how these functions might be delivered or by-passed in future. Later sections of this study will explore technologies and solutions to deliver this outcome.

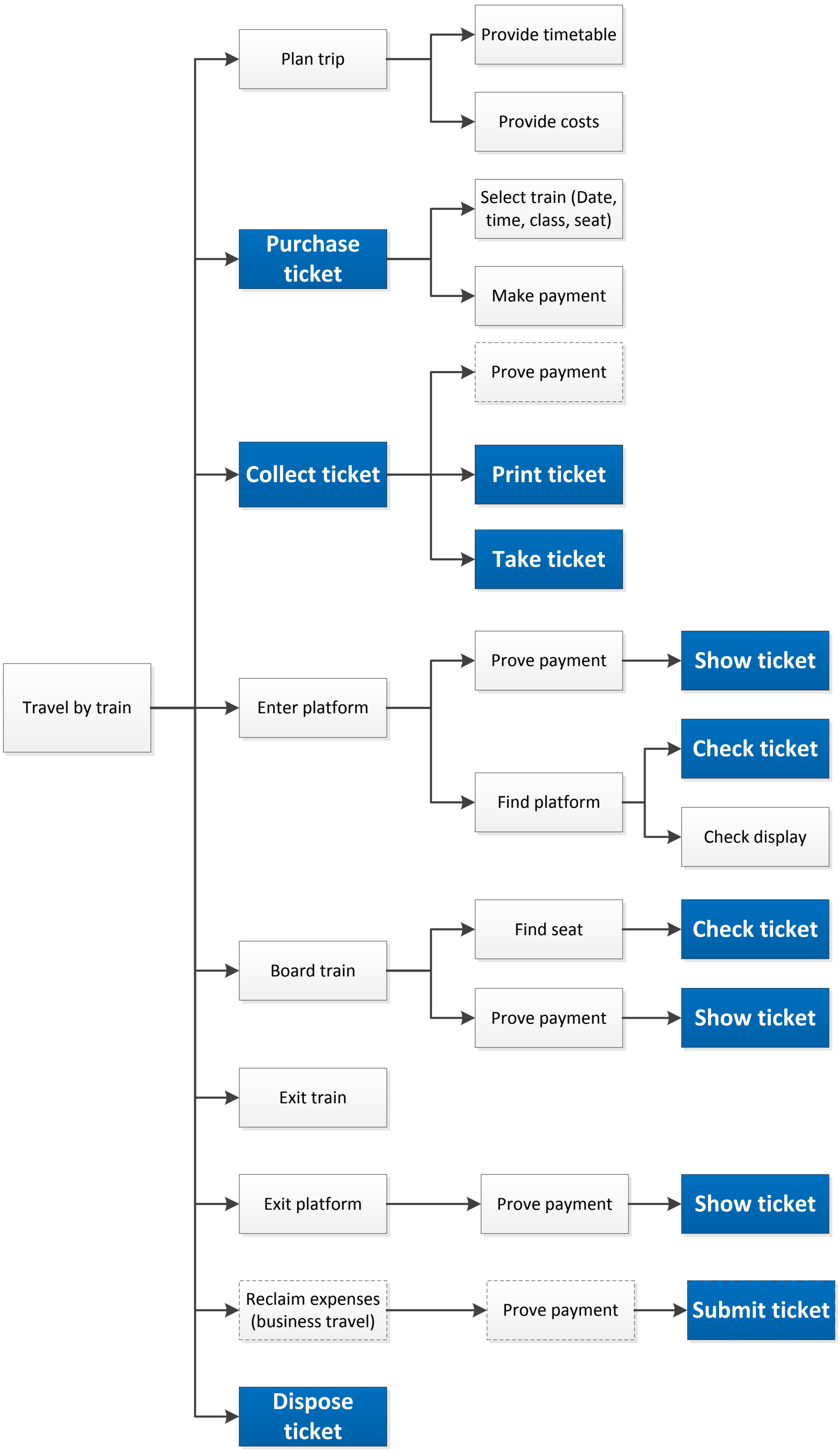


Figure 4: Function tree – travel with ticket

2.3.4 PROVISION OF MAIN PARAMETERS OF VALUE (MPVS)

The following main parameters of value were identified for the ticketing function:

Passengers per minute checked. The speed at which payment for use of travel can be verified, measured in units of passengers per minute.

Revenue protection. The ratio between total revenue due and lost revenue to fraud and fare evasion.

$$\text{Revenue protection} = \frac{1}{\%fraud}$$

Information (data) transfer rate. The amount of information which can be transferred between the passenger and the transport provider (both ways).

$$\text{Information transfer rate to passenger (download)} = Bits/second$$

$$\text{Information transfer rate to transport provider (upload)} = Bits/second$$

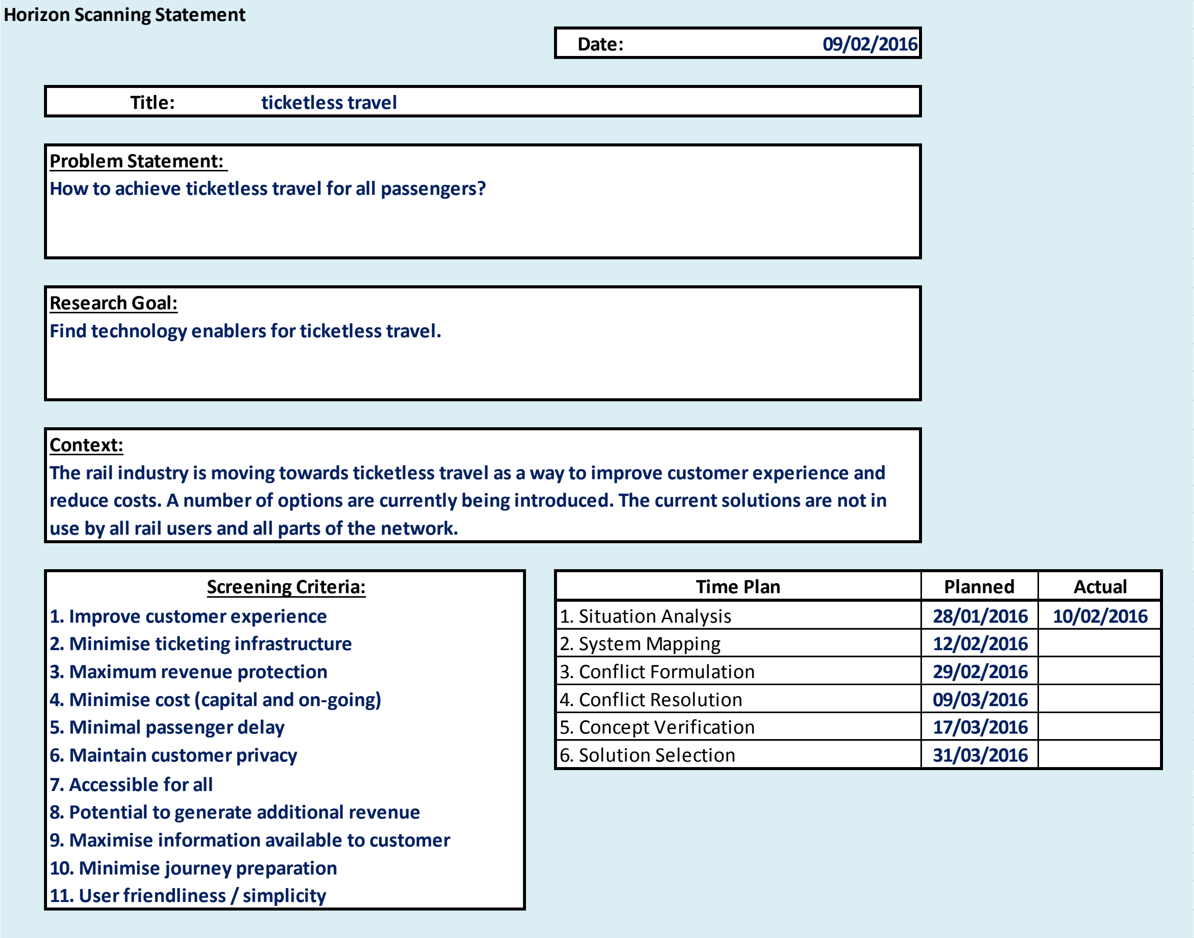
Encryption algorithm security level. One method for measuring the security level of data encryption is to calculate the entropy level measured in bits:

$$\text{Entropy (bits)} = Log_2\,(Number\ of\ combinations)$$

For example, a 4-digit PIN code has 9,999 combinations so its entropy level is $\text{Log}_2(9999) = 13.3$ bits.

2.3.5 HORIZON SCANNING STATEMENT

The following horizon scanning statement was produced as a result of this analysis:



Horizon Scanning Statement

Date: 09/02/2016

Title: ticketless travel

Problem Statement:
How to achieve ticketless travel for all passengers?

Research Goal:
Find technology enablers for ticketless travel.

Context:
The rail industry is moving towards ticketless travel as a way to improve customer experience and reduce costs. A number of options are currently being introduced. The current solutions are not in use by all rail users and all parts of the network.

Screening Criteria:

1. Improve customer experience
2. Minimise ticketing infrastructure
3. Maximum revenue protection
4. Minimise cost (capital and on-going)
5. Minimal passenger delay
6. Maintain customer privacy
7. Accessible for all
8. Potential to generate additional revenue
9. Maximise information available to customer
10. Minimise journey preparation
11. User friendliness / simplicity

Time Plan	Planned	Actual
1. Situation Analysis	28/01/2016	10/02/2016
2. System Mapping	12/02/2016	
3. Conflict Formulation	29/02/2016	
4. Conflict Resolution	09/03/2016	
5. Concept Verification	17/03/2016	
6. Solution Selection	31/03/2016	

2.4 STEP 2: SYSTEM MAPPING

2.4.1 PROCESS MAP

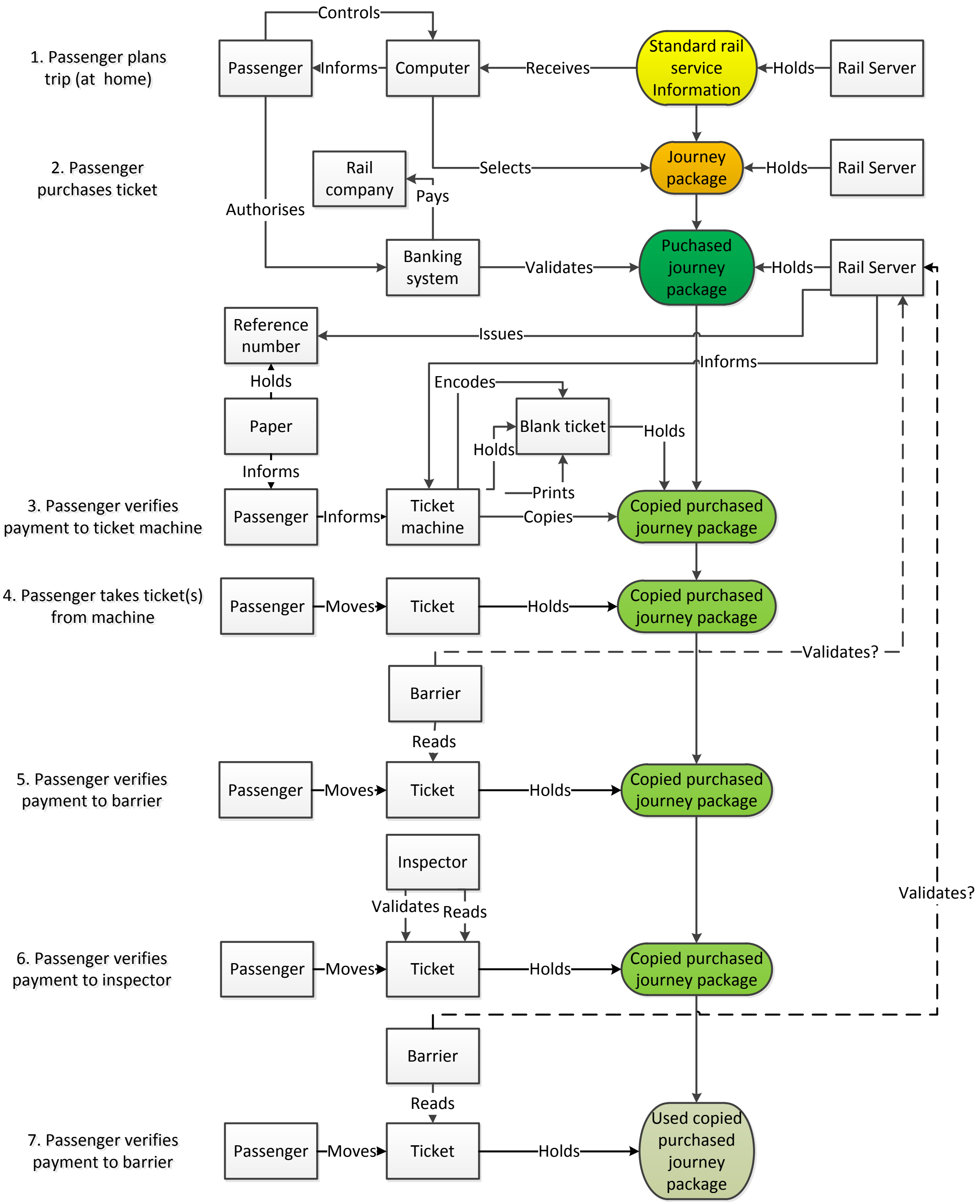


Figure 5: Process map – rail journey with ticket

A process map (figure 5) was prepared to show a typical “with ticket” rail journey. The diagram shows the interactions between the ticket, passenger and the rail company. The diagram highlights the following points:

- The high number of times that the passenger is required to prove payment through the journey.
- The reason there are so many payment checks in the process is that the initial purchase of the journey package cannot be relied on – i.e. the passenger may not have purchased the journey package before travelling.
- The limited amount of information (if any) about the journey progress which is fed back to the rail company.
- The low security level of checking (quick visual inspection or non-encrypted magnetic strip reading) for proof of payment.
- The ticket is simply a copy of the “journey package” that has already been purchased
- At the end of the journey the ticket does not indicate that the journey package has been spent.

2.4.2 HISTORY OF RAIL TICKETS

Starting from the first fare-paying passenger railway service in 1807, there has been a need for the railway company to verify that the passenger has paid (or will pay) for their journey. This “proof of payment” function was provided by the introduction of the railway ticket as a means to check payment before, during and after the train journey. The railway ticket can be considered to be a form of currency – the passenger has exchanged money for the currency of the railway with the ticket acting as the promissory note.

The first rail tickets were handwritten for each journey which proved to be time consuming and inconvenient. A handwritten format was also vulnerable to fraud by the railway staff or passengers. For example, a dishonest railway employee might simply pocket part of the fare paid as there was no way to check the number of tickets issued.

A significant improvement came with the introduction in 1840 of the Edmondson ticket. These tickets were pre-printed and then date stamped when they were issued, considerably speeding up the process of issuing tickets. They also had serial numbers enabling security checks to be made for fraud by railway staff or passengers. During the journey tickets were punched or stamped to indicate that they had been used (spent).

The pre-printed ticket remained the dominant solution for over 100 years. It was not until the 1980’s that the next major change in ticketing technology occurred. The adoption of tickets printed at the point of sale characterised by the APTIS (All-purpose ticket issuing system), introduced by British Rail from 1982, allowed more specific information relating to the journey to be printed on the ticket. This change came about as a result of the development of new computer-based printing methods. The new ticket format also incorporated a magnetic strip enabling information to be recorded on the ticket and checked automatically with magnetic readers. The magnetic storage was very limited (24 bytes) and the data was not encrypted in any way. In addition, early portable ticket dispensing machines carried by the inspectors did not have the capability to write or read to the magnetic strip.

The next big change in ticketing came with the introduction of smartcard tickets which could be read automatically by means of a magnetic strip or radio frequency identification (RFID). The Oyster card which was first introduced in 2003 by TfL, is a well-established and successful example of this contactless technology. Information can be downloaded to and uploaded from the smartcard by radio frequency transmission.

More recently systems have been introduced which transfer the functions of the ticket to other devices commonly held by rail users such as contactless payment cards and mobile phones functioning as smartcard tickets. Contactless payment cards use a type of radio frequency identification called Near Field Communication (NFC) for making secure payments. TfL have adapted the Oyster card readers to be able to read NFC cards. Some mobile phones are also equipped with NFC so that they can serve as a contactless payment system. Currently the read time for this format is relatively slow compared with Oyster cards. In addition to their NFC capabilities, mobile phones can be used as e-tickets (electronic tickets) by using the screen to display a QR code (2D bar code) which can be scanned by QR code readers.

Another related technology that has been field trialled but not yet introduced is a system referred to as “be-in-be-out” (BIBO). In a smartcard ticketing system such as Oyster, passengers “check in” and “check out” at the start and end of the journey without tracking the journey as it progresses. In a BIBO system there are no barriers to delay or hinder the movement of passengers and the presence of the passenger on the train is tracked by identification sensors on the train. This provides an accurate track of the journey being made, providing useful information to the train company and also ensuring that the correct fare is paid. It does however still require some form of random “ticket” inspection as it does not prevent passengers travelling without a ticket.

For over a 100 years there was limited change in railway ticketing but in the last few years a wide range of different technologies have been introduced, some of which no longer use a physical paper ticket. Currently there are many competing technologies in use providing flexibility and choice for the passenger, but also the potential for confusion and complexity!

2.4.3 PATENT ANALYSIS

The patent database was searched for all patents containing the key words of “railway” and “ticket” in either the title or abstract. The number of patents filed per decade is shown in Figure 6.

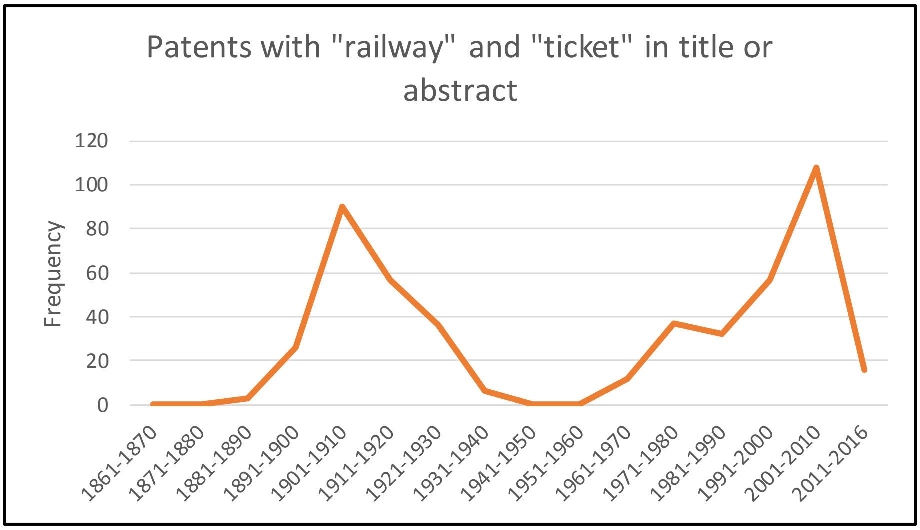


Figure 6: Railway ticket patent frequency from 1861 to current day

A number of observations can be made from this data:

- First period of activity 1890 to 1930:
  Improvements in machines (apparatus) to print, date and hold paper tickets. This is related to the first "S-curve" of pre-printed Edmondson tickets (replaced handwritten tickets from 1840).
- During the period from 1940 to 1970 there was very little patent activity.
- Second period of activity 1970's to 2000:
  Automation of systems (devices, machines, apparatus, methods) to check (examine) and issue (vend) tickets. This is related to the second "S-curve" of the computer machine printed at point of sale tickets such as APTIS.
- Third period from 1990s to current day:
  Diversification of ticket media and associated handling systems (paper, thermal, card, magnetic, electronic, non-contact). This could perhaps relate to a third "S-curve" of the smart ticket.

To gain a further insight to the changing technologies of railway tickets the most frequently occurring patent classification codes (CPC) relating to the railway ticket patents were identified (see table 1).

CPC Code	Description	Number of patents with "railway" in title or abstract
B42	**Printing:**	
B42D	…..printed matter characterised by identification or security features; printed matter of special format or style not otherwise provided for; devices for use therewith and not otherwise provided for; movable-strip writing or reading apparatus	62
G07	**Checking Devices:**	
G07B	Ticket-issuing apparatus; fare-registering apparatus; franking apparatus	50
G07C9	Individual entry or exit registers	22

Table 1: CPC patent codes relating to railway tickets

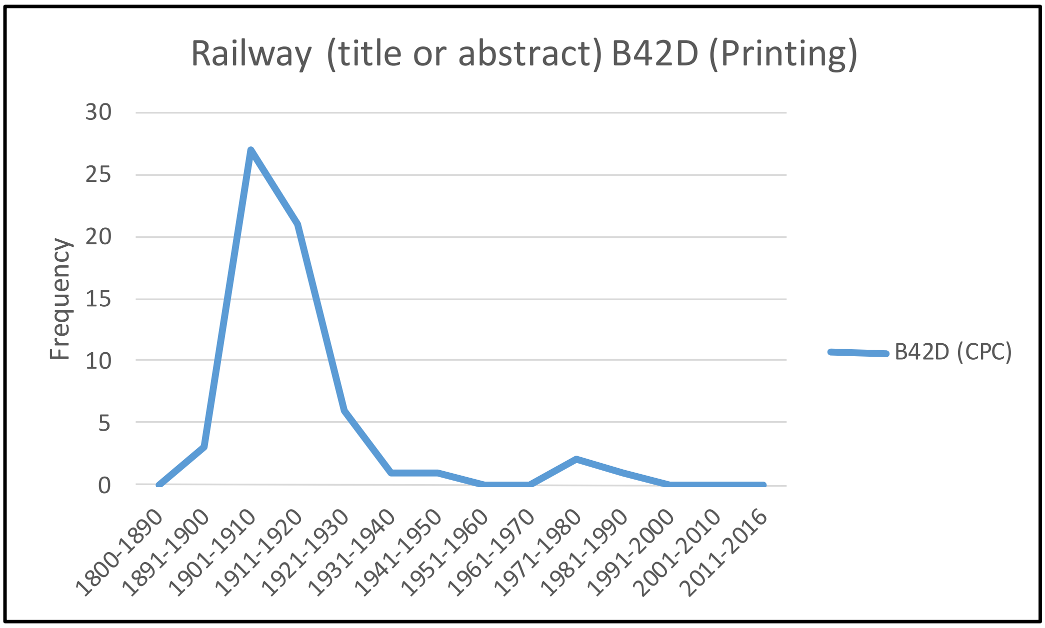


Figure 7: Railway patent frequency for CPC B42D printing

Patent code B42D relates to the printing of tickets and as might be expected shows a high patent activity in the early 1900's and no recent activity. These patents relate to improvements in the design and printing of the ticket itself (the 1st S-curve of pre-printed Edmondson tickets).

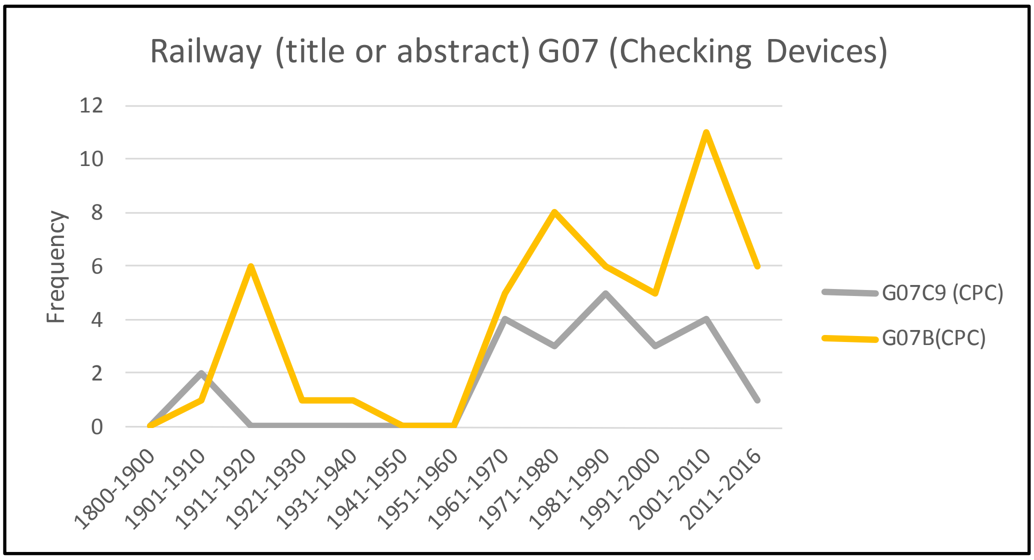


Figure 8: Railway patent frequency for CPC G07 checking devices

Patent code G07B and G07C9 relate to ticket issuing apparatus and individual entry/exit checking. These codes show three peaks of activity:

- 1910 to 1930 – Improvements in printing and handling tickets and cash
- 1960 to 2000 - Automatic systems (methods, apparatus) for identifying (checking) tickets

New ticketing technologies & solutions

- 2000 to current day - Systems for detecting and checking passengers, electronic tickets

2.4.4 MAIN PARAMETERS OF VALUE

Table 2 shows how the main parameters of value (MPVs) have progressed with the introduction of new ticketing technologies from the first hand written tickets through to the current smartcard and contactless payment methods.

Date	**Ticketing technology**	**MPV1: Passengers checked per minute**	**MPV2: Revenue protection**	**MPV3: Information (data) transfer rate**	**MPV4: Security**
1807	Hand written ticket	2 to 10 ppm (estimate)	Ticket inspector	Download – Human writing (20 bit/s) Upload – Human reading (100 bit/s)	Authorisation stamp (1 bit entropy)
1840	Edmondson pre-printed ticket	2 to 10 ppm (estimate)	Ticket inspector	Download – Printed ~10kbit/s Upload – Human reading (100 bit/s)	Serial number
1982	Print at point of sale & magnetic strip e.g. APTIS		Ticket inspector + some check in/check out barrier control	Download – Printed ~10kbit/s, magnetic write 24 bytes Upload – Human reading, magnetic read	Printed serial number & Information on magnetic strip not encrypted (No personal data on ticket)
2003	Contactless payment card e.g. Oyster (RFID - ISO/IEC 14443)	Target 350mS with maximum of 500mS (TfL) 12 ppm actual v 24 ppm RSSB standard (see S158)	Check in/check out barrier control	Storage 1-8kB Download & upload RF transfer	Advanced Encryption Standard (AES) (128 bit entropy)
2011	Mobile e-ticket (Chiltern Railways)		Check in/check out barrier control & ticket inspection(?)	~2kB information	QR code (2D bar code) – can be encrypted?
2014	NFC cards (credit, debit or specialist)		Check in/check out	Download & upload 424 kbits/s	Chip + Pin (not used during contactless

			barrier control		payment 13 bit entropy), maximum transaction limit
2015	NFC phones	950ms (currently too slow by TfL target)	Check in/check out barrier control	Download & upload 424 kbits/s (& 4G 100 Mbits/s where available)	Fingerprint (iPhone), PIN code (13 bit entropy)
(Field trial 2005)	Be in/be out		Be in/be out & random ticket inspection		

Table 2: Main parameters of value for railway ticket technologies **[1, 2]**

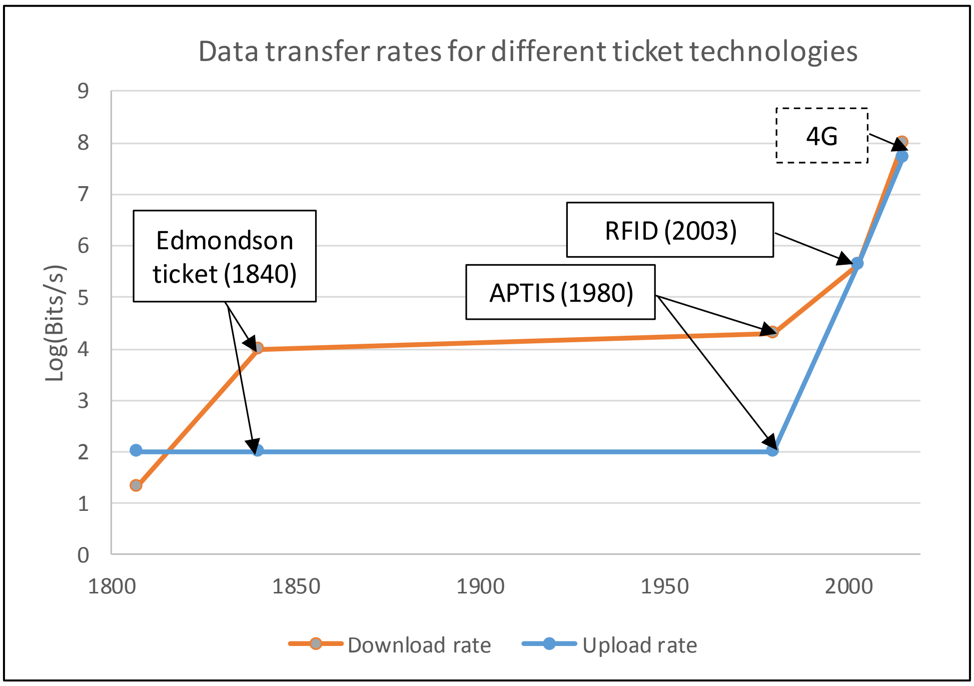


Figure 9: Data transfer rates for ticketing technologies

Figure 9 shows the trend of increasing data transfer rates for different ticketing technologies over time. As can be seen, the introduction of RFID technologies was a major step change and the use of mobile phones opens up the possibility of accessing the very high data rates of 4G.

2.4.5 CAUSE EFFECT ANALYSIS

A key rail company concern for "ticketless" travel is to ensure revenue is protected and fraud is prevented. Figure 10 shows a cause-effect map which seeks to find the root causes of lost revenue.

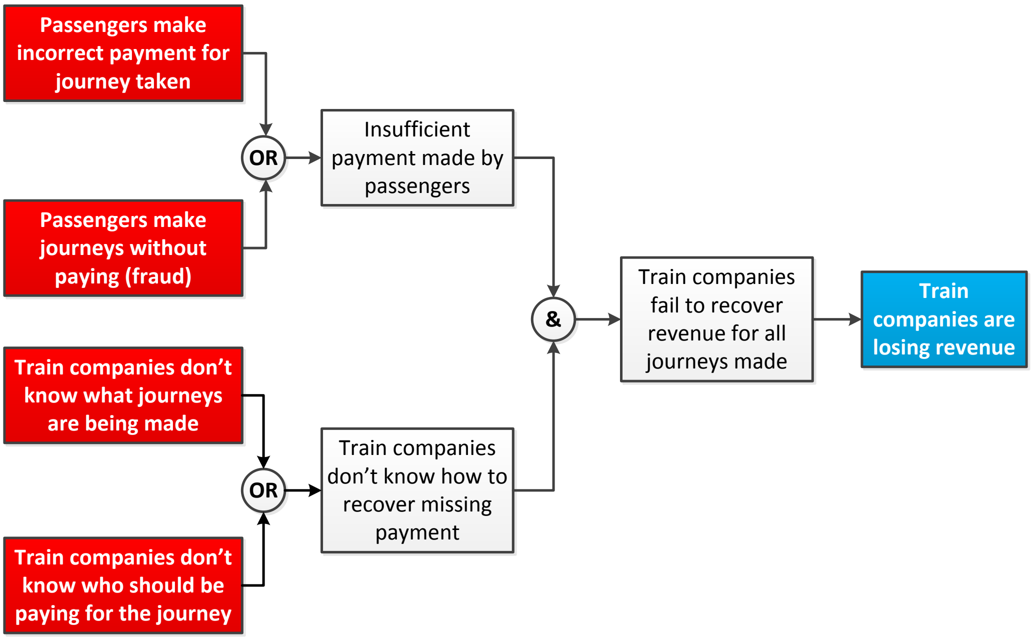


Figure 10: Cause effect analysis for loss of revenue

The cause-effect analysis highlighted the following key insights:

- There are two ways in which a train company can address the issue of lost revenue; they can ensure passengers pay the correct amount before taking their journeys or they can implement an effective means to recover any missing payment for journeys made. Addressing either of these areas will solve the problem of lost revenue.
- There are two causes for passengers not paying the correct amount; passengers making an incorrect payment for the journey taken and passengers making journeys without paying. Both of these causes must be addressed to ensure the correct amount is paid.
- Alternatively for the train company to recover missing payment they must both know the journeys being made and know who should be paying for the journey.

A secondary concern, from the passenger perspective, of "ticketless" travel is the lack of a means to provide journey information. Figure 11 shows a cause-effect map of the starting problem "passenger lacks information".

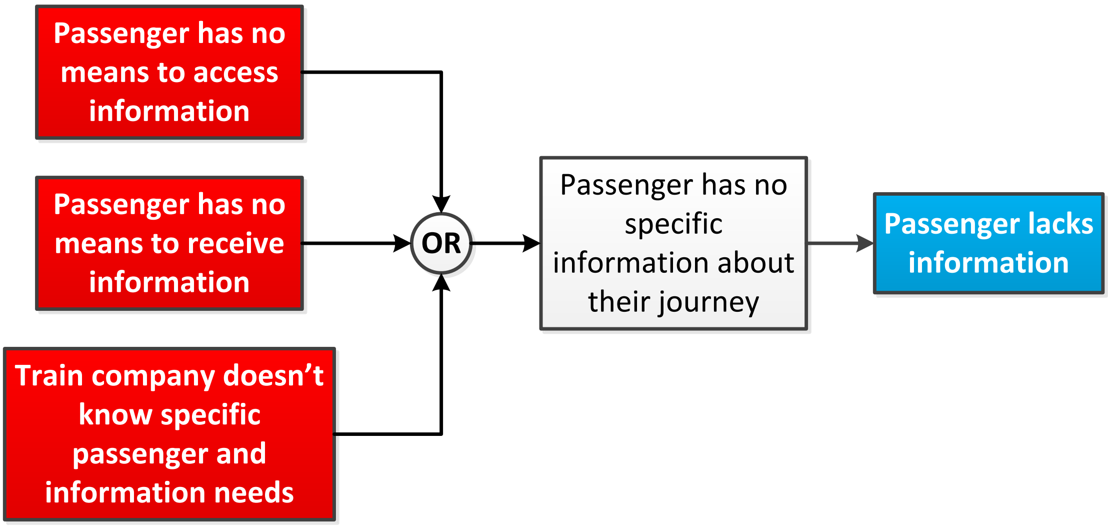


Figure 11: Cause effect analysis for passenger lacking information

The cause-effect analysis highlighted the following key insights:

- Three things are required to ensure that the passenger has the required information; train service provider knowledge of specific passenger and information needs, a means for the passenger to receive appropriate information and a means for the passenger to access that information.
- There is a common theme between both cause-effect analyses expressed as a need for increased passenger-specific train company knowledge.

2.4.6 NINE SCREEN MAPPING AND IDEAL OUTCOME

All technological systems exist within a hierarchy; that is, any system is part of a higher level system or super-system and is composed of lower level systems or sub-systems. Typically, needs of the super-system drive changes in the system while developments in the sub-system enable changes in the system. Nine screen mapping provides a way to visualise the system being studied in the context of both the super system which it serves and its supporting sub-systems. Figure 12 shows the nine-screen map developed for the past and present proof of payment system.

	Past	**Present**	**Future**
Super System	Revenue collection system	Revenue collection system	?
System	Proof of payment system	Proof of payment system	?
Sub-System	Paper ticket, inspectors	Ticket*, gates, inspectors, rail company server	?

* includes paper ticket, smart card ticket, NFC payment card, NFC phone, mobile e-ticket

Figure 12: Nine-screen map for proof of payment

The nine-screen map shows that very little change has occurred in the fundamental system and super system functions, even though a range of technologies have been applied, especially in the recent past. When we look to options for the future, the TRIZ trends of evolution indicate an increasing level of value for this system – reference the main parameters of value in table 2. Value in TRIZ is defined by the following equation:

$$Value = \frac{\sum Useful\ functions}{\sum Harmful\ functions + Costs}$$

Value can be improved by increasing the numerator (useful functions) and/or decreasing the denominator (harmful functions and costs). In TRIZ the concept of the "ideal system" considers how the value of a system might approach infinity. There are two routes to achieve this; reduce harmful functions and costs to zero while maintaining the useful function or increase the level of useful function to infinity. When this thinking is applied to the proof of payment system, two different future scenarios (or ideal outcomes) emerge – see figure 13.

	Future A	**Future B**
Super System	Revenue for travel collected	Optimised rail operations for maximised revenue
System	Proof of payment delivered	Infinite data channel between passengers and rail company
Sub-System	No system	X-Component = Enabling platform for infinite data transfer

Figure 13: Alternative ideal outcomes for proof of payment system

In future A the denominator of the value equation is minimised. This is a true “ticketless” travel situation in which payment is proven, enabling revenue to be collected but without the need for any of the current sub-systems such as tickets, gates and inspectors.

In future B the numerator of the equation moves towards infinity, in other words the number of useful functions increases exponentially. Proof of payment has been and is delivered by various forms of information system. A main parameter of value for any information system is the rate of data transfer – i.e. information upload and download rates. Figure 9 shows that certain enabling technologies are experiencing radical growth in this MPV.

Both future options will be used in conjunction with the other insights gained from the analysis in this section to help formulate conflicts in the next stage of this project – step 3: Conflict Formulation.

2.5 STEP 3: CONFLICT FORMULATION

2.5.1 PROCESS OVERVIEW

Each root problem from the cause-effect maps, detailed in section 2.4.5, was analysed using a conflict identification process. The analysis starts by stating both the root problem and corresponding Ideal outcomes (derived from the Future A and Future B outcomes stated in section 2.4.6). Figure 14 shows a summarised listing of root problems and ideal outcomes for the two problems of “train companies are losing revenue” and “passenger lacks information”. Some related root problems have been combined.

Root problems	Ideal outcome
Passengers make incorrect payment for journey selection	Passengers make correct payment for journey selection with no ticketing system
Passengers make journeys without paying (fraud)	Passengers pay for the journeys they make with no ticketing system
Train companies don’t know what journeys are being made	Train companies know what journeys are being made
Passenger has no means to receive and hold information	Passenger has means to receive and hold information with no ticketing system
Train company doesn’t know specific passenger and information needs	Train company knows specific passenger and information needs

Figure 14: Root Problems and corresponding Ideal Outcomes for “train companies are losing revenue” and “passenger lacks information”

In the following sections specific barriers to the resolution of each root problem will be briefly reviewed.

2.5.2 BARRIERS TO RESOLVING “PASSENGERS MAKE INCORRECT PAYMENT FOR JOURNEY SELECTION”

There are a number of factors which currently prevent this problem from being resolved. The prices charged for tickets change depending on the train company involved, the time of travel, the route taken, time of booking and various discounting methods such as rail cards and season tickets. This complex pricing structure is often not transparent to passengers, causing them to use the wrong train, the wrong routes and to travel at the wrong times. A further issue is that passengers in a hurry may not have the time to get a ticket – in other words, the process to purchase a ticket takes too long.

2.5.3 BARRIERS TO RESOLVING "PASSENGERS MAKE JOURNEYS WITHOUT PAYING (FRAUD)"

There will always be people actively looking for ways to fraud the railway. The incentive to fraud is increased when the chances of being caught are low and the consequences for non-payment are not perceived to be severe. Reducing the use of barriers and ticketing systems can only make the situation worse.

2.5.4 BARRIERS TO RESOLVING "TRAIN COMPANIES DON'T KNOW WHAT JOURNEYS ARE BEING MADE"

As rail tickets don't normally relate to the specific train used or the time the journey is taken, there is currently no way to tell how many people are on each train. In order for the train companies to find out more about the train journeys being made, it will be necessary to increase the number of checks made throughout each journey. One way to do this would be to increase the number of barriers although this would be expensive and would cause delays at peak times. Alternatively additional ticket inspections could be implemented but this would be time consuming and costly. Even if these checks were made there would need to be systems in place to collect and analyse the information – currently, it appears that the rail industry does not gather such data.

2.5.5 BARRIERS TO RESOLVING "PASSENGER HAS NO MEANS TO RECEIVE AND HOLD INFORMATION"

Not everyone has a smartphone or personal device to enable them to hold and receive information. In addition, mobile device reception is not always good for passengers traveling on the UK rail system. Another way to provide passenger information would be to increase the number of displays available but this would be costly.

2.5.6 BARRIERS TO RESOLVING "TRAIN COMPANY DOESN'T KNOW SPECIFIC PASSENGER AND INFORMATION NEEDS"

At present the information the rail companies receive about passenger rail use tends to be fragmented and spread across multiple companies. Due to this issue, train companies have little or no information about customer preferences. In addition, many rail passengers have privacy concerns which might limit the amount of information the rail companies can hold.

There may even be a disincentive for rail companies to gather passenger usage information as it may jeopardise pre-defined rail company revenue arrangements.

2.6 STEP 4: CONFLICT RESOLUTION

2.6.1 PROCESS OVERVIEW

TRIZ tools were applied to identify strong solutions to each of the problems outlined in section 2.5. Functional search statements were prepared to enable research to find suitable technologies and solutions which are already in use in other industry sectors. The outputs of this section should be viewed as “partial solutions” to the relatively complex problem area of ticketing. In practice, two or more conceptual solutions or technologies may need to be combined to provide a comprehensive answer to the issue. Possible options to combine solutions will be explored further in step 6 – Solution Selection. A more detailed review of the steps conducted in this analysis are outside of the scope of this report.

2.6.2 KEY FINDINGS FROM THE TRIZ ANALYSIS

When the underlying conflicts and limitations in the ticketing system were analysed using TRIZ, the following overall solution directions were identified:

- Separate payment from travel authorisation – i.e. perform each task at most convenient time
- Investigate methods for secure payment authorisation
- Find ways to check passenger’s identity to establish if they are authorised to travel
- Focus on finding and stopping unauthorised rail users rather than screening all users
- Use an intermediary to protect passenger privacy – i.e. instead of identifying the passenger, identify their device.

2.7 STEP 5: CONCEPT VERIFICATION

2.7.1 PROCESS OVERVIEW

Research was conducted to find technologies and concepts which make use of the required physics and functions defined in the previous step. Contacts were identified in leading areas where the underlying technologies found are already routinely used and well understood. An analysis was conducted into the resources which are already present in the challenge situation to find out if any of these could be used to deliver the required functions and physics. A list of potential technologies and solutions was generated and documented.

2.7.2 CONCEPT VERIFICATION OUTPUTS

Figure 15 shows a typical ticket barrier system and lists the five key focus areas relating to the ideal outcome statements in section 2.5, the future B statement from section 2.4.6 and the solution directions listed in section 2.6.2. These areas are further grouped under the two headings of “ensure revenue protected” and “optimise rail operations”.

Figure 15: Key focus areas for technology and conceptual solution research

The functions described in the headings were used to structure the research work to find potential technologies and solutions shown in figure 16. In order to deliver each of the functions, certain sub-functions are required (shown in the nine blue-fill boxes). Under each of these are technology categories which could be relevant for future rail industry application. The focus of this horizon scanning study has been on emerging technologies rather than those currently in use by the rail industry.

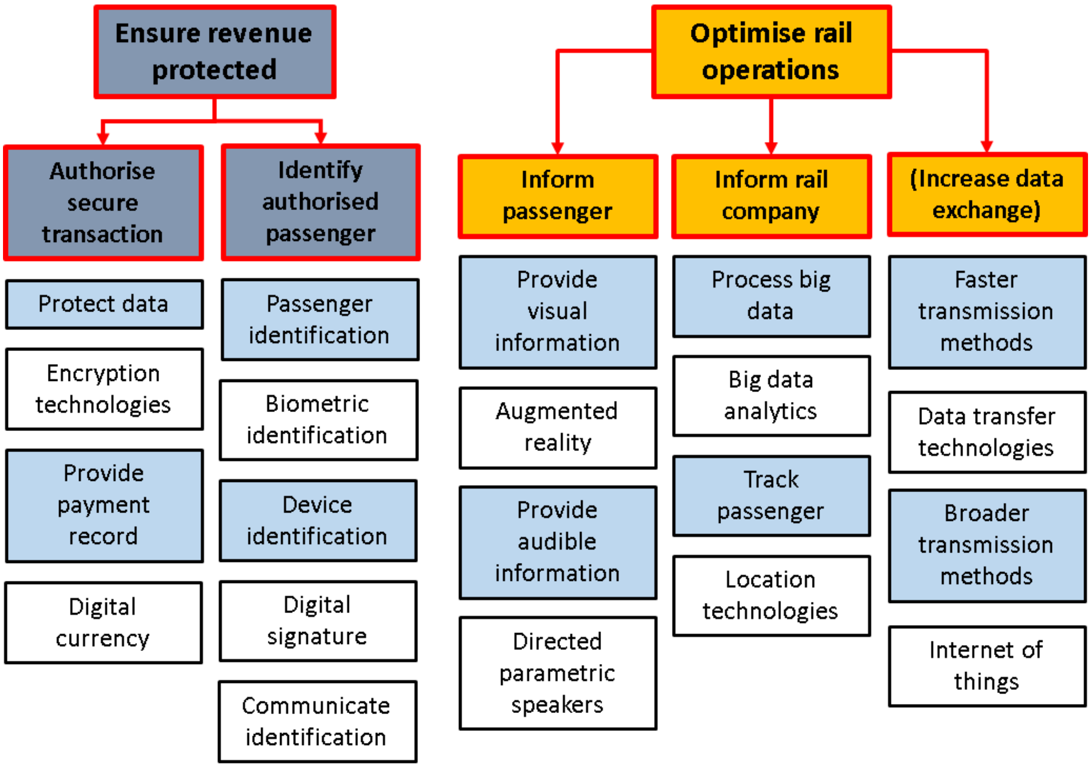


Figure 16: Summary listing of technology areas

In the following sections of this report each of the technology areas will be explored, detailing the operating principle of the underlying technologies or solutions, discussing how they might be applied in the rail industry and providing evidence of the readiness of the solutions for rail industry use.

In several of the above technology areas (e.g. "Identify Authorised Passenger" and "Track Passenger") it is necessary to sense the presence of the passenger. Human sensing (direct and indirect via a device) can be delivered at a range of different levels. Figure 17 shows the five spatial-temporal levels of human sensing **[3]**.

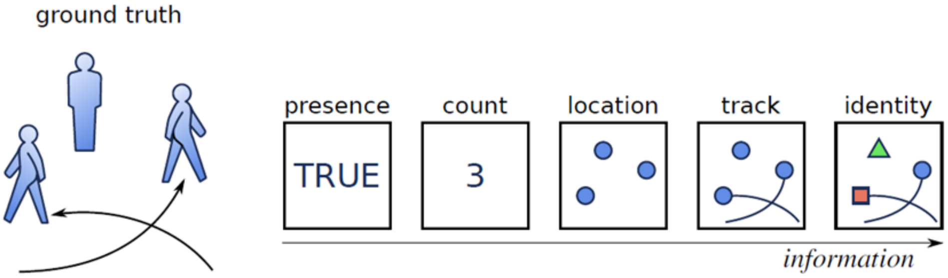


Figure 17: Five spatial-temporal levels of human sensing

The five levels shown in figure 17 can be listed as follows:

- Presence – Is there at least one person present?

- Count – How many people are present?
- Location – Where is each person?
- Track – Where was this person before?
- Identity – Who is each person? Is this person John?

Human sensing methods which only detect presence, count or position do not provide the required level of passenger identification needed to ensure rail industry revenue is protected, however, they may be sufficient to provide useful information to the rail company.

2.7.3 PROTECT DATA – ENCRYPTION TECHNOLOGIES

Operating Principle

In order to ensure that revenue is protected and passenger and rail company data remains secure, it is important to consider technologies which prevent unauthorised access to information. A main parameter of value for data security was identified in section 2.3.4, the entropy level. This can be calculated using the following formula:

$$\text{Entropy (bits)} = Log_2\,(Number\ of\ combinations)$$

For example, a 4-digit PIN code has 9,999 combinations so its entropy level is $\text{Log}_2(9999)$ = 13.3 bits. Moving to a 6-digit PIN would increase this entropy level to $\text{Log}_2(999999)$ = 19.9 bits.

Currently, many communication systems have entropy levels of 128 bits and there are some moves towards 256 bits. As the number of bits is increased, the security algorithms that are being used to encrypt and decrypt the messages become more computationally intensive, requiring more time and/or more powerful computers.

128 bits is equivalent to 3.4 x 10^38 combinations – even the fastest computers in the world all working together would take millions of years to compute every possible combination (this is known as "the brute force" method of breaking the code). In fact, it would require the entire energy consumption of the earth for ten years to power the computers (if they existed) to crack this code using the brute force method **[4]**. This level of effort is often described as being infeasible – a term used by the cryptographic industry to describe something which is practically impossible to achieve.

It must be remembered that this entropy level is the theoretical maximum level of cover that can be achieved. In practice the security level is often much lower. For example, when choosing passwords, we tend to use real words that are often related to us – this limits very dramatically the number of combinations that need to be searched.

Hash function

The first building block in the encryption process is known as the hash function. The hash function is an encryption algorithm that takes a message of any length and converts it into a hash or digest of a fixed length e.g. 128 or 256 bits – see figure 18. The hash function has the following attributes:

- it is quick to compute the hash value for any given message
- it is infeasible to generate a message from its hash value

- it is infeasible to modify a message without changing the hash value
- it is infeasible to find two different messages with the same hash value

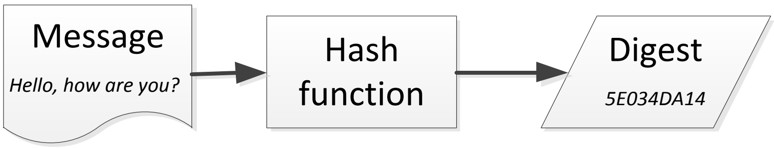


Figure 18: Hash function to produce an encrypted digest

If one bit of the message was to change, the hash would be completely different. For example, a hash function could be used to create a 256-bit hash of the whole bible. If just one character of the bible was to be changed, anywhere in the bible, and then the hash recreated, the hash would be completely different.

One application of the hashing function is to protect the security of website login passwords. Rather than store the actual passwords, a company would store the digests computed by hashing the passwords. If there was to be a security breach and these digests became public, the security of the original passwords is not compromised.

Symmetric encryption

To ensure that confidentiality is protected i.e. the content of the communication, the message is encrypted before sending using a “code book” called a key. The receiver of the message also has access to the same key (hence the term symmetric) and uses this to decrypt the message – see figure 19. This method is bidirectional and can be very secure – for example if a 128-bit key is used it is infeasible for the message to be decrypted using the brute force method.

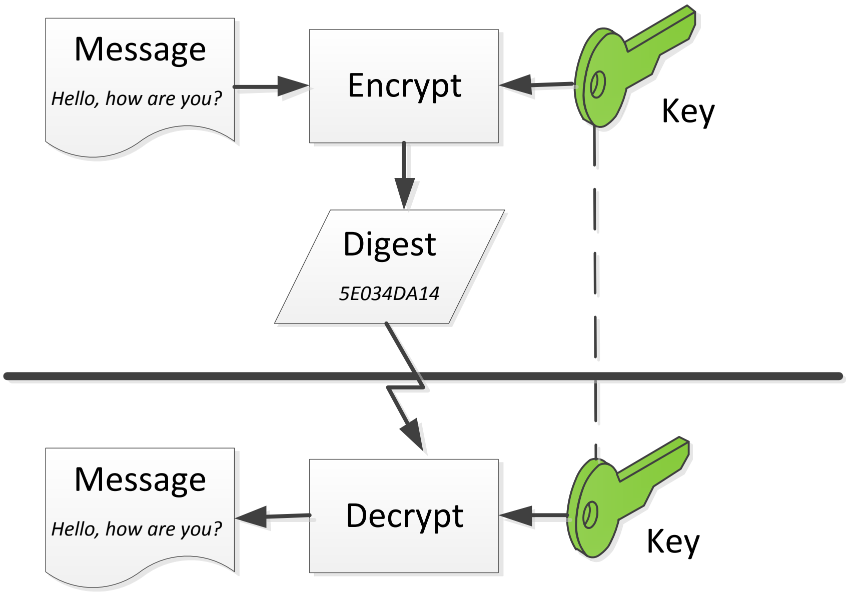


Figure 19: Symmetric encryption to ensure confidential, secure communication

The risk is that the key becomes public and eavesdroppers can then access the message. When a new communication between two parties is initiated, it is necessary for one party to send the other the key that they are going to use – any eavesdropper would then also have access to the key.

To avoid this vulnerability, asymmetric encryption was developed.

Asymmetric encryption

Asymmetric encryption uses a pair of keys:

- Public key – used to encrypt message before sending (anyone who has the public key can encrypt)
- Private key – used to decrypt message (if key remains secure then nobody else can decrypt)

The additional security compared to symmetric encryption is that the private key never needs to be transmitted and provided it remains secure, there is no way for anyone to decrypt the message except the private key holder as shown in figure 20.

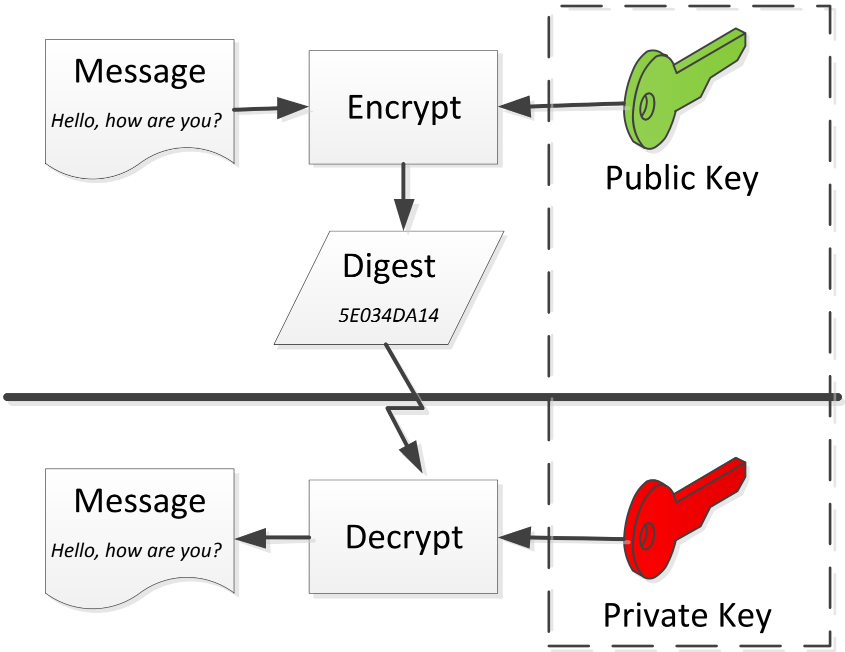


Figure 20: Asymmetric encryption to ensure confidential, secure communication

Because of the computational complexity of asymmetric encryption, it is usually used only for small blocks of data, typically the transfer of a symmetric encryption key (e.g. a session key). This symmetric key is then used to encrypt the rest of the potentially long message. The symmetric encryption/decryption is based on simpler algorithms and is much faster (x 1000 compared to asymmetric). The process is as follows:

1. Alice (e.g. a bank) creates a private and public key pair
2. Alice sends Bob (e.g. a customer) the public key
3. Bob encrypts a message using the public key (the message might be a new symmetric key)

4. Bob sends the encrypted message to Alice (it doesn’t matter if it is intercepted as it is encrypted and nobody but Alice can decrypt it)
5. Alice decrypts the message (receives the symmetric key)
6. Bob and Alice can communicate confidentially using the symmetric key (less computationally demanding and bidirectional)
7. Once the communication session is completed, the symmetric key can be discarded and not used again

It is important to recognise that the encryption described above is protecting the confidentiality of the message, but it is not confirming who the communicating parties are. In the above example, it might be possible for somebody to pretend to be Bob. There would be no way of Alice confirming that she was talking to the real Bob unless he was able to provide some information that only the true Bob would know.

One method to authenticate the message sender, is to use a digital signature – this is described in more detail in section 2.7.6.

Railway solution – use of encryption technologies to protect payment data and reduce fraud

The rail industry is increasingly being asked to deal with important payment and passenger sensitive information. In order to enable the use of some of the other technologies outlined in this report, it will be necessary to implement secure systems based on appropriate encryption standards. It is proposed to make use of encryption technologies for payment authorisation and customer information handling.

Potential benefits

- Enables compliance with data protection legislation
- Reduces fraud
- Enables the use of other payment and identification technologies

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- Secure encryption requires processing time and power. How can the free flow of passengers be maintained while providing the required level of protection?
- How can passengers be reassured that they are protected?
- What is the most effective way to deliver the required level of protection?
- What are the implications for the rail industry of introducing encryption technologies of the type detailed across all operations?

Solution readiness

The encryption technologies detailed in this section are already commercially available.

2.7.4 PROVIDE PAYMENT RECORD – DIGITAL CURRENCY

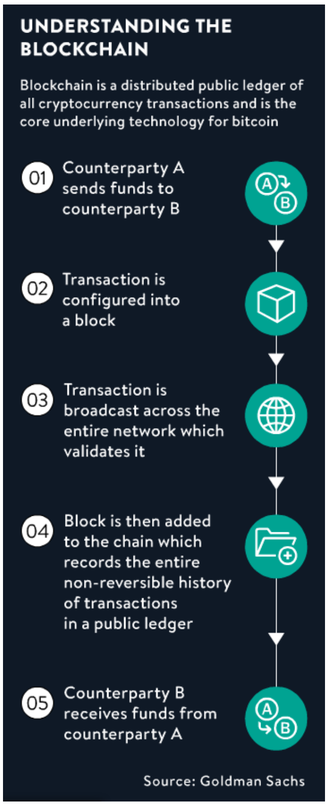
Operating Principle

A digital currency (e.g. bitcoin) is comprised of two elements; a payment mechanism enabling a financial transaction to take place and a means to keep track of the payments made – a ledger.

The key innovation of digital currencies is the ‘distributed ledger’ which allows a payment system to operate in an entirely decentralised way, without intermediaries such as banks. This innovation draws on advances from a range of disciplines including cryptography (secure communication), game theory (strategic decision-making) and peer-to-peer networking (networks of connections formed without central co-ordination).

When payment systems were first computerised, the underlying processes were not significantly changed. Distributed ledger technology represents a fundamental change in how payment systems work. In principle, this decentralised approach is not limited to payments but can be applied to other items which are bought and sold and therefore require tracking **[5, 6]**.

In a distributed ledger, the history of every transaction is encoded cryptographically in a permanent record called the blockchain. When one person pays another this payment history, which is distributed and accessible rather than centralised, is automatically checked to ensure the person has previously received the amount of currency they want to spend. Figure 21 shows how the blockchain works.


UNDERSTANDING THE BLOCKCHAIN

Blockchain is a distributed public ledger of all cryptocurrency transactions and is the core underlying technology for bitcoin

01 Counterparty A sends funds to counterparty B

02 Transaction is configured into a block

03 Transaction is broadcast across the entire network which validates it

04 Block is then added to the chain which records the entire non-reversible history of transactions in a public ledger

05 Counterparty B receives funds from counterparty A

Source: Goldman Sachs

Figure 21: how the blockchain works **[7]**

A distributed ledger of transactions can conceivably be used for any unit of value, from loyalty points to cash, to complex contracts. Many technology start-ups are building their own blockchain inspired distributed ledgers to take advantage of the revenue generating opportunities around the technology.

Railway solution – railway industry to implement a digital currency

It is proposed to introduce a digital railway-related unit of value whose transactions are be tracked using a distributed ledger based on a blockchain. The unit of value traded could be in the form of "railway miles". Passengers would purchase (exchange money for) railway miles for a specific journey, for a series of journeys (e.g. a carnet or season ticket) or as a tradeable commodity.

Potential benefits

- Passengers have flexibility in terms of when and where they pay
- Passengers can make a payment without risk of revealing any personal information
- The transaction information is transparent to everyone – rail company and passenger
- Low transaction fees
- Fewer risks to the rail company – reduced fraud
- Easier to compensate passengers
- Potential to simplify ticketing fee structure

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- Currently the public has low awareness and understanding of the potential benefits of digital currencies. How long will it take until there is sufficient passenger demand for this form of solution?
- The technology behind digital currency is still being developed. How long will it be before the technology is sufficiently mature to support this solution?
- Early forms of digital currency have experienced high levels of fluctuation in value. How will the risk of currency volatility be mitigated in this case?

Solution readiness

While digital currency is still in its infancy, a number of companies are now accepting digital payment through bitcoin, including Amazon, Subway, Tesla, Expedia, Sears, Dell and the App Store **[8]**. Other companies are using distributed ledgers for non-cash items such as loyalty cards **[9]**.

2.7.5 PASSENGER IDENTIFICATION – BIOMETRIC IDENTIFICATION

Operating principle

In section 2.7.2 five spatial-temporal levels of sensing were introduced. Biometric identification enables the specific person travelling to be identified (level 5), which is important for payment authentication. Biometric identifiers are the distinctive, measurable characteristics used to label and describe individuals. Biometric identifiers are often categorized as physiological or behavioural characteristics. Physiological characteristics are related to various parameters of the human body. Examples include, but are not limited to fingerprint, palm veins, face recognition, DNA, palm print, hand geometry, iris recognition, retina and odour/scent. Behavioural characteristics are related to the pattern of behaviour of a person, including but not limited to typing rhythm, gait, and voice.

Table 3 provides an overview of various current and emerging biometric sensing technologies which may be relevant for future use by the rail industry, detailing human trait measured, sensing method used together with advantages and shortcomings **[10, 11]**. A key trend in biometrics is the use of combined "multimodal" sensing **[12]** to enable better discrimination and robustness against fraud.

Human trait	**Sensing method**	**Advantages**	**Potential shortcomings**
DNA	Chemical-electronic	Strong unique and unchanging identifier	Long analysis time Sample required for measurement Privacy, legal and civil liberty concerns
Shape of ear	Optical	Good level of accuracy Not affected by facial expression or age	Obstructed visual access
Iris pattern and form	Near infra-red optical	Low chance of false match Not affected by facial expression	Early versions can be fooled by a reverse engineered printed image of an eye **[13]** Currently requires cooperative subject measured at close range
Retina pattern	Infra-red optical	Highly accurate because no two people have the same retinal pattern Relatively fast analysis	Measurement accuracy can be affected by disease and astigmatism Currently requires cooperative subject measured at very close range
Face form	Optical, 2D, 3D and thermal infra-red	Does not require cooperation of subject can identify individuals from a crowd	Sensitive to facial expression, angle of viewing and lighting levels
Fingerprint	Optical, ultrasonic, capacitive	High accuracy Generally accepted by public	Sensitive to condition of fingertip
Finger and hand geometry	Optical	Easy to use Generally accepted by public	Geometry of hand is not unique
Vascular geometry	Near infra-red optical	High level of security due to need for blood flow within veins	Device is expensive and relatively large User resistance to placing finger inside device
Gait	Optical	Unobtrusive remote identification	Gait can be affected by a number of factors including mood, injury, clothing, floor surface, age and viewing angle
Odour	Chemical-electronic Infra-red Optical	Some technologies may enable remote tracking and identification	Only preliminary demonstration of effectiveness
Dynamic Signature	Capacitive or optical	Dynamic signature characteristics are unique and hard to forge	Large sample variability can lead to difficulties in recognition
Keystroke	Keyboard and device	Can enable continuous verification	Less suited to identification than to ruling out certain users
Voice	Microphone	Seen as a non-invasive biometric	Sensitive to environmental noise and voice changes due to illness and age

		Enables remote identification	

Table 3: Current and emerging biometric identification technologies

For further information on comparing the different biometric methods see appendix 1.

Railway solution – use of biometric identification to authenticate payment

Biometric identification is being used increasingly for secure access to financial services and to verify transactions **[14]**. It is proposed to use single mode or multimode biometrics to provide secure payment for rail services. There are alternative ways that this authentication could be provided; via secure measurements made on a personal device (e.g. keystroke, voice, fingerprint), via point of sale terminal located on the station, via point of sale device located on the train (e.g. at the seat).

Potential benefits

- Avoids the need to remember passwords
- Potential for a greater level of transaction security
- Increased convenience for the passengers
- Possible to increase amount of information gathered on passengers and their behaviour

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to these solutions:

- Will passengers accept the use of biometric identification?
- What level of security can be derived from simple biometric checks?
- What is the risk of fraud?

Railway solution – use of biometric identification for rail system access control

It is proposed to use single mode or multimode biometrics to provide access control to the railway system. There are alternative ways to provide this control; use of normally open gates in conjunction with remote biometric identification (visually identifiable traits such as face form, gait, shape of ear, height) to stop unauthorised passengers, use of biometric identification as a secondary check in the absence of a personal device.

Potential benefits

- Reduces delays at the gates
- Potential for a greater level of rail security
- Increased convenience for the passengers
- Possible to increase amount of information gathered on passengers and their behaviour
- Rail company can set the security parameters for passenger identification i.e. should the system be biased to screen out unauthorised or minimise inconvenience to authorised passengers?

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to these solutions:

- Will passengers accept the use of biometric identification?

- How quickly can the unauthorised passenger be identified?
- What level of security can be derived from remote biometric checks?
- What is the risk of incorrectly stopping authorised passengers and admitting unauthorised passengers?

Solution readiness

Since 2001 the field of biometric identification has been rapidly developing as illustrated by the broad listing of biometric identification technologies. Figure 22 shows the growth in biometric identification patents.

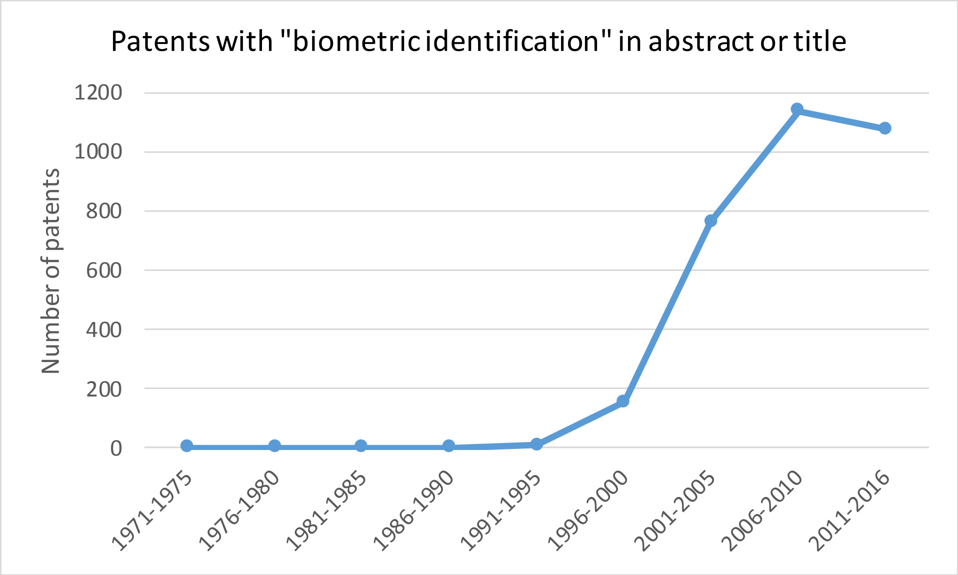


Figure 22: Growth of biometric identification patents since 1971

2.7.6 DEVICE IDENTIFICATION – DIGITAL SIGNATURE

Operating principle

As described in 2.7.3, encryption methods are used to protect confidentiality of the data contained in a communication. Encryption can also be used to identify and verify the source of the information sent using a digital signature. The digital signature uses the asymmetric encryption method detailed earlier, with one important difference – the private key is now used to encrypt the message to form a digital signature before sending and the public key is used to decrypt the message after receipt. Both the digital signature and the original message are transmitted. The receiver verifies the signature by the following steps (see figure 23):

1. Decrypting the signature with the signer's public key
2. Comparing the decrypted message with the original message
3. If the two messages are the same, then the sender’s identity is confirmed

The equality check detailed above also confirms no changes have occurred since signing. Notice that in this process, the message confidentiality is not protected.

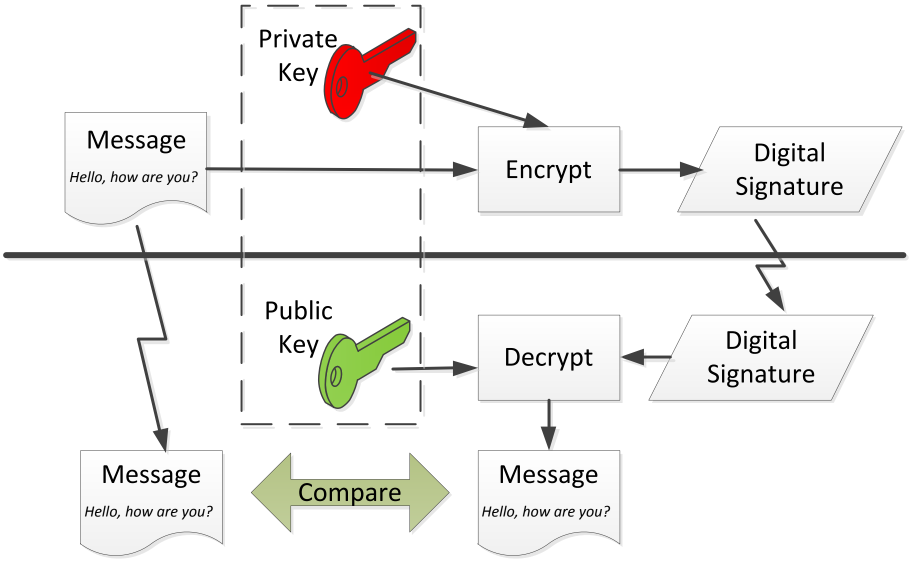


Figure 23: Digital signature to authenticate the sender and the integrity of the message

Railway solution – use of digital signature to identify sender's device

It is proposed to use a digital signature to provide a "proof of identity" function. The private key could be implemented in hardware (e.g. smart card) or software (e.g. on a smartphone). The "signature" could be in the form of a PIN, password or biometric trait e.g. fingerprint. Figure 24 shows a potential embodiment of this solution.

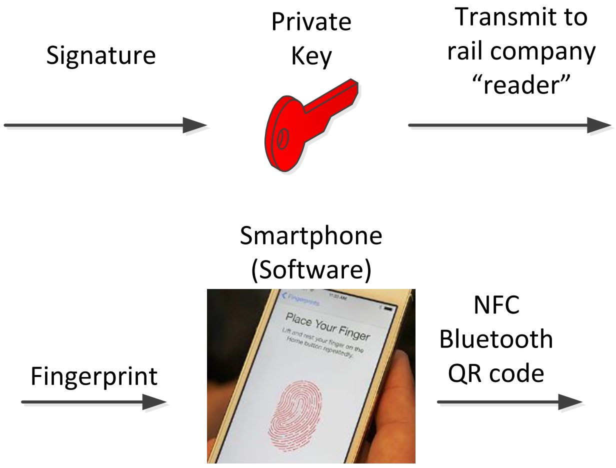


Figure 24: Potential digital signature based identification solution

Potential benefits

- Increased fraud protection
- Improved passenger privacy

- Potentially offers a more convenient way to access rail services

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- How to provide the identification function without causing extra inconvenience for the user and slowing passenger flow?
- How to enable access to the public key when identification is required (currently there are no connections between the gates and the central rail servers where the public keys would need to be stored)?

Solution readiness:

The encryption technologies required for the digital signature are already available and in use.

2.7.7 DEVICE IDENTIFICATION – COMMUNICATE IDENTIFICATION

There are a number of current and emerging technologies that enable a device (e.g. smart phone or smart card) to communicate identification. In the following sections these technologies will be described in further detail.

RADIO FREQUENCY IDENTIFICATION (RFID)

Operating principle

Radio frequency identification (RFID) is a form of wireless communication that uses radio waves to identify and track objects with the following benefits:

- Uniquely identify an individual item
- Identify items without direct line-of-sight
- Identify multiple items simultaneously
- Identify items across a range of distances from a few centimetres to several metres

An RFID system consists of readers and tags that use radio waves across a range of frequencies from 30KHz up to 3GHz (see table 4). RFID tags can be very small and “passive” devices do not need a battery to store information and exchange data with readers. This form of device is becoming increasingly affordable and can be used to be identify or track a wide range of objects.

Category of RFID	Frequency	Applications	Standards	Range
Low frequency, LF	30-300KHz	Access control, livestock	ISO 14223, ISO/IEC 18000-2	< 10 cm
High frequency, HF	3-30MHz	Ticketing, payment, data transfer, tracking	ISO 18092 - NFC ISO 14443 – (proximity) ISO 15693 – (vicinity)	10cm – 1m

Ultra-high frequency, UHF	300MHz-3GHz	Inventory tracking, anti-counterfeiting, device identification	Gen2 (ISO 18000-6C)	12m passive, 100m active

Table 4: Different frequency categories of RFID

Active devices

Active RFID tags typically operate in the UHF band and have their own transmitter and power source, usually a battery. Active tags broadcast their own signal to transmit the information stored on their microchips up to a range of 100m. The tags can be transponders that are “woken” when they receive a signal from the reader or beacons that transmit at regular intervals, potentially consuming more energy.

Passive devices

In passive RFID systems, the tag is powered by the radio signal transmitted from the reader. Passive RFID tags can operate from low to ultra-high frequency but have a smaller range of less than 10m due to the limited power in the radio signal. Because passive tags do not require a power source or transmitter, and only require a tag chip and antenna, they are cheaper, smaller, and easier to manufacture than active tags.

RFID technologies are already being widely utilised as a smart card ticketing technology in transportation applications including in the rail industry **[1]**. To harmonise smart card ticketing across the different UK rail and bus companies, the ITSO (Integrated Transport Smartcard Organisation) system has been established. The objective is that in the long term, all smart card tickets will be ITSO compliant. However, the most widespread smart card ticketing system currently in use, the Oyster card, is not currently ITSO compliant.

Railway Solution – use UHF RFID to communicate device identity within the railway system

It is proposed to use longer range RFID (UHF RFID passive or possibly active) to identify passenger devices while they are within the railway system (in stations and on trains). The RFID could be carried in in a range of forms (e.g. ITSO compliant smart card). It should be noted that it is the RFID device that is being tracked and not the passenger – this means that it would be possible for the passenger to remain anonymous to the system, although this might limit the benefits that could be provided.

Potential benefits:

- Charging could be related directly to journey made
- Rail companies could gather a large amount of data on the journeys being made
- The range between the reader and the RFID can be quite large (~100m) which means that a few readers can cover a large area e.g. 1/railway carriage
- The passenger does not need to remove the RFID from their pocket or wallet in order to be identified

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- How to ensure interoperability across the whole transportation network?
- How to identify unauthorised passengers not carrying an RFID?
- How to protect the privacy of passengers?
- How to ensure the security of the data being gathered?
- What might be the cost of implementation for an RFID-based solution?

Solution readiness

The “Be In/ Be out” trials mentioned in section 2.4.2 made use of vicinity RFID tags **[2]**.

OPTICAL DIGITAL IDENTIFICATION

Operating principle

A barcode is a machine-readable optical label that contains information about the item to which it is attached. Original barcodes were one-dimensional, consisting of varying widths and spaces of parallel lines to represent data. The introduction of two-dimensional barcodes increased the data density that could be stored. Although still referred to as barcodes, the information is stored as a series of square dots. One widely applied format is the QR (quick response) code. There have also been some limited applications of three-dimensional barcodes where the height (or depth) of the dots can be read **[15]**.

Many modern devices such as smart phones have screens and cameras that can display and read codes, providing a method for digital identification; already widely used as an e-ticketing solution in transportation including the railway industry.

In the future it is likely that QR codes will become more dynamic, enabling the data contained in the QR code to the updated.

Railway solution – dynamic QR codes for digital identification and journey tracking

It is proposed to use a device with screen and camera to display and read dynamic QR codes. As the journey progresses, the data held on the QR code is updated, enabling the details of the journey to be tracked and uploaded. In addition, travel information could be transferred to the passenger’s device by displaying a QR code to the device. In other words, the QR codes provide an optical data channel.

Potential benefits

- Customer behaviour doesn’t need to change (if already using e-tickets)
- Increased journey information available for rail company use
- Increased journey information for passenger use
- Passenger privacy is maintained

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- What are the implications for the rail industry of introducing QR displays as well as QR readers?
- How quickly can the QR-based communication take place?
- How close does the device have to be to the reader and will it work in all lighting conditions?

Solution readiness:

The rail industry is already starting to introduce QR readers for e-ticketing **[16]**. There are proprietary software packages available which enable a QR code to be updated.

ACOUSTIC DIGITAL IDENTIFICATION

Operating principle

Audio frequency signals can be encoded to carry data between a speaker (transmitter) and a microphone (receiver). If a high audio frequency is used e.g. 20KHz, this is generally not audible to the human ear. The possible data rates for this form of communication are be relatively low (~ 1kbit/s) but it could still provide a simple, low cost (using existing resources), short range data channel. Communication devices such as mobile phones, laptop computers, public address systems all include speakers and microphones that would be suitable for use as an acoustic data channel.

Railway Solution – use of audio signal transmission for digital identification

It is proposed to use an audio signal transmitted from a personal device such as a mobile phone as a digital identification whenever “proof of identity” is required. This might take the form of a digital signature (see digital signature section 2.7.6). The receiver could be another portable device e.g. carried by an inspector, or it could be at a fixed location in the station e.g. entrance to platform, or inside the train carriage itself.

Potential benefits:

- The transmitter and receiver can be several metres apart with no line of sight required, increasing the time available to perform the identification
- The personal device does not require WiFi (internet) or radio frequency reception
- Utilises existing resources already widely available
- Wide range of personal devices can be used – laptop computer, music player, tablet computer, non-smart phone etc.
- Public address systems could be used to send data to passengers

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- What would be the effective range?
- Would the signal penetrate a pocket or bag?
- Would it work in a noisy environment such as a train or station?
- How would multiple devices share the same bandwidth?
- What data rate could be reliably achieved?
- A robust solution relies on use of a digital signature. How to enable access to the public key when identification is required (currently there are no connections between the gates and the central rail servers where the public keys would need to be stored)?

Solution readiness

US patent 2007/0232355 **[17]** discloses a method for generating a digital identification code using an acoustic signal. Figure 25 shows a schematic of the digital identification method disclosed in the patent.

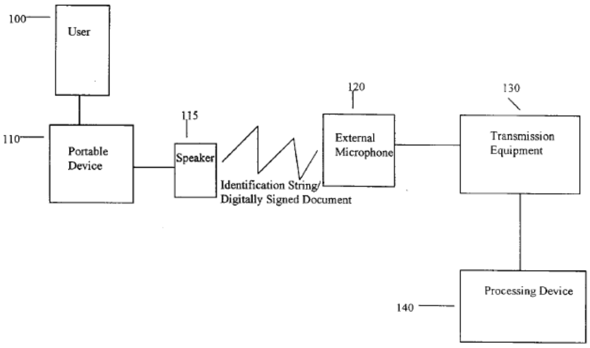


Figure 25: Schematic for acoustic digital identification (US Patent 2007/0232355)

An acoustic data transmission solution for mobile devices is already available in the market - Chirp. The following is a short description taken from the company website: “Chirp is a highly open system. Because a chirp is a sonic link, it can be used to share almost any data you can think of. Use cases include **ticketing**, media sharing, 2FA applications... and many more. “**[18]**. Figure 26 shows the range of different devices which can be used for acoustic communication with Chirp.

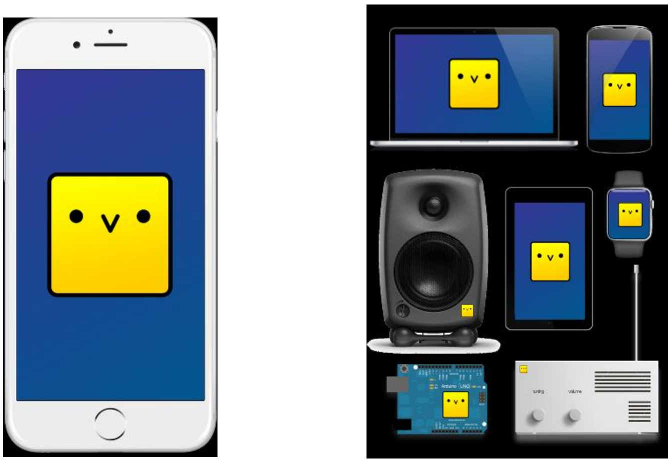


Figure 26: Acoustic communication between different devices using Chirp (www.chirp.io)

2.7.8 PROVIDE VISUAL INFORMATION – AUGMENTED REALITY

Operating principle

In augmented reality (AR) graphics, audio and other sensory enhancements are superimposed over a real-world environment in real time. AR presents a direct or indirect (i.e. via a device) view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as graphics, sounds, tactile feedback and even smell. As a result, the technology functions by enhancing the user's current perception of reality. By contrast, virtual reality replaces the real world with a simulated one. The additional input or augmentation in AR is delivered in real-time and in semantic context with environmental elements, such as sports scores on TV during a match. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally movable. Figure 27 shows an illustration of AR viewed through a hand held device which provides addition information about a real object.

This spectacular sci-fi sculpture is the creation of Bay Area artists Sean Orlando, Nathaniel Taylor, David Shulman and the dedicated crew of the Five Ton Crane Arts Group, who helped to bring their fantastic vision to fruition – a larger than life 1930's-1940's pulp fiction space ship, gleaming silver legs forever prepped for

Figure 27: Hand held device AR view

Video game, smart phone and automotive applications are driving the development of augmented reality. Everyone from tourists, to soldiers, to someone looking for the closest railway station can benefit from the ability to place computer-generated graphics in their field of vision.

Railway solution – use personal device to display an augmented reality overlay which provides passenger with additional information

It is proposed to offer rail passengers the opportunity to use AR Apps on their personal devices which can provide context relevant information while using the rail system. The following items of information are listed to demonstrate possible relevant content:

- Up to date train arrival information
- Travel fare advice and information
- Information about station services and retail offers
- Directions to the passenger's specific train
- Indication of carriage with available seating
- Points of interest during the journey
- Early warning of arrival at destination
- Onward travel information

Potential benefits:

- Improved passenger flow through the station – passengers know where to go
- Reduced dwell time – increased passenger awareness of arrival at destination
- Improved passenger satisfaction

- Increased revenue for train operating companies – increased passenger awareness of additional rail company services

Secondary considerations and research questions

There are a few secondary considerations and research questions related to this concept:

- What is the best way to display context specific information to the passenger?
- How will the system take account of the user's information preferences in a seamless way?
- Are there any additional safety concerns if passengers spend even more time looking at their personal devices?

Solution readiness

Since 2009, Yelp has provided an addition to their App called Monocle which enables iPhone users to find nearby businesses and restaurants using the phone's camera as an AR viewfinder **[19]**. The AR feature provides a natural extension of Yelp's core functions of providing information on local establishments, their contact details and relevant deals, as well as crowdsourced reviews. Further AR apps have since been developed for a range of uses including interactive print (where users can view embedded digital content in books, magazines, product labels and posters), text translation (e.g. from foreign language signs), virtual tour guide, driving assistance and even multi-player games **[20]**. The rail industry is also already starting to use Augmented Reality in support of maintenance work **[21]**. Figure 28 shows an example of an AR display on a personal device.

Figure 28: A typical personal device-based AR display

Railway solution – use interactive displays and projection to create an augmented reality overlay to provide information and warnings to passengers.

It is proposed to provide rail passengers with addition information by projecting or displaying context relevant information onto the railway station floors, wall and ceiling, onto the train exterior and within the train carriage. Projected images could be used to show a virtual "gate" in front of unauthorised passenger or to highlight passengers who haven't paid. Interactive wall displays could enable users to gain multi-level information from a relatively simple display or poster. Projected images of ticket inspectors could also be used as an additional deterrent. Platforms might be illuminated to show the train boarding positions and train doors highlighted to indicate which carriages still have available seating. Journey information could be shown by using displays integrated into the train windows.

Potential benefits

- Improved passenger flow through the station
- Reduced dwell time
- Improved passenger satisfaction
- Increased revenue for train operating companies
- Increased deterrence of fare evasion

Secondary considerations and research questions

There are a few secondary considerations and research questions related to this concept:

- When is it best to provide information through passenger's personal devices or through projected displays?
- How will such display systems work in all likely ambient lighting conditions?
- Are there any additional safety concerns if passengers are distracted by projected information displays?

Solution readiness

Interactive projected displays combining dynamic image projection with vision systems have been available since 2006. To date their main use has been in entertainment and leisure applications. Figure 29 shows an example of an interactive projection being demonstrated.

Figure 29: Interactive projection example

A number of companies supply interactive projection systems. A special glass with integrated display technology has been developed by OSG under the brand name of ScreeneX [22]. Figure 30 shows an illustration of ScreeneX in use within a rail carriage.

Figure 30: Illustration of ScreeneX in a railway carriage

2.7.9 PROVIDE AUDIBLE INFORMATION – DIRECTED PARAMETRIC SPEAKERS

Operating principle

Directed parametric speakers work in an entirely different way from conventional loudspeakers. The biggest difference is that they generate ultrasound (high-frequency sound waves) using an array of electrical devices called piezoelectric transducers. Ultrasound is used because its higher-frequency waves have a correspondingly shorter wavelength and diffract (spread out) less as they travel, which means they stay together in a beam for longer than ordinary sound would. Also, having an array of many, small transducers makes sound diffract less than it would do from a single, large speaker – see figure 31.

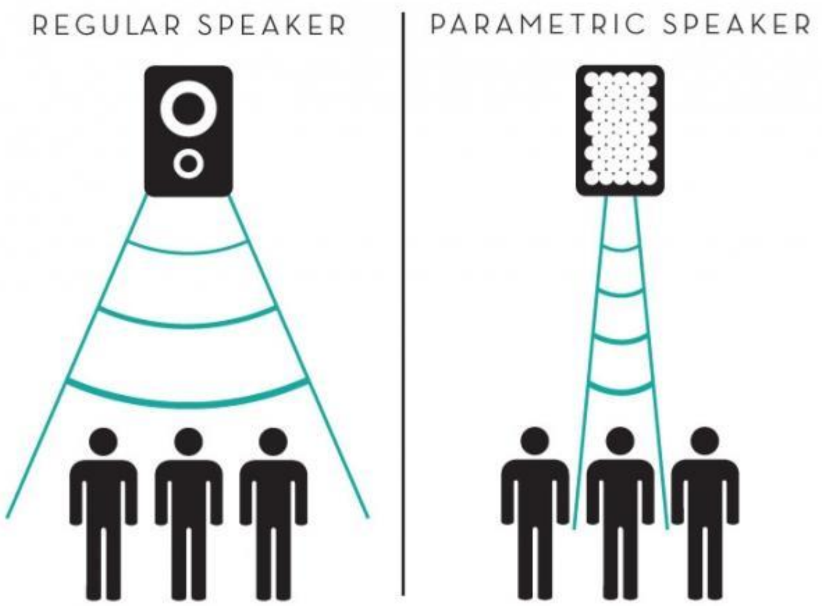


Figure 31: Comparison of standard and parametric sound delivery

The speaker array produces a modulated wave made of two separate ultrasound waves. One of them is a steady, reference tone of a constant 200,000 Hz frequency (the carrier wave) and the other is the signal that fluctuates between 200,200 Hz and 220,000Hz (the modulating wave). Although they're combined, it's easiest to think of them as two separate waves traveling out in parallel straight lines through a column of air without overlapping. If they meet an obstruction, they interfere constructively (by adding together) and destructively (by subtracting from one another). By the principle of wave superposition, two ultrasound waves of those frequencies can subtract from one another to produce a third wave with a much lower frequency in the range 200-20,000 Hz— in the audible frequency range. An electronic circuit attached to the piezoelectric transducers constantly alters the frequency of the two waves so they produce the correct lower, audible frequency when they collide and "demodulate." (It also encodes the signal in a unique way that ensures there's less noise and distortion when it separates out in the listener's ear.) The process by which the two ultrasound waves mix together is technically called parametric interaction, which is why speakers that work this way are sometimes called parametric loudspeakers.

One of the biggest advantages of directional loudspeakers that they can make sound travel much further. In theory, sound from a conventional speaker follows what's called the inverse-square law, so doubling the distance from the speaker reduces the intensity by much more than half. A directional speaker sends its sound in a much more tightly focused column, with far less energy dissipation. In practice, that means sound produced this way can travel up to 20 times further than that from a conventional speaker.

Railway solution – use directed parametric sound for enhanced and personalised passenger communication both at the station and within the train

It is proposed to combine passenger identification and tracking technologies with a controllable directional sound array to steer sound delivery towards a specific location, enabling targeted travel information to be delivered to a specific passenger while they are at the station or on the train.

Potential benefits:

- Improved passenger satisfaction through enhanced and timely personalised information provision
- Reduced dwell time due to improved passenger awareness
- More efficient passenger movement within stations
- Possibility to deliver relevant advertising for additional revenue generation
- Improved guidance for partially sighted and blind passengers

Secondary considerations and research questions

There are some secondary considerations and research questions related to this concept:

- Would rail passengers be comfortable with personalised information provision through this form of direct communication?
- Would this system provide sufficient resolution to enable individual passengers to be addressed accurately?
- Could this technology be used in conjunction with conventional speaker systems to enhance general passenger communication?

Solution readiness:

Since the early 1960s, researchers have been experimenting with ways to create directive low-frequency sound from nonlinear interaction of an aimed beam of ultrasound waves. The first modern device was created in 1998 and is now known by the trademark name "Audio Spotlight" **[23]**. A number of other companies are now marketing directional parametric sound systems which provide enhanced and personalised information provision **[24, 25, 26]**. Figure 32 shows a typical system made by Soundlazer.

Figure 32: Soundlazer directional arrays

2.7.10 PROCESS BIG DATA – BIG DATA ANALYTICS

Operating Principle

Big data is a term that describes the large volume of data that inundates a business on a day-to-day basis. This volume is growing in three dimensions, often referred to as the three V's: increasing volume (amount of data), velocity (speed of data in and out), and variety (range of data types and sources). The data sets are so large that they cannot be analysed using conventional methods and require new techniques – Big Data Analytics – to uncover hidden patterns, unknown correlations, market trends, customer preferences and other useful business information. The analytical findings can lead to more effective marketing, new revenue opportunities, better customer service, and improved operational efficiency.

"Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization." Gartner 2012 **[27]**.

As has already been highlighted, UK rail companies have very little data about the actual train journeys that are being made. In many cases the data does exist, but there is currently no mechanism to gather and collate it into a big data set that could be mined using the big data analytics discussed above. Listed below are some examples of existing data sources which railway companies could analyse:

- Ticket sales (Time of purchase, method of purchase, location, payment method, type of ticket purchased)
- Additional purchases – car parking, underground, station catering
- Train occupancy levels
- Train punctuality and dwell times

New ticketing technologies & solutions

- Ticket inspections
- Barrier usage
- CCTV recordings
- Weather information
- Date and time
- Requests to staff and complaints
- Major events (e.g. football matches)

Potential future data sources:

- Location tracking (GPS, RFID)
- Seat occupancy
- Carriage weight
- WiFi usage

Railway solution – use of big data analytics to minimise ticket fraud

It is proposed to use big data analytics to help minimise ticket fraud. For example, this might involve selectively targeting train journeys or stations for ticket inspection where the analysis indicates the probability of fraud is at its highest.

Potential benefits:

- Reduced need for barriers and inspections
- Faster passenger flow through stations
- Increased confidence amongst authorised rail users
- Increased revenue for rail companies

Secondary considerations and research questions

There are some secondary considerations and research questions related to this concept:

- How will passengers react to the use of big data analytics for fraud prediction?
- How will the necessary data be collected?
- How effective will a big data analytics based approach to fraud prevention be?

Solution readiness:

Big data analytics are already in use in crime prevention and detection **[28, 29]**.

Railway solution – use of big data to optimise profit

It is proposed to use big data analytics to enable rail companies to optimise operational costs. Monitoring key parameters such as seat occupancy and revenue per seat could enable more efficient use of rolling stock and availability driven pricing. Passenger feedback (e.g. in the form of tweets) could be used to highlight key issues on the network.

Potential benefits:

- Increased profits for the rail company
- Improved customer experience for the passenger

Secondary considerations and research questions

There are some secondary considerations and research questions related to this concept:

- How will passengers react to the use of big data analytics in this application?
- How will the necessary data be collected?
- How effective will a big data analytics based approach be for profit optimisation?

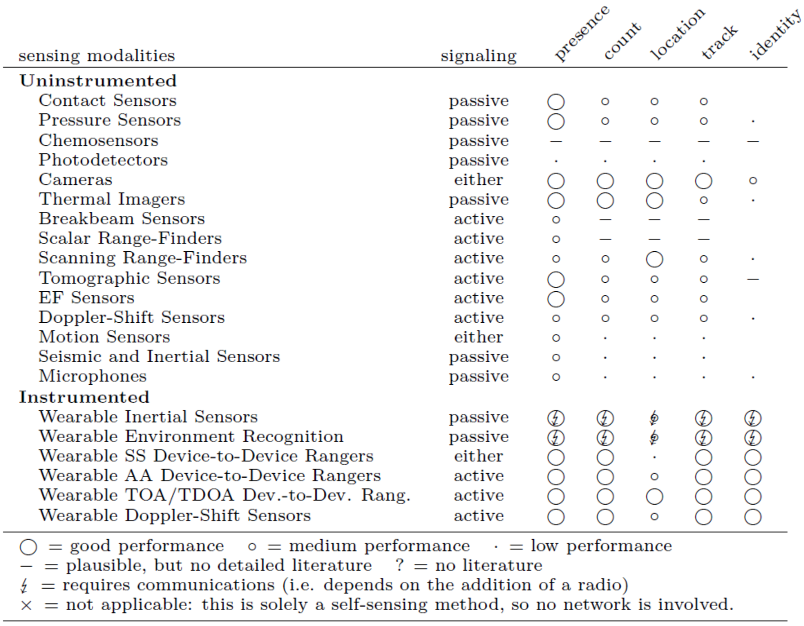
Solution readiness:

Many organisations are already benefiting from the use of big data analytics **[30]**. Big data has already been gathered in the UK rail industry. C2C offered free WiFi and provided an automatic delay refund to any passengers who used their app. In return passengers agreed to allow their usage data to be gathered. In certain situations this data is then sold on to selected third parties **[31]**.

2.7.11 TRACK PASSENGER – LOCATION TECHNOLOGIES

Operating principle

There is a wide range of technologies available to locate passengers and track their movement with time. Table 5 summarises the range of technologies (or modalities) which can be used to sense the five spatio-temporal levels detailed in section 2.7.2 **[3]**. The symbols illustrate how well each technology delivers its sensing function.



sensing modalities	signaling	presence	count	location	track	identity
Uninstrumented						
Contact Sensors	passive	◯	∘	∘	∘	
Pressure Sensors	passive	◯	∘	∘	∘	·
Chemosensors	passive	—	—	—	—	—
Photodetectors	passive	·	·	·	·	
Cameras	either	◯	◯	◯	◯	∘
Thermal Imagers	passive	◯	◯	◯	∘	·
Breakbeam Sensors	active	∘	—	—	—	
Scalar Range-Finders	active	∘	—	—	—	
Scanning Range-Finders	active	∘	∘	◯	∘	·
Tomographic Sensors	active	◯	∘	∘	∘	—
EF Sensors	active	◯	∘	∘	∘	
Doppler-Shift Sensors	active	∘	∘	∘	∘	·
Motion Sensors	either	∘	·	·	·	
Seismic and Inertial Sensors	passive	∘	·	·	·	
Microphones	passive	∘	·	·	·	·
Instrumented						
Wearable Inertial Sensors	passive	◯ϟ	◯ϟ	∘ϟ	◯ϟ	◯ϟ
Wearable Environment Recognition	passive	◯ϟ	◯ϟ	∘ϟ	◯ϟ	◯ϟ
Wearable SS Device-to-Device Rangers	either	◯	◯	·	◯	◯
Wearable AA Device-to-Device Rangers	active	◯	◯	∘	◯	◯
Wearable TOA/TDOA Dev.-to-Dev. Rang.	active	◯	◯	◯	◯	◯
Wearable Doppler-Shift Sensors	active	◯	◯	∘	◯	◯

◯ = good performance ∘ = medium performance · = low performance
— = plausible, but no detailed literature ? = no literature
ϟ = requires communications (i.e. depends on the addition of a radio)
× = not applicable: this is solely a self-sensing method, so no network is involved.

Table 5: Sensing technologies for passenger location

Railway solution – camera location with RFID identification

One example of an application of the technologies listed above would be to combine camera location technology with RFID identification to locate and if necessary track authorised and unauthorised passengers.

Potential benefits:

- Prevent or highlight unauthorised rail travel
- Reduced fraud level
- Utilise existing surveillance resources
- Increased information of rail usage

Secondary considerations and research questions

There are some secondary considerations and research questions related to this concept:

- What are the legal implications of increased passenger location and tracking?
- How many sensors would be required to provide sufficient cover for effective location and tracking?

Solution readiness

Systems for the location and tracking of individuals are already being researched and applied in such field as driverless cars **[32]**, weapons systems **[33]** and airport security **[34]**

2.7.12 FASTER TRANSMISSION METHODS – DATA TRANSFER TECHNOLOGIES

Background

Passengers (and railway staff) within the rail network are utilising mobile communications to transmit and receive information (voice and data). Very little, if any, of this communication is between the rail company and the passenger.

Existing wireless solutions such as 3G/4G and WiFi experience a number of problems within the rail industry:

- High density requirement – i.e. when a large number of people arrive at the same location at the same time, all requiring data/voice bandwidth.
- Attenuation of radio signals by the train carriages making reception inside the trains difficult.
- When trains travel at speed it can make it difficult for the networks to provide a seamless handover between base stations.
- Trains travel through rural, sparsely populated areas where the network coverage is poor.
- Railway infrastructure such as bridges, stations, cuttings and tunnels create “not spots”.

The result of these problems is a less than satisfactory passenger experience - a survey by Global Wireless in 2014 found that 1 in 3 internet tasks and 1 in 7 voice calls on commuter trains into London failed **[35]**. The rail industry together with the Department for Transport and mobile network providers are working together to address this issue with the target that high speed internet access will be available to 70% of rail commuters by 2019 **[36, 37]**.

General concept – an infinite data channel between the passenger and the rail company

In section 2.4.6 two future options were highlighted; proof of payment delivered with no ticketing system and an infinite data channel between the passenger and rail company. If such a channel could be established for reliable, secure and high speed data transfer, then there are a number of potential benefits:

- Passengers would have a reliable connection for mobile internet and voice communication
- Passengers could be provided with real time journey information such as connections, delays, seat location.
- Rail companies would be able to track passengers through the journey
- Rail companies would be able to assimilate information such as train occupancy levels, passenger behaviours etc.
- Rail companies could provide personalised services such as targeted offers and customer loyalty programmes.
- The data channel could form part of a flexible, secure and convenient payment systems

In addition to the existing mobile technologies of 3G, 4G and WiFi there are two new mobile technologies on the horizon that might offer some significant benefits; LiFi and 5G.

LIFI (VISIBLE LIGHT COMMUNICATION)

Operating principle

LiFi is a bidirectional communication technology similar to WiFi that makes use of the visible light spectrum instead of radio frequencies to enable high-speed wireless data transmission. It could be used to complement existing WiFi networks by providing additional bandwidth particularly for the higher demand downlink, or even as a replacement in areas where the technology might have a significant advantage over radio frequency transmission. LiFi is a specific type of the more general category of optical wireless communication which includes infra-red, ultra-violet and visible light – see figure 33. One key advantage of LiFi is that it can utilise the same visible light source (LED lamp) that is being used for illumination, reducing the complexity and energy consumption of the data transfer system.

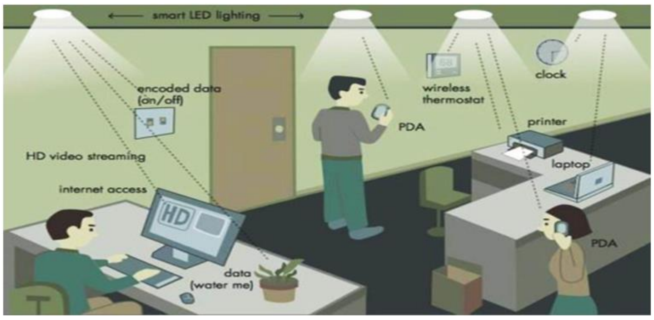


Figure 33: Illustration of a LiFi-based data communication system

Data is transmitted by modulating the intensity of the light, which is then received by a photo-sensitive detector. This modulation is not visible to the human eye. There are a number of potential benefits that LiFi offers:

- Very high speed data transfer rates (10Gbits/s)
- Wide, uncrowded frequency spectrum (10,000 x Radio Frequency (RF) spectrum used for WiFi)
- Short range providing increased security (light does not travel through walls)
- Spatial re-use of the bandwidth, providing very efficient use of the spectrum
- Immune to radio frequency interference and does not create any RF transmission
- Lower power consumption than RF transmission

Railway solution – The use of LiFi to provide an infinite data channel between the passenger and the rail company

It is proposed to use LiFi technologies to complement existing RF networks to provide a secure, reliable, high speed data channel across the rail network. LiFi access points would be integrated into the lighting systems in trains and possibly on stations. Customers would use LiFi enabled personal devices such as smartphones to receive and possibly also transmit data.

Potential benefits:

- Deliver very high download data rates, enabling a high passenger density (e.g. in a train carriage) to simultaneously stream data intensive content such as films
- Utilise existing led lighting systems in the train (or in stations)
- Provide the rail company with additional passenger data e.g. location
- Enable the rail company to provide real time journey data to the passengers

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to these solutions:

- When will personal devices such as smartphones have affordable LiFi capability?
- What range can LiFi transmission deliver e.g. from ceiling of station concourse to platform level?
- How sensitive is LiFi to different lighting conditions?
- Are the benefits of LiFi compared to radio frequency solutions such as 4G or WiFi sufficient to justify the move to a new technology?

Solution readiness

LiFi products including modified smart phones have already been demonstrated at a number of trade shows **[38]**. Apple is rumoured to be investigating the addition of LiFi capabilities to the iPhone and a reference to LiFi has been discovered in the latest iOS **[39]**. A recent analysis of patents in this area showed that this to be an expanding area of innovation with Samsung leading the way with 26 patents **[40]**.

5G DATA COMMUNCATIONS

Operating Principle

The mobile phone industry introduces a new operating standard approximately every 10 years (1G - 1982, 2G-1992, 3G-2001 and 4G-2012) and it is likely that the next generation, 5G will be introduced by 2020. The standard is currently being developed and there have already been a number of technology demonstrations **[41]**. Although the standard is not yet finalised it is claimed to offer a number of improvements over the current 4G standard:

- Very high data rates – up to 10 Gbit/s
- Faster response times
- Higher capacity (more devices can be connected concurrently and instantaneously)
- Better connectivity irrespective of the geographic region
- Higher reliability of communication
- More efficient (Lower cost of infrastructural development and lower energy consumption)

Railway solution – The use of 5G to provide an infinite data channel between the passenger and the rail company

It is proposed to use 5G to provide a secure, reliable, high speed data channel across the rail network.

Potential benefits

- Deliver very high download and upload data rates, enabling a high passenger density (e.g. in a train carriage) to simultaneously stream data intensive content such as films.
- Enable multiple systems, sensors and actuators within the rail infrastructure to be connected to the internet (the Internet of Things) e.g. train seats, carriage doors, etc.
- Provide the rail company with the opportunity to collect additional passenger data e.g. location
- Enable the rail company to provide real time journey data to the passengers

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- Can a standard for 5G be approved and when will it be implemented?
- How well will 5G handle the specific challenges of the rail industry given above?
- Will the claimed benefits of 5G be realised?

Solution readiness

While the technical feasibility of 5G has already been demonstrated, the timescale for any introduction is less clear. The current 4G standard is still being rolled out and the coverage is improving. The network providers have made a very large investment in 4G and will be looking for a return on this investment. The move to 5G will require a substantial new investment, both by the network providers and the handset producers. It is likely then that business factors, rather than technical difficulties, will dictate when 5G will be widely available.

2.7.13 BROADER TRANSMISSION METHODS – THE INTERNET OF THINGS

Operating principle

The Internet of Things (IoT) is the network of physical objects—devices, vehicles, buildings and other items—embedded with electronics, software, sensors, and network connectivity that enables these objects to collect and exchange data. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems.

A thing, in the Internet of Things, can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tyre pressure is low – or any other natural or man-made object that can be assigned an IP address. Figure 34 shows a range of industrial and consumer devices connecting to the internet, enabling the use of big data analytics as described in section 2.7.10.

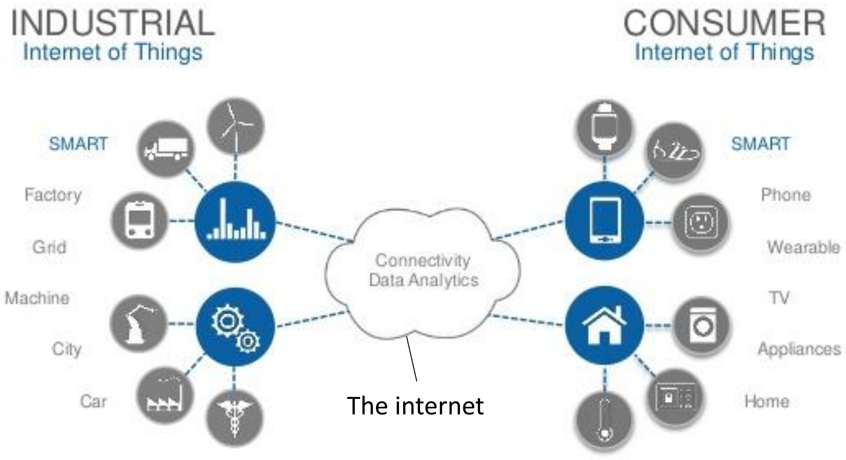


Figure 34: Industrial and consumer internet of things **[42]**

Railway solution

It is proposed to assign IP addresses to every seat on a train. The seat has sensing to detect the presence of a passenger and the means to identify the passenger using the seat or the passenger's device – using technologies described in section 2.7.7. This information is made available to the central railway server.

Potential benefits

- Increased information on seat utilisation for the rail company
- Improved fraud detection
- Ability to inform passenger of seat availability on the train
- Opportunity to take payment at the seat

Secondary considerations and research questions

There are a number of secondary considerations and research questions related to this solution:

- How is connectivity between the seat and central server assured?
- How will the passenger's potential privacy concerns be addressed?
- How will the sensing systems be made robust to possible misuse?

Solution readiness:

The new fleet of IEP trains being produced by Hitachi will have dynamic seat reservation functionality, connected to a central rail server **[43]**. This facility allows the seat status to be updated as the train journey progresses and could be developed to support the solution described above.

2.8 STEP 6: SOLUTION SELECTION

2.8.1 TECHNOLOGY AND SOLUTION EVALUATION

The technologies and solutions described in section 2.7 were reviewed against the evaluation criteria listed in the original project horizon scanning statement in section 2.3.5. Table 5 shows the evaluation matrix used to review each of the technologies and solutions against the screening criteria.

	1. Improve customer experience	2. Minimise ticketing infrastructure	3. Maximum revenue protection	4. Minimise cost (capital and on-going)	5. Minimal passenger delay	6. Maintain customer privacy	7. Accessible for all	8. Potential to generate additional revenue	9. Maximise information available to customer	10. Minimise journey preparation	11. User friendliness / simplicity
Encryption to protect payment data and prevent fraud	N/A	🟧	🟨	🟧	N/A	🟨	N/A	N/A	N/A	N/A	N/A
Railway digital currency	🟨	N/A	🟨	N/A	N/A	🟩	N/A	🟨	N/A	N/A	🟧
Biometric identification for rail system access	🟨	🟨	🟨	🟧	🟨	🟧	🟨	N/A	N/A	🟨	🟨
Digital signature to identify sender's device	🟨	🟨	🟨	🟨	🟨	🟩	🟧	N/A	N/A	N/A	🟨
UHF RFID to communicate device identity	🟨	🟨	🟨	🟧	🟨	N/A	🟧	N/A	N/A	🟨	🟨
Dynamic QR codes for digital identification and tracking	🟧	🟧	🟧	🟨	🟧	🟨	🟧	N/A	🟨	🟨	🟨
Audio signal transmission for digital identification	🟨	🟨	🟨	🟨	🟨	🟨	🟧	N/A	N/A	🟨	🟨
Personal device to display augmented reality	🟨	N/A	N/A	🟨	🟨	N/A	🟧	🟨	🟩	🟨	🟨
Interactive displays and projection for AR overlay	🟨	N/A	N/A	🟧	🟨	N/A	🟨	🟨	🟨	🟨	🟨
Directed parametric sound	🟨	N/A	N/A	🟧	🟨	N/A	🟨	🟨	🟨	🟨	🟨
Big data analytics to minimise ticket fraud	N/A	🟨	🟨	🟧	🟧	🟧	N/A	🟨	N/A	N/A	N/A
Big data analytics to optimise profit	N/A	N/A	N/A	🟧	🟧	🟧	N/A	🟨	N/A	🟨	N/A
Camera location with RFID	🟨	🟨	🟨	🟧	🟨	🟧	🟧	N/A	N/A	🟨	🟨
LiFi to provide an infinite data channel	🟨	N/A	N/A	🟧	N/A	N/A	N/A	🟨	🟨	N/A	N/A
5G to provide an infinite data channel	🟨	N/A	N/A	🟨	N/A	N/A	N/A	🟧	🟨	N/A	N/A
IP address for every train seat	🟨	🟨	🟨	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨

Potential shortfall	🟧
Likely to fit brief	🟨
Proven to fit brief	🟩

Table 5: Evaluation matrix and colour code key for ticketing technologies and solutions

The purpose of this evaluation is to provide a first-pass indication of the suitability of each option to satisfy the criteria defining a satisfactory step-free access solution. At this stage in the study it is common for the options presented to offer “partial solutions” to the overall requirement and it is therefore important to understand their potential strengths and weaknesses. This analysis can then be used to provide a framework to highlight potentially strong solutions created from combinations of the options presented.

While many of the solutions listed offer the chance to improve the customer’s experience, reduce ticketing infrastructure and increase revenue protection, many of the options require additional capital investment. Some of the solutions offer additional benefits in terms of increased revenue generation and improved operational efficiency which could be used to justify this cost.

As the rail industry gets better at passenger identification, rail users may become more worried about protecting their privacy. Two technology areas which might cause particular concern for passengers are biometric identification and big data analytics. Even though passenger data can be kept secure and anonymous, the issue of public perception may be harder to address. One potential solution to this conflict is to make use of an intermediary such as a portable device (e.g. through secure digital signature).

Not all rail users will want to carry personal devices so rail companies will need to offer additional non-device-based solutions (e.g. biometric identification or printed QR codes). The implication of this is that rail companies will need to provide multiple methods to prove identity and payment.

Due to the broad scope of the technology areas discussed in this report, and the need for multiple solutions, it is impractical (and would be misleading) to present a shortlist of the most promising solutions. A key aim of this document is to stimulate further discussion in the rail industry on future travel payment, authorisation and information sharing methods.

2.9 CONCLUSIONS

It might be tempting, when considering future ticketing technologies, to re-create the existing paper-based system in electronic format. Exploiting some of the new technologies listed in this report could offer far greater benefits than simply replacing current ticketing systems with their electronic equivalent.

A key finding of this study is that the rail ticket is an information system, providing data to the rail company and to the passenger. A measure of effectiveness for any information system is the rate of data exchange. Many of the solutions listed in this report support far higher levels of data transfer than is currently possible. This increased richness of data will mean that the rail company can build a much better understanding of passenger behaviour and system utilisation while providing the passenger with greatly enhanced information and services.

As the amount and quality of information exchange increases, the core “revenue protection” function of the ticketing system can also be enhanced, however, it is likely that security and privacy will become far greater concerns. Technologies such as encryption and digital signature will be crucial to the smooth operation of the rail industry.

Having completed this study, it is clear that the technology areas covered are broad and experiencing rapid change. Depending on input from the rail industry, many of these areas might require further research.

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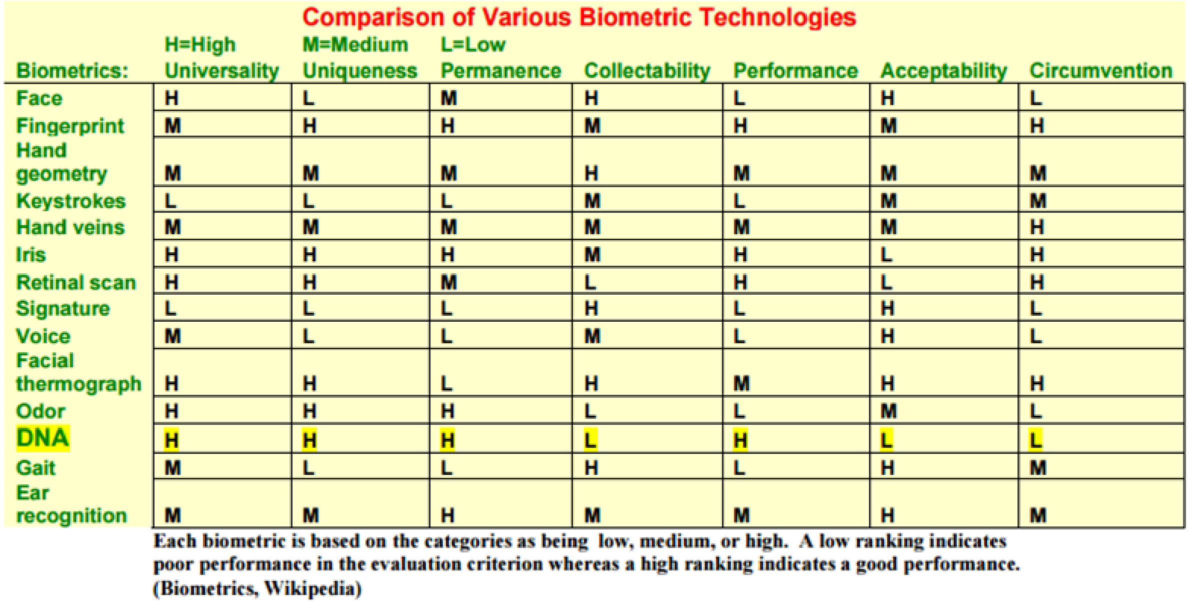
4. APPENDICES

1. Comparison of various biometric technologies

Source: https://danishbiometrics.files.wordpress.com/2009/08/nst.pdf



Comparison of Various Biometric Technologies

H=High M=Medium L=Low

Biometrics:	Universality	Uniqueness	Permanence	Collectability	Performance	Acceptability	Circumvention
Face	H	L	M	H	L	H	L
Fingerprint	M	H	H	M	H	M	H
Hand geometry	M	M	M	H	M	M	M
Keystrokes	L	L	L	M	L	M	M
Hand veins	M	M	M	M	M	M	H
Iris	H	H	H	M	H	L	H
Retinal scan	H	H	M	L	H	L	H
Signature	L	L	L	H	L	H	L
Voice	M	L	L	M	L	H	L
Facial thermograph	H	H	L	H	M	H	H
Odor	H	H	H	L	L	M	L
DNA	H	H	H	L	H	L	L
Gait	M	L	L	H	L	H	M
Ear recognition	M	M	H	M	M	H	M

Each biometric is based on the categories as being low, medium, or high. A low ranking indicates poor performance in the evaluation criterion whereas a high ranking indicates a good performance. (Biometrics, Wikipedia)