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Condition Monitoring for Airport Baggage Handling in the Area of Industry 4.0

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Abstract

Purpose: The findings of a recent study are presented, which was conducted with the objective of addressing the problem of the failure of baggage carts within the high-speed baggage tunnel at Heathrow Terminal 5 through the development of an innovative condition-based maintenance system designed to meet the requirements of 21st century airport systems and Industry 4.0.

Methodology: An empirical experimental approach to this action research was taken to install a vibration condition monitoring pilot test in the north tunnel at Terminal 5. Vibration data were collected over a 6-month period and analysed to determine the threshold for good quality tyres and those with worn bearings that needed replacing. The results were compared with existing measures to demonstrate that vibration monitoring could be used as a predictive model for condition-based maintenance.

Findings: The findings demonstrated a clear trend of increasing vibration velocity with age, with the wheel mass unbalanced inertia of the carts being transmitted to the tracks as vibration. This research demonstrates that a healthy wheel produces a vibration of less than 60mm/s whereas a damaged wheel measures up to 100 mm/s peak to peak velocity, which can be used in real-time condition monitoring to prevent baggage cart failure. It can also run as an autonomous system linked to AI and Industry 4.0 airport logic.

Originality/Value: Whilst vibration monitoring has been used to measure movement in static structures, such as bridges, and in rotating machinery, such as railway wheels (Tondon and Choudhury, 1999) this application is unique as it is the first time vibration monitoring has been applied to a stationary structure (tracks) carrying high-speed rotating machinery (baggage cart wheels). This technique has been patented and proven in the pilot study and is in the process of being rolled out across all Heathrow terminal connection tunnels. It has implications for all other airports world-wide, and also to other applications that rely on moving conveyor belts.

Keywords: Condition Monitoring, Time-based Maintenance, High-speed DCV systems.

Introduction

Competition between airports throughout Europe, including the UK, is increasing, with approximately 63% of the population residing within two hours travelling time of two airports. Effective baggage handling therefore contributes to customer choices (Bracaglia et al., 2014; Wiltshire, 2013).

Increases in baggage volumes are leading airports to invest in new and faster baggage handling technology in order to maintain revenues, as their operations and maintenance (O&M) management are being challenged more than ever to reduce costs and the risk of system breakdown. (Scholing, 2014; Luther, 2007).

However, baggage handling has often been overlooked at capital airports, despite passengers' needs. This applies to London Heathrow, which developed from a single runway, one terminal business with several hundred employees in the 1950s to multiple terminals and runways with several tens of thousands of employees today.

Passengers' expectations are simple: they want to check in as quickly as possible with their bags, then at their destination to be speedily reunited with their undamaged bags. After check-in luggage disappears behind a wall, and if everything works correctly it reappears on a reclaim arrival carousel at the destination airport. Effective, economical baggage handling is therefore critically important, but failure of just one component within the system can shut down the whole facility for many hours. This can cause thousands of bags to miss flights, causing significant inconvenience and a negative financial impact, not just for the passengers, but all those affected, especially airports, airlines and their stakeholders

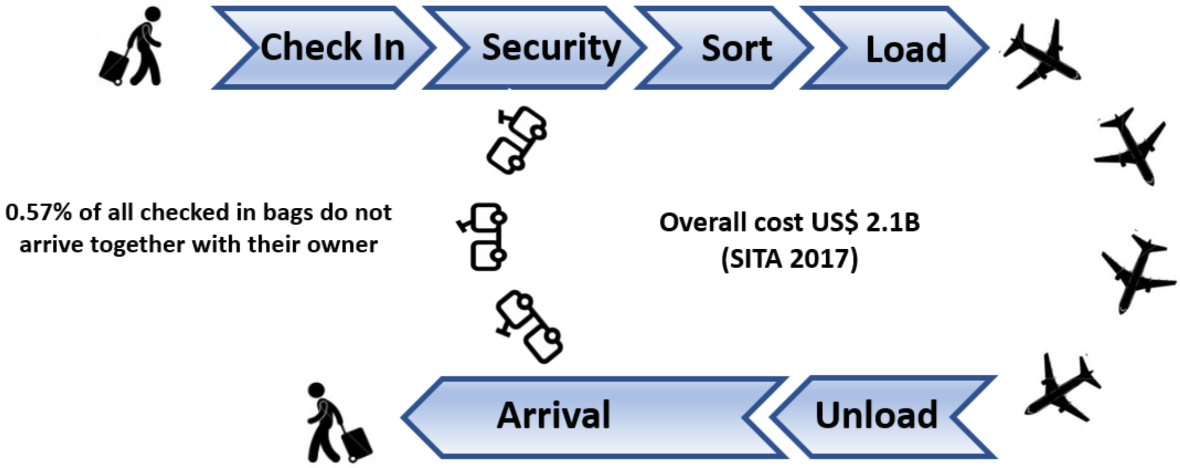


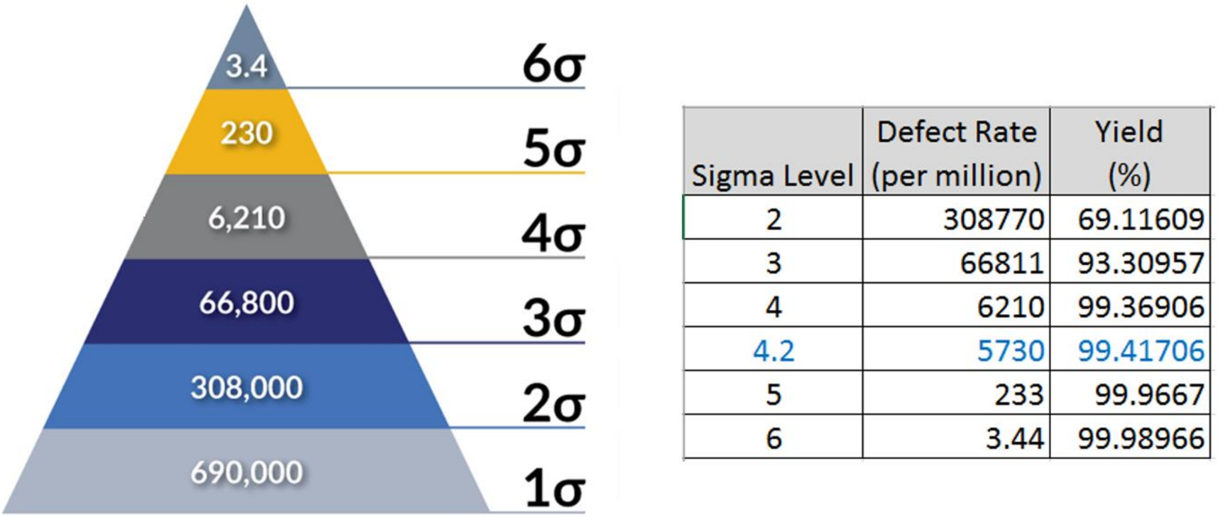
Figure 1: The baggage handling cycle

The worst ongoing weakest link involves baggage handling for passengers transferring from one aircraft to another. In 2016, 47% of delayed bags occurred between connecting flights, especially when there was a tight time frame. The purpose of this document is to present the findings of a recent study which had the objective of addressing the problem of baggage cart failures within the high-speed baggage tunnel at Heathrow Terminal 5, through the development of an innovative condition-based maintenance system designed to meet 21st century airport systems and Industry 4.0 requirements.

Mishandled Baggage at Major Airports

Costs associated with the extra handling of bags that miss flights needs to be avoided. SITA has been tracking baggage mishandling statistics for the last 10 years, including all bags reported delayed and/or damaged by airlines and/or their handling companies. Over this time passenger volume has increased by more than 1.41 billion, leading to additional pressure on airport baggage handling systems (SITA 2016).

Heinz and Pitfield (2011) noted that investment to improve the reliability of baggage handling systems in the last decade has resulted in a reduction in baggage mishandling rates by over 60%, from a peak in 2007 of 19 bags per thousand passengers. It is obvious that investment in baggage handling system automation, processes and maintenance has already made a significant difference to the reliability of baggage handling systems (Heinz & Pitfield 2011). However, the industrial average remains (Sigma 4), meaning that there is the potential for improvements to be made within the baggage handling process.



Sigma Level	Defect Rate (per million)	Yield (%)
2	308770	69.11609
3	66811	93.30957
4	6210	99.36906
4.2	5730	99.41706
5	233	99.9667
6	3.44	99.98966

Figure 2: Six sigma diagram for the baggage handling process
(Pyzdek & Keller 2010)

Instances of airlines mishandling baggage reached an all-time low in 2017. According to SITA's Baggage Report 2017, 5.73 bags per thousand passengers went astray in 2016, a 12.25% drop compared to the previous year and a 70% reduction over the past decade. This is despite the fact that the global passenger volume reached a record level of 3.77 billion in 2016 (Sita 2017). SITA reported a cost of US$ 2.1 billion to the aviation industry in 2016 for recovering and returning lost bags.

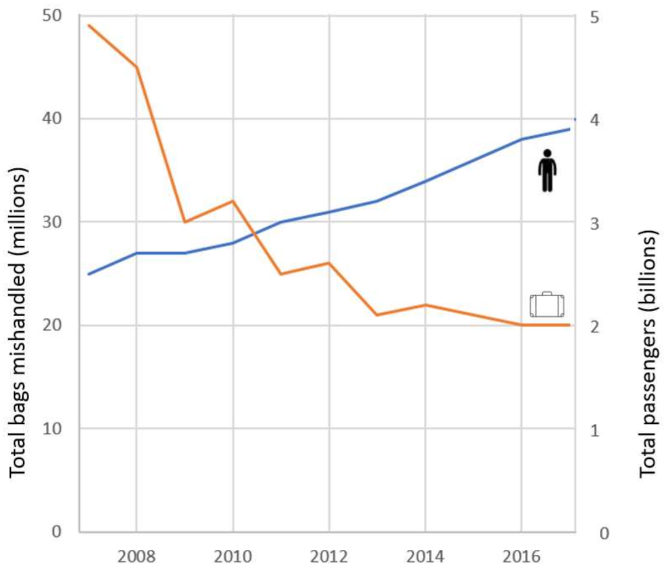


Figure 3: Numbers of 'total bags mishandled' and 'total passengers' since 2007
Source: SITA 2016

Role for GPS / RFID tracking in helping to find lost bags

Thousands of bags are stranded at airports due to inefficient baggage handling systems that regularly break down. Often, airlines and passengers do not know where lost bags are located; they could be stranded in the baggage handling system at the departure airport, possibly in a protection net outside the conveyor line, or alternatively, they could have been accidently placed on flights to destinations different from where their owners will arrive. In some instances they are never found at all (IATA Baggage Services 2016).

Airport staff at intended destinations of the bags cannot confidently answer questions about where a missing piece of baggage might be. Whatever the scenario, re-uniting lost bags with their owners is labour intensive, and thus time consuming and expensive. Currently, about four out of every thousand bags are not reunited with their owners at the intended destination, leading to angry passengers naturally making demands on airline staff. Ironically, there are many tracking and labelling techniques available, such as those regularly used by parcel services, and this has helped lead to a new resolution: IATA 753 (IATA Baggage Services 2016).

From June 1st, 2018 airlines must be able to track baggage at the following points:

- Passenger handover to airline
- Loading to the aircraft
- Delivery to the transfer area
- Return to the passenger

Resolution IATA 753 was approved by the Joint Passenger Service Conference (JPSC) in 2013 thereby enabling sufficient time for implementation. It is intended to encourage airlines to reduce mishandling by implementing cross-industry tracking for every baggage journey, so that when a bag does not arrive with a passenger there will be much more information available to facilitate recovery. However, it is important to note that Resolution 753 will not solve broader issues and problems with baggage handling systems, as covered in this paper, which are concerned with establishing complimentary predictive maintenance technology to also help avoid bags being mishandled.

The role for GPS tracking technology will be to enable passengers to receive real-time updates on the whereabouts of their lost bags (Mishra & Mishra 2010). Self-service kiosks and even smartphone applications will allow passengers to report losses and receive notifications on the progress of their report.

Maintenance of Baggage Handling Systems

At present, capital airports' maintenance is based on time-based/preventative and run-to-failure maintenance strategies. To reach the target of zero unplanned downtime the maintenance strategy for the baggage handling system needs to change.

Maintenance is a logistical and operational function for achieving the availability of resources to ensure the quality of output. Its performance efficiency and effectiveness are difficult to measure in absolute terms, so this has to be defined and measured in relative terms of economic, technical or organisational ratios (Muchiri et al. 2011). In general, maintenance is described as preventative or predictive maintenance regimes.

Preventive Maintenance (PM), also known as time-based maintenance, was introduced in the 1950s, and a common definition in the literature is: 'The care and servicing by personnel for the purpose of maintaining equipment in satisfactory operating condition by providing for systematic inspection, detection and correction of incipient failures either before they occur or before they develop into major defects' (Ahmad & Kamaruddin 2012). The main aim of PM is to follow planned guidelines to avoid breakdown or malfunction, and its strategy relies on estimated probabilities that equipment will break down. This is known as 'Mean Time Between Failures' (MBTF), and is a measure of how reliable a hardware component is (Engelhardt & Bain 1986). Typical PM work includes inspection for wear, cleaning, lubrication, parts replacement and re-adjustment, undertaken routinely to prevent breakdown. PM consists of planned or scheduled maintenance conducted after specific periods of time and machine usage (Duffuaa & Ben-Daya 2009). PM has been adopted by some airports as a first countermeasure to reduce the likelihood of breakdowns (Holloway and Nwaoha 2012; Campbell and Reyes-Picknell, 2016).

Predictive Maintenance (PdM) is also known as condition-based maintenance, and is designed to determine the condition of equipment whilst it is working. By observing working equipment, accurate, timely information can be acquired on its condition and performance, enabling equally accurate knowledge and decisions to predict when maintenance should be scheduled (Mobley 2002).

PdM therefore brings cost savings over PM because its requirement are based on actuality, rather than estimates of condition and performance (Tickoo et al. 2010), and consequently, PdM requires less spare parts to be held. In PdM the diagnostic techniques used to measure condition are temperature, noise, vibration, lubrication monitoring. When indicators reach a predetermined deterioration level, maintenance is undertaken to bring the equipment back to the desired condition, which means that equipment is only taken out of service when evidence exists that deterioration has occurred. PdM is based on the same principles as PM, but involves a different standard for determining requirements for specific maintenance services. The advantage of PdM emanates from the fact that maintenance is scheduled when needed (Hashemian and Bean 2011).

A better way to avoid breakdowns is a maintenance strategy that monitors the condition of a machine or device in use, in order that its remaining life can be estimated. This is called condition monitoring or diagnostic engineering management. Researchers have noted considerable evidence that PdM provides economic advantages in most industries, and is the best available strategy for preventing unexpected system downtime (Rao 1996; Randall 2010; Carden 2004). The most common methods utilised in PdM are infrared, lubricant or vibration condition based monitoring. This paper focuses on vibration theory (Blake, 1988) and 'vibration condition monitoring' to meet the requirements of next generation, or Airport 4.0 opportunities.

Methodology

Technical action research methodology was selected as 'an approach in which the action researcher and stakeholders collaborate in analysis of the problem and in development of a solution based on the diagnosis.' (Avison et al., 1999; Coughlan & Coghlan, 2002; Wieringa 2014). It was selected because it is known to be a strong method to assist in rapid problem-solving.

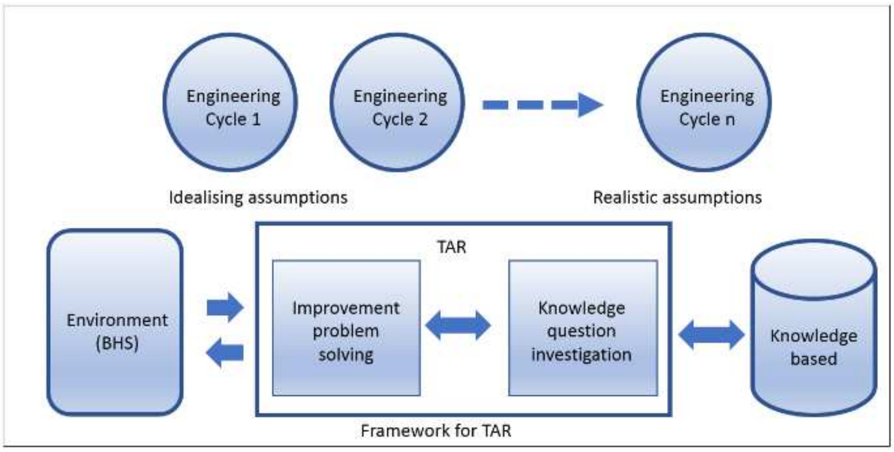


Figure 4: The technical action research cycle
(Trist 1980)

One of the authors negotiated a role as a facilitator between Heathrow as the practitioner and Siemens as the technical solution provider. Airport baggage handling system are huge technical systems and so socio-technical systems theory was applied (Baxter & Sommerville 2011). This research technique has a high level of practical relevance and can be used with quantitative and qualitative data, enabling in-depth knowledge about baggage handling assets, their technology and potential issues to be understood. However, the solutions proposed are novel and untested and must be accepted by stakeholders prior to implementation.

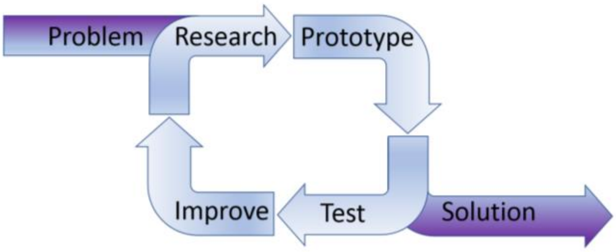


Figure 5: The engineering cycle

It is common for new developments to run through the engineering cycle several times (Life Cycle Engineering 2015), and this starts with the identification of the problem followed by research. Testing refers to planning and carrying out investigations, then analysing and interpreting the data generated. Depending on the results a solution is deemed either to be satisfactory or to require further improvement. Any further improvements again require analysis and the interpretation of data, followed by research, prototyping and testing. The engineering cycle ends with a solution that yields satisfactory test results (Life Cycle Engineering 2015).

As this system is the first of its type, the concept itself needs to be proven. An empirical experimental approach was taken to install a vibration condition monitoring pilot test in the north tunnel at Terminal 5. This tunnel contains high speed conveyors that are operational 18 hours per day and are capable of running at 14m/s with a second slow running line that runs at 2m/s. At 14m/s the speed is too fast for radio frequency identification detection (RFID), so a new innovative solution was required to identify the carts passing the station. Two vibration sensors, one for each track, were mounted on the fast rail and vibration measurements were captured and sent to a server. A pair of photo sensors were also installed facing the passing carts; one to read a binary identity-code strip so the vibration sensor analysis can be matched to a specific cart, and the other to read 17 alternating bits used to trigger the binary code reading of the code strip. The sensors were connected to the server via an input module.

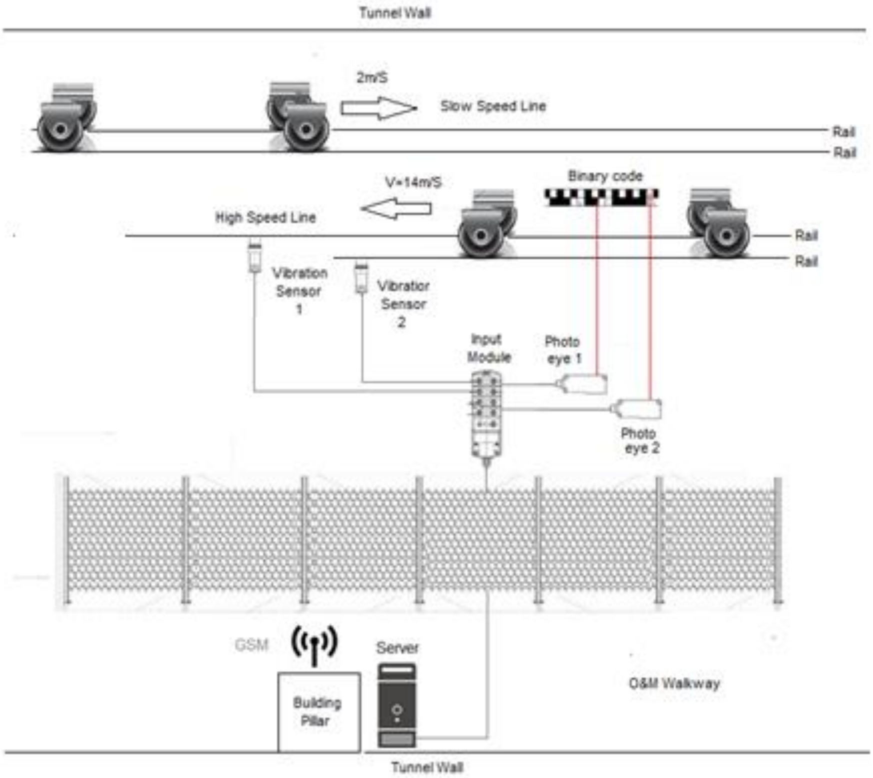


Figure 6: Diagrammatic representation of the pilot study

Data were collected over a period of six months, and 3.5 million vibration measurements were analysed to determine the threshold vibration peak-to-peak velocity. The data were used to track the wear of wheels over time and to determine which wheels needed replacing. The results were compared with existing measures to demonstrate that vibration monitoring could be used as a predictive model for PdM.

The first step in this research was to design, build and install a vibration measuring system on the high-speed system in Heathrow's north tunnel. The aim was to determine whether measuring the vibration generated by the wheels of passing carts is sufficient to distinguish between carts which were useable and those which were close to the end of their useful life. The next step was the detection of a cart specific binary code and to link the vibration data to specific carts, concurrent with the development of a database containing all the cart specific vibration data. The aim of this step was to determine whether the measured data was consistent and plausible. Overall, the research aimed to provide O&M with a system that identified the order in which carts should be serviced.

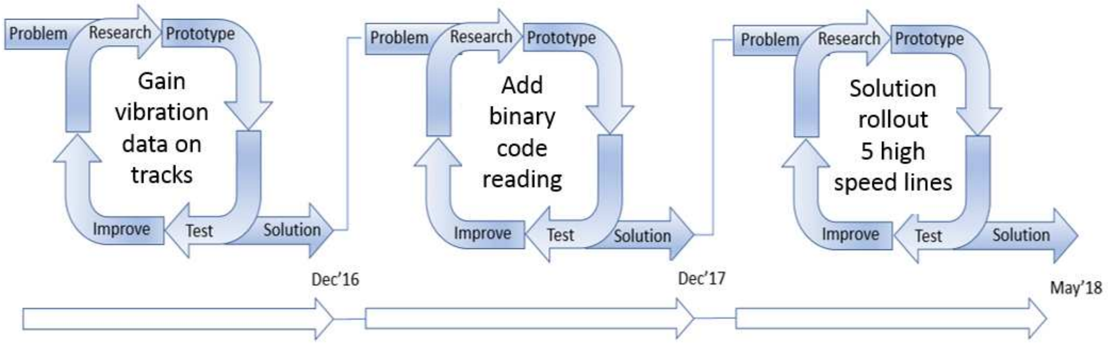


Figure 7: The planned engineering cycles

A review of the literature will conclude with modern maintenance strategies such as PdM of structures and rotating machinery. As the majority of airport baggage handling systems are still maintained with time based or run to break legacy strategies, the motivation of airports to investigate modern maintenance methods, will be described, driven by their escalating costs for mishandled luggage. Finally, a case study is presented of Heathrow's direct coded vehicles (DCV) baggage handling system, covering failure analysis, solution findings and planned implementation.

Vibration monitoring

During the 1970s and 1980s the oil industry made considerable efforts to develop vibration damage detection methods for offshore platforms (Fujino 2002), and the technique proved useful for other building structures. Vibration damage detection aims to identify the exact location of any structural damage, and further development of structural vibration monitoring occurred during the development of missile technology. However, structural health monitoring problems are fundamentally different from those experienced by rotating machinery (Farrar & Worden 2007; Fan & Qiao 2010; Gentile & Gallino 2008).

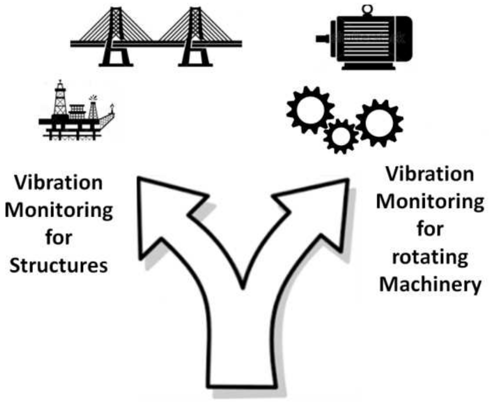


Figure 8: The two major paths of vibration condition base monitoring
(Basu 2005; Fugate et al. 2001)

The problem that was reported at Heathrow was unpredictable breakdowns, whereby the wheels of the direct coded vehicles (DCV) became blocked, causing a mass derailment of carts within the connection tunnels. The solution is based on vibration sensors called accelometers, which were placed on the track to measure the vibration generated by the wheels of passing carts. A problem was observed during operations concerning a minority of carts that passed with symptoms of wheel mass centreline issues, and the O&M provider removed these carts from service for wheel replacement.

There are two well developed vibration monitoring methods; structural vibration measurement and stationary vibration measurement (Tondon & Choudhury 1999).

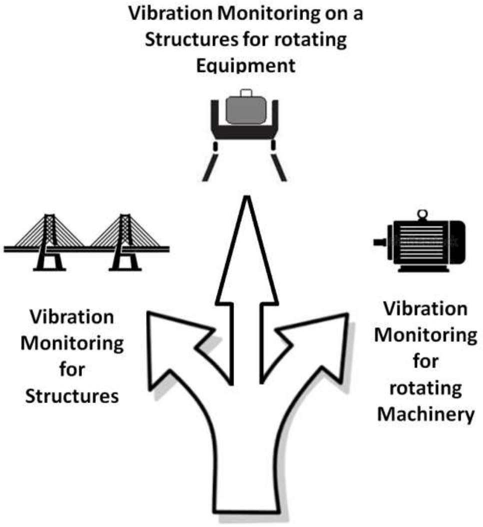


Figure 9: Vibration condition based monitoring for structures passing rotating machinery

Structural vibration monitoring was first used during the development of missile technology and was intended to enable the identification of the exact location of structural damage (Basu 2005).A third and new approach uses techniques from structural and rotating vibration monitoring methods, and until now no report of this new patented innovation has been published.

Baggage Handling Systems

Failure in a baggage handling system can be divided into 'avoidable' and 'non-avoidable'. Non-avoidable failures are those that occur on a daily basis, with the most common being bag jams when baggage is caught on side guards or belts. Given the nature of the current systems and the huge variation among bags, such failure is common, and airports simply live with this failure and have staff available to clear the problems as quickly as possible.

Supervisory Control and Data Acquisition (SCADA) systems are commonly used in airports for condition and status monitoring of baggage handling systems (Bailey & Wright 2003). SCADA enables 'daily non-avoidable' problems to be shown via a visualisation system, making it part of the daily routine to manage failures, and minor problems are cleared in minutes. Baggage handling systems are continually monitored by SCADA operators in control rooms, from where they communicate failures to the field maintenance technicians. However, component failures caused by wear cannot necessarily be fixed in minutes and cannot therefore be considered to be minor problems. Consequently, airports need to anticipate, target and avoid component failure that might require several hours of repair and unexpected downtime.

The most common strategy to avoid component failure is PdM, and while there is no direct evidence, there are indicators that Heathrow's O&M provider does not follow the maintenance plan. Avoidance of fatal component failure has led Heathrow to question this maintenance strategy.

Common vibration condition monitoring

The most common PdM applications are based on sensors connected to a variety of computer hardware, and these solutions have been used for rotating machines for several decades. More complex machine PdM applications have been custom designed, as standard software solutions were not available (Alvandi & Cremona 2006). The disadvantage for such custom engineered and developed solutions is their high costs, and for most industrial processes such solutions were too expensive. For decades, only NASA, the aviation and oil rig industries have investigated more complex PdM solutions to their problems. Another issue that caused several projects to fail was the non-availability of sufficient processor speeds (Brandt 2011).

New generation vibration condition monitoring

The trend in PdM may lead to standard solutions, with wireless sensors communicating via a modem to central host systems (cloud solutions), with data from many users hosted on a remote server. While the first versions of the associated standard software are planned or already available, this new version needs a lot of development, although the advantage already established is that installation costs are very low and local server hardware is unnecessary (Mackensen et al. 2012). The Bluetooth sensor technique has some technical limitations and cannot be used for all applications, meaning that research is needed if this new technique is to solve the 'return of investment' issue that halted many PdM projects in the past.

London Heathrow and Siemens have funded research on high-speed DCV baggage handling systems, together with three 'low cost' PdM studies for baggage hoists, arrival reclaim carousels, and straight conveyors, as part of Airport 4.0 studies.

The biggest problem identified lies with the DCV system, where there is a high risk that the baggage handling of an entire terminal might come to a standstill. Motivation at Heathrow to change the maintenance processes for DCV carts from PM to PdM is very high, whereas for the baggage hoists, reclaim carousels, and straight conveyors, the pressure to implement PdM is not as high as for the DCV system. However, research to determine a cost-effective PdM solution for these three applications is required.

Predictive Maintenance of Direct Coded Vehicle Systems

The DCV system in Terminal 5 began operation in 2008; as in many other large airports, baggage is transported in carts on rails in order to quickly cover long distances. The design is similar to that of a rollercoaster, with individual carts on wheels running on tracks, each cart being boosted along the rails via a succession of magnetic linear motors positioned at various locations along and beneath the tracks (Heinz & Pitfield 2011).

For years, maintenance departments at Heathrow received little executive attention. When the existing system was relatively new and stable, O&M professionals followed the manufacturer's recommendations on how to maintain it. However, after extensive use, system downtime incidents increased and the maintenance strategy was questioned. The life cycle of the baggage handling system at Heathrow can be described by a 'bathtub' graph (Denson 1998): it commenced with a phase called 'burn-in', followed by the useful-life phase, where the frequency of failure is reduced, and then as components reach their end of life through wear and tear, such systems enter a wear-out period where the failure rate begins to rise (Romeu 2003).

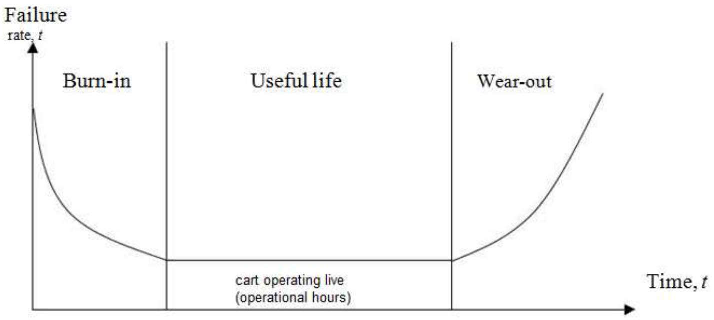


Figure 10: Bathtub Diagram System operating lifecycle curve
(Adapted from Denson, 1998)

It is important to detect wear in the very early stages, thereby providing sufficient time to make the appropriate maintenance decisions before failure occurs, rather than detecting it when systems are in the 'useful-life' or 'wear-out' period. Linear motors, metal rails and carts are not greatly impacted by wear and tear to the extent that the polyurethane treads of the wheels and wheel bearings are. Manufacturers recommend a wheel check every three years, but in practice, several carts are isolated to a rail siding for a visual check of their wheels and diameter. The wheels are typically spun by hand to listen for obvious sounds of bearing deterioration, and any obviously worn or defective wheels are replaced. Heathrow O&M reported that blocked wheel bearings were the primary cause of several system breakdowns that had occurred in recent years.

Depending on the location of a cart failure, this can become a major incident. Most carts in Terminal 5 have wheels within their useful-life phase, a minority have been overhauled and have new bearings or wheels at the beginning of their operational life, but some carts possess parts close to the end of life. Over time, more and more carts will have bearings and/or treads that are approaching their end of life; therefore it is reasonable to conclude that the risk for breakdowns is increasing.

Where to measure vibration?

This research started with a site survey of Heathrow's baggage system, where it was observed that DCV carts ran smoothly on lines that operated slowly (0.5 to 2.5 m/s) but their behaviour at high speed was different; some carts ran smoothly, others generated some noise, and a few generated loud oscillating thuds. These observations led to the question why there were so many differences in the noise generated and why the differences were so drastic on the high-speed lines.

Literature about mass centreline interia revealed that good quality research had been conducted in the automobile industry, and the reason for the differences in generated noise became obvious, as a centrifugal force created by conditions of inbalance increases by the square of the rotation speed of the wheel rpm. Therefore, if the speed of the cart is doubled, the force quadruples, and if the speed is tripled then the force increases by a factor of nine. An equation for estimating this force is:

$$Cf = m \times \left(\frac{rpm}{1000}\right)^2$$

m (Mass)
rpm (Rotation per Minute)

While this has been reported for automobile tyres, it nevertheless provides a good explanation of the observations made at Heathrow. At 14 m/s, the speed in the tunnel line is over 10 m/s greater than on other lines in the system. Cnsequently, the exponential contribution of the centrifugal force created by a wheel inbalance, causes cart parts to fail. This force is extremely high, causing a dramatic shortening of the useful life of the bearings .(Goodwin et al. 2003)

The example for a centrifugal force (Cf) caused by 0.03g -in of inbalance at various speeds is very interesting, and clearly shows the impact of inbalance (Gough & Whitehall 1962). As the centrifugal force increases exponentially on high-speed lines, the vibration transmitted to the tracks during the high-speed section and its intensity varies greatly, depending on the condition of the wheels on the cart.

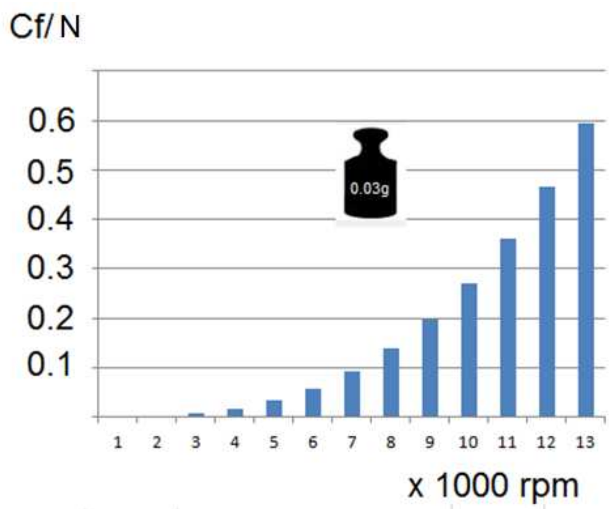
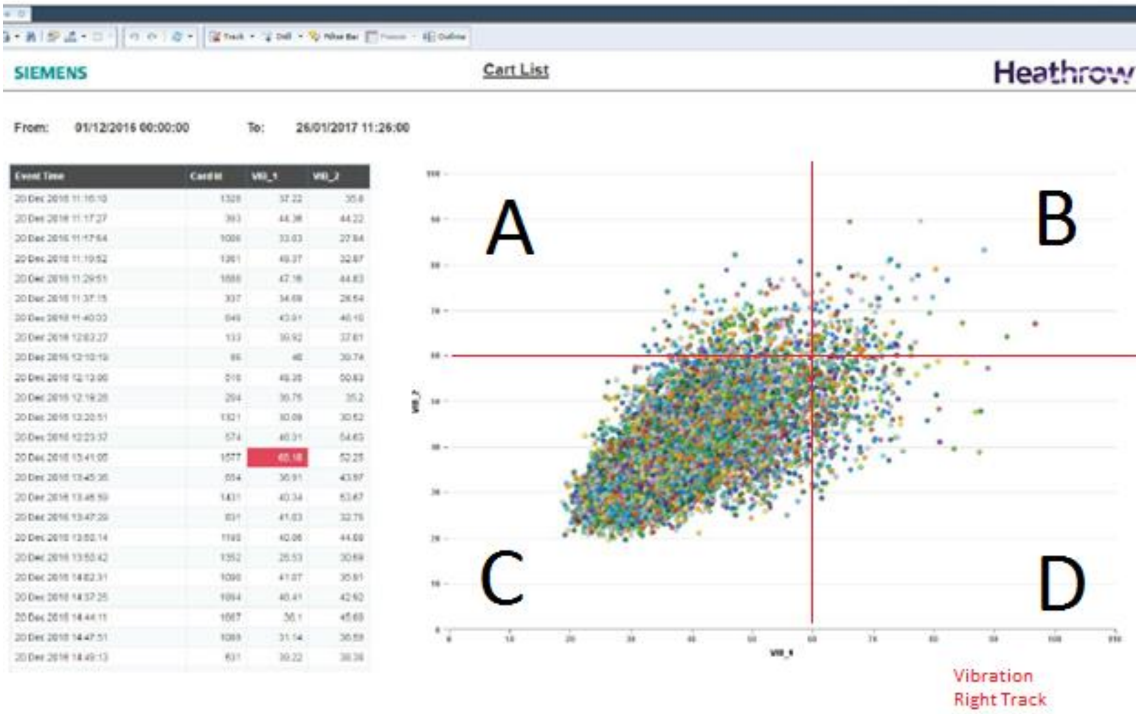


Figure 11: Centrifugal force (Cf) in a car tyre caused by a 0.03g -in inbalance at various speeds

Results

A controlled test was conducted and data from passing carts were collected over a three week period. The data was used to create a dart diagram, as shown in Figure 12. An analysis of this diagram indicates the following:

- Lowest produced vibration was about 20 mm/s
- Highest vibration measured was close to 100 mm/s
- Carts in useful life generate vibrations under 60 mm/s (quarter: C)
- Carts close to end-of-life generate vibration over 60 mm/s are (quarters: A,B, D)



From: 01/12/2016 00:00:00 To: 26/01/2017 11:26:00

Figure 12: Vibration data dart diagram

Data validation using standard deviation

The dartboard diagram was useful and could be used to develop hypotheses. For example, measurements of right and left track vibration might indicate a cart close to its end-of-life as this would produce greater vibration than a cart with new wheels.

To support such hypotheses, the data used to generate the dart diagram was also used to generate Figure 13, which enabled the hypothesis that carts producing a vibration up to 60 mm/s are within their useful life and carts with over 60 mm/s are close to end-of-life. However, as Heathrow's baggage handling system is live, leaving carts with a vibration over 60 mm/s within the system was not appropriate, although it is not known how much remaining life there may be in a cart that has reached the 60 mm/s mark.

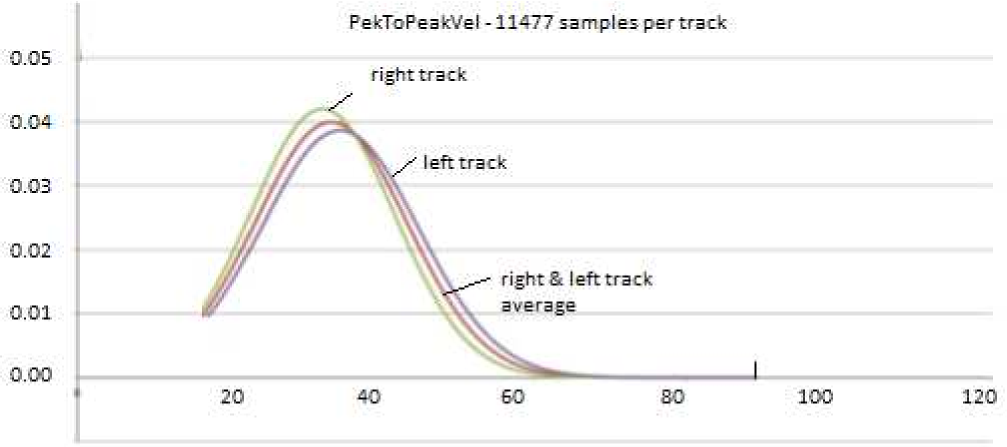


Figure 13: Standard deviation graph for 11477 samples

Repeatability and data validation

Data for single carts were analysed to determine whether the generated vibration data were reproducable. The data for several hundred carts were utilised and vibration over time was analysed. The results were found to be very similar and the data for a single cart, No. 1690, is used to explain the findings. Data for this cart was collected from 7th May 2017 for three weeks and 12 data points were recorded when the vibration was 70 mm/s (tolerance of plus/minus 5 mm/s), therefore it was assumed to be close to the end-of-life. It was taken out of service on 28th May 2017 and serviced, with all four wheels being replaced. Subsequently, it generated a vibration of 30 mm/s (tolerance of plus/minus 5 mm/s).

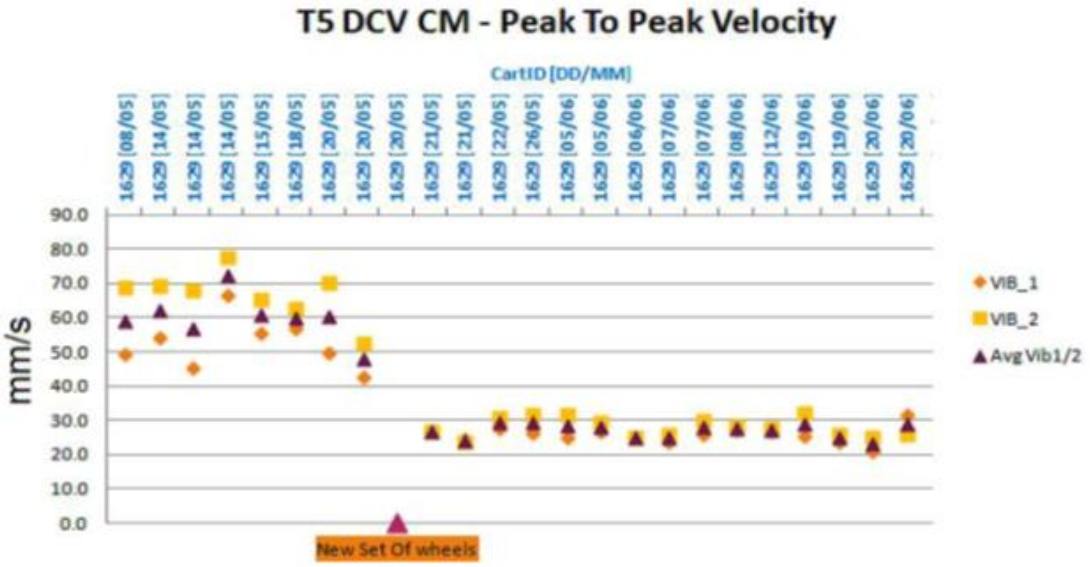


Figure 14: Vibration data for cart No. 1629 before and after service

This analysis enabled the following assumptions to be made:

- The vibration produced on the right track is always slightly higher compared to that on the left track
- Vibration signals vary for carts close to their end-of-life by plus/minus 10 mm/s
- Vibration signals vary for carts with a new set of wheels by less than plus/ minus 5 mm/s
- Carts with a new set of wheels generate a vibration of 28 mm/s

Explanation of tolerance and variations

There is a simple explanation for the variance in vibration noted. The carts have a triangular shape that causes loads to be unbalanced. Therefore for an average size bag the centre of gravity is not necessarily going to be in the centre of the cart. Weight also has an impact and explains the uncertainty of tolerances observed. Depending on the baggage weight, which can be up to 70 kg, the vibration generated for a cart can vary.

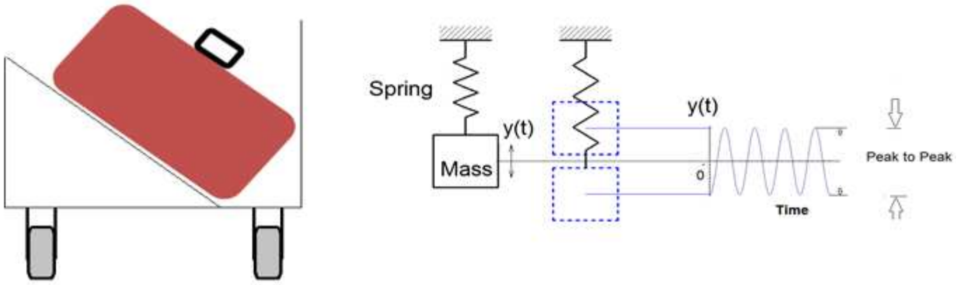


Figure 15: Triangular shape of a DCV cart and the mass spring system

Following Hooke's law, the equation for a mass spring system is:

$$L = \frac{m * g}{k}$$

Where L is elongation, m is mass, k is a constant, and g is a gravitational constant (Rychlewski 1984). Elongation (L) depends on the mass and the spring used. The mass is an influencing parameter, and the fact that DCV carts can be empty (40kg), contain an average loaded (60kg) or a maximum load (100kg), explains the variance in vibration velocity of cart No. 1629 of 22mm/s to 32mm/s.

Discussion

For the DCV system the findings demonstrate a clear trend of increasing vibration velocity with age and use of the baggage cart wheels. This vibration is caused by wheel mass unbalanced inertia, which is transmitted to the tracks as vibration. Figure 16 shows the vibration values of all the circulating carts in terminal 5; the Y-axis shows peak-to-peak velocity, whilst the X-axis shows cart numbers, from No. 1 to No. 2016.

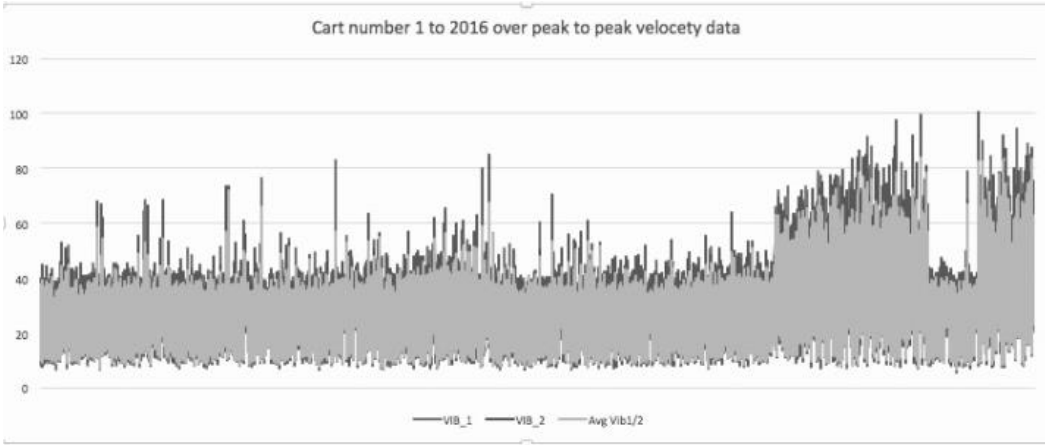


Figure 16: Peak-to-peak velocity of carts numbered 1 to 2016

Analysis of the results shows that at about 60 mm/s, the vibration of the cart wheels will be close to their end of life. However, outliers were found with vibration patterns over 80 mm/s, and two blocks of carts generated even higher vibration patterns; the first block started with cart No.1600 and the second block with No. 1950. Both blocks show a sudden increase from an average of 30 mm/s to an average of 55 mm/s, and these indicate the cart numbers where rolling maintenance had stopped under the previous O&M provider. The data either side of these blocks also provides interesting information, as the average vibration pattern is around 30 mm/s with several carts showing data up to 40 mm/s. These cart wheels are in their useful life phase; however, there are a few carts in these sections generating vibrations close to 60 mm/s that show as spikes within the data set where the average vibration was 30-40 mm/s. Consequently, this pilot study has been extended to detect carts where the vibration is close to 60 mm/s so that these can be withdrawn from service and the wheels replaced.

Conclusions

Capital airports throughout the world are already operating at full capacity, and it is predicted that passenger numbers will grow at 4.6 percent annually from now until 2030 (SITA 2016). This increase in air traffic and the strain it puts on baggage handling systems means that a situation that is already critical could well become disastrous at many levels. System failures are not inevitable since solutions to prevent them are possible, and these very same airports are on the brink of a new era that will be influenced less by what is happening in their own operations, than by developments in the wider digital transformation industry. Smart Airports and Airport 4.0 are already part of this.

Now is therefore the time to not only prevent looming failure, but to harness the opportunities available to achieve operational excellence through the rapid implementation of digital and cloud-based tools. This will help O&M at airports in decision-making processes and resource optimisation. PdM systems can deliver cost-saving opportunities and many other benefits for all involved. Siemens has already equipped some of Heathrow's DCV tracks with sensors to help predict, prevent, and recover from operational disruptions caused by blocked DCV cart wheels. These sensors also work well in other devices, such as baggage hoists, reclaims and belt conveyors, and Heathrow and its passengers are already benefitting from these solutions.

Pilot projects are essential for airports to start to test the capabilities of their organisation before conducting digital-transformation methodologies. The target of this project was operational excellence in baggage handling to match Heathrow's overall performance as one of the busiest, most efficient and popular airports in the world. Adoption of this project's findings provides an excellent opportunity to not only solve Heathrow's specific problem, but also represents a highly valuable solution which could be adopted in many other busy capital airports.

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