Improving Maintenance Quality in Airport Baggage Handling Operations

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Pauline Found is the Professor of Lean Operations Management at the University of Buckingham. She spent 10 years as a Senior Research Fellow at the Cardiff University Lean Enterprise Research Centre, preceded by a successful management career in industry. She is a co-author of the Shingo Prize winning book *Staying Lean: Thriving not just surviving*, and has written a number of papers on lean and supply chain management. She was President of the Production and Operations Management Society College of Behaviour in Operations Management 2009-2011, and is a Fellow of the Institute of Chartered Institute of Logistics and Transport.

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Abstract

Purpose

The findings of a recent study at Heathrow are presented. The objective of the study was an operational quality issue with the baggage reclaim process and addressed the problem of unexpected downtime of baggage carousels during operational hours. For airlines and airports, the reclaim carousel is a key element in the process whereby passengers decide about the quality of their journey. Failure that leads to longer waiting times or even the relocation of baggage to another carousel results in passenger dissatisfaction and therefore needs to be avoided. The current regime of 'time-based' or 'preventative' maintenance can be classified as 'run-to-break' or 'reactive', causing frequent and costly downtime. A novel condition-based monitoring method to improve the reliability of the time critical baggage reclaim process is described. Reclaim carousel maintenance quality was improved by the development of innovative condition-based maintenance systems designed to meet the requirements of 21st century airport systems and Industry 4.0 in cooperation with Siemens DF (digital factory) and their internet of things (IoT) platform Mindsphere.

Methodology

A technical action research approach was undertaken at one of the biggest capital airport baggage handling systems in Europe. From June 2016 a condition monitoring pilot system on one operational carousel was established using engineering cycle theory. A solution was designed, installed, continually monitored and the results discussed with practitioners from the operation and maintenance (O&M) department. Root cause analysis was used to identify reasons for abrasive wear, followed by failure simulations during operation. Technical vibration data was collected so that an adequate condition monitoring system could be developed and optimised that improved the maintenance quality of reclaim carousels and reduced the costs associated with unexpected failure of the baggage handling system.

Findings

Run-to-break maintenance is never conducive to quality maintenance and control, and results in great uncertainty and unreliability. Meeting the objective of improving quality was difficult, because the assets are hidden and baggage carousels are in constant use; however using wireless beacon technology it was possible to identify what problems might occur and when. Using the cloud based IoT and Airport 4.0 also necessitated many sophisticated checks and measures, which are now in development.

This study highlights the value of changing from the antiquated ‘run to break’ maintenance of hidden assets in airport baggage handling carousels to high quality maintenance through the use of condition monitoring using wireless vibration sensors linked to a cloud based IoT ecosystem.

Originality/Value

With this solution in operation, maintenance quality has been approved and heavy damage can be avoided. The solution addresses problems caused by a variety of hidden equipment needing the highest possible maintenance quality. It can instantly secure the best quality of service for critical assets in an operation that cannot afford any unplanned downtime.

Keywords: Condition monitoring, Time-based maintenance, Reclaim carousel maintenance, Service 4.0, Wireless battery powered sensors.

Introduction

At Europe's biggest airport there is a daily average of 110,000 passengers, and every day there are approximately 550 angry passengers waiting at reclaims for their baggage to appear (Graham, 2014). Airports are complex socio-technical systems that often contain thousands of different assets, and employ various processes that have to follow rules and regulations (Baxter and Sommerville, 2011). All these components are combined and designed to fit within the space available in airport baggage halls in order to create a baggage handling system (Bradley, 2010). Failure of just one component can cause essential parts of the system to go out of service or to only work at reduced capacity. Mishandled baggage reached an all-time low in 2016, when according to the SITA Baggage Report 2017, 5.73 bags per thousand passengers went astray, a 12.25% decrease compared to the previous year and a 70% reduction over the past decade, despite the global passenger volume reaching a record 3.77 billion in 2016 (SITA, 2017). Aviation IT specialists expect the rate of mishandled baggage to drop even further after the IATA Resolution 753 comes into force in June 2018. This policy requires member airlines, representing 80% of the total scheduled global air traffic, to keep track of every item of baggage at four mandatory points: check-in, during aircraft loading, during transfers between aircraft, and on arrival as luggage is returned to passengers (SITA, 2017). Several airlines have added the ability to use online tracking to monitor the location of checked-in luggage, for example Delta Air Lines announced last year that it was adding radio frequency identification (R.F.I.D.) tags to its baggage-tracking system so that customers could see the real-time location of their luggage via the Fly Delta smartphone app (Ashton Morrow, 2016). To cut down on inexplicably lost luggage and the number of extremely angry customers, other airlines are also offering bag-locator services, and Alaska Airlines and Lufthansa now provide electronic tags for luggage, while American Airlines has an online baggage-tracker webpage (Ashton, 2009). In addition, third-party devices for tracking luggage are also available. While safety and security always remain the top priority, airport leaders are also focused on ways to streamline the business and its operations, including leveraging technology to meet and exceed goals and objectives; in today's digital world there is no escaping the power of data, so harnessing its benefits is key. A bag may be lost or delayed at any stage during the baggage handling system at either the origin or destination airport, although it is generally at the reclaim carousel, at the conclusion of their journey, where a passenger will realis their bag is late or lost (Davies, 2015). The design of baggage reclaim has not changed noticeably since the 1960s, and the maintenance performed is usually time-based and run-to-break (Anand and Rajaram, 2016). Therefore there is an opportunity is to digitalise the reclaim carousel by harnessing the potential of both the internet of things

(IoT) and condition monitoring solutions in order to deliver improved maintenance quality through condition-based maintenance.

Baggage Reclaim at Airports

Airports have been using reclaim carousels since they were pioneered in the 1960s to reunite baggage with passengers, and they have been the subject of substantial research due their key role in the arrivals process. The literature describes reclaim carousels built of friction driven claim conveyors assembled into a continuous loop using modular units (De Barros, 2015). The main components are straight beds, normal curves, reverse curves and drive units, and depending on load, reclaim carousels have one or more drive units fitted into a straight bed, usually at the end of the most heavily loaded straight section. A single drive unit has sufficient capability to drive a claim conveyor with a chain length of 50 to 75m. Chain links are made of cast aluminium, with each link possessing a take-up mechanism used for adjusting the length of the entire closed chain loop. A wheel with a quiet running polyurethane tyre is fitted onto each chain link and provides side guidance. Synthetic rubber slats are typically 1200mm long and 8mm thick, and a pressed steel slat carrier is mounted onto each chain link at a 250mm pitch and carries polyurethane tyre support wheels at both the top and bottom for quiet and smooth operation. Rubber slats and support buffers are mounted to each carrier to provide a continuous carrying surface (Saffarzadeh and Braaksma, 2000).

Much of the literature in the field of baggage reclaim carousels is related to passenger flow, waiting times, and passenger complaints and focusses on the customer experience (Xin et al., 2014; McKechnie et al., 2011). The reclaim carousel is where a passenger realises that something has gone awry with the journey of their baggage, even though the reclaim as a device is not necessarily the root cause for their late or lost bags (Henrique and Martinez-Moyano, 2010). Social science research has been conducted into passengers' behaviour when waiting for their luggage at reclaim carousels, and a combination of factors, including uncertainty as to whether their baggage will arrive or not, arriving after a long flight, time zone changes and/or a lack of sleep, can result in both stress and nervousness (Loch et al., 2007). In January 2005 US Customer and Border Protection (CBP) began recording average daily passenger times at 20 of the 285 airports that receive international air traffic. If everything goes well then after disembarking an aircraft the average time before a passenger leaves the airport is 40 minutes, including 12 minutes spent waiting at the arrival carousel to be reunited with their luggage (Atuahene et al., 2013).

Passenger queuing time and complaints have also been the subject of recent research (Correia et al., 2008; Padin and Svensson, 2017). Optimised customs processes, such as biometric passports and automated passport control, have allowed passengers to pass quickly through immigration and customs, and thus arrive earlier at reclaim carousels (Graham, 2014). This often leads to extended waiting times at baggage reclaim because optimisations to the process of unloading an aircraft and delivering baggage to the reclaim carousel have not kept pace.

Airfield baggage cart traffic management system projects have been attempted with the target of optimising the process of aircraft unloading and delivering baggage to the reclaim docking station. One of the authors was involved in designing and building a traffic management system based on electronic information boards. These were positioned along the way from the airplane parking lot to the reclaim loading dock and the traffic management system was connected to the passenger information board in the arrival hall. In cases when something happened in the arrival hall, for instance a technical issue affecting part of the arrival conveyor system, then the ground handler received information about the newly assigned reclaim carousel instantly (Figure 1).

Figure 1: Airfield baggage tug traffic management system

Other research has focused on the impact of the new generation of aircraft, with the doubling of passengers and bag numbers causing capacity problems for many reclaim carousels. In some cases it has been recorded that two smaller carousels have been joined together to make a A380-capable carousel, while other airports have optimised induction logic to allow more bags onto the carousel (Hill and Jones, 2007). As passenger numbers double every decade, the impact on the reclaim carousel is longer operational hours and heavier loads to carry, which in turn leads to a shorter life cycle of wearing parts. The common maintenance practice for baggage handling systems is ‘time-based’, but this is not adhered to and frequently drifts into ‘run-to-break’ maintenance, resulting in unplanned system downtime and causing high costs to be incurred (Militaru and Georgescu, 2009).

With the continuously increasing numbers of passengers and the constant requirement for reclaim carousel capacity, every deviation from normal operation can lead to problems, which passengers experience as additional waiting time. Many airports cannot compensate for the loss of a reclaim carousel during operational hours, as this would extend waiting time even further (SITA, 2017). The worst-case scenario in an arrival hall would be for a reclaim carousel to fail during operation, as bags already introduced to the carousel would jam up conveyors on their way to the arrival reclaim carousel. While these bags would be within walking distance of the passengers, they would remain in the secured area of an airport (Price and Forrest, 2016a).

Airlines and airports are now investigating the use of RFID technology, which is becoming more widely adopted. Systems are already on the market that can identify the location of any bag wherever it is, and passengers can start to use such technology via a phone app (Figure 2) so that location identification becomes possible (Datta et al., 2008).

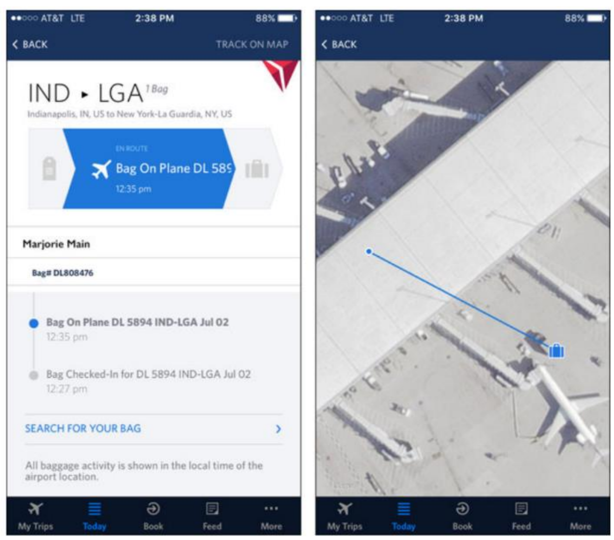


Figure 2: The Delta Airlines luggage location tracker App

Passengers knowing the exact position of their bag will increase the probability that waiting passengers will start searching in order to recover their bags; every airport’s horror scenario is passengers with mobile phones in hand, searching for bags that are trapped behind walls in secure areas jammed up by an out-of-service reclaim carousel. There are already reports of passengers not willing to tolerate long waits, gaining access through security shutters to search for their bags (Price et al., 2016).

Airports’ major focus is on reducing operational risks that could cause potential delays or incidents. For operation and maintenance (O&M) departments reclaim carousals were always known for their high reliability; however, the new situation of increased passenger numbers shifts reclaim carousels more into the focus of O&M management (Price and Forrest, 2016b). The question is how can the reliability of such devices be significantly improved? Research indicates effective use of Industry 4.0 solutions, in sectors where reliability of time-cricial operations is the key, will lead to enhanced operational performance (Tortorella et al., 2018; Závadský and Závadský, 2018) by predicting failures or systems breakdown in advance for taking preventive actions (Park et al., 2017). Similarly, there is a lot of literature on maintenance quality improvement, and a common direction is the move from run-to-break or time-based maintenance procedures towards condition-based maintenance (an example of Industry 4.0 application) using condition monitoring technology (Friedli et al., 2010). Currently, there is no literature on condition monitoring of reclaim carousels, the common failure modes or the common root causes of wear. Reclaim carousels are designed for operation in public areas, like arrival halls, where hundreds of moving parts, such as guide rollers on tracks and motors driving a chain, are hidden underneath rubber slats and stainless-steel cladding, and together with several hundred meters of rail, this makes time-based maintenance a time consuming and costly challenge.

Consequently, research is required to determine what are the common root causes of wear and unexpected downtime, and what condition monitoring solutions would allow O&M management to make the appropriate maintenance decisions to deliver reclaim carousels with the highest possible level of availability, monitored near real time using new capabilities available by IoT sensors and cloud computing. Such research needs to demonstrate that the theory of improved reliability can be achieved through:

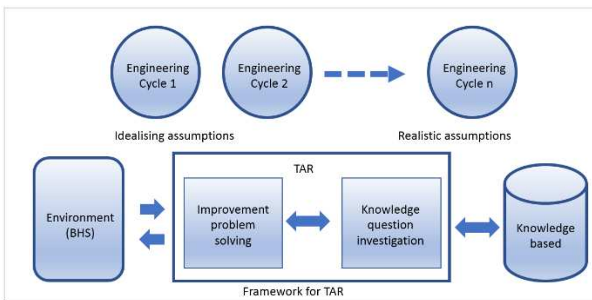
- Condition monitoring based on automated measurements
- Measurement evaluation followed by the appropriate triggering of service or preventive actions
- Reduced efforts for inspection
- Less service personnel during operational hours
- Fewer high skilled and cost intensive specialists
- Reduced preventive maintenance tasks based on predictive maintenance
- Optimised spare part storage
- Less wear and damage by verifying that installation or maintenance parameters are correct, for instance correct chain tensions

- Ability to act instantly when wear is causing events to occur, for instance obstructed and blocked wheel caused by a loose luggage lock that could cause substantial and ongoing damage if not cleared quickly

(Wang and Wang, 2018)

Methodology

Technical action research (TAR) 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 as a strong method for assisting in rapid problem-solving.



(Trist 1980)

Figure 3: The technical action research cycle

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 systems are huge technical systems and so socio-technical systems theory was applied (Baxter and Sommerville, 2011) . This technique has a high level of practical relevance and can be used with quantitative and qualitative data, and it enabled the acquisition of in-depth knowledge about baggage handling assets, their technology and potential issues. However, the solutions proposed are novel and untested and must be accepted by stakeholders prior to implementation.

It is common that new developments run through the engineering cycle (Figure 4) several times (Life Cycle Engineering, 2015). The engineering cycle starts with the identification of the problem, followed by research, and for the reclaim carousel an analysis about the wearing parts was performed. Testing refers to planning and carrying out investigations and then analysing and interpreting data. Depending on the results a solution is deemed to be either satisfactory or to require further improvement, with any further improvements again requiring analysis and interpretation of the data, followed by research, prototyping and testing. The engineering cycle ends with a solution when satisfactory test results are achieved (Life Cycle Engineering, 2015).

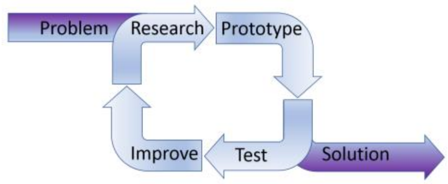


Figure 4: The Engineering Cycle

Based on feedback from O&M staff servicing the reclaim carousels, as well as interviews with a technical product manager of reclaim carousels, a condition monitoring pilot system was planned for one operational carousel beginning in January 2016. Solution engineering started with the target of first addressing the issues reported to be the worst wear-causing, and trials were carried out before a problem-solving solution was developed. The theory behind this is that by solving the worst problem first, other problems can be foreseen as they will be impacted by the biggest problem (Tan and Raghavan, 2007).

The engineering cycle theory was chosen for developing a technical solution, since for reclaim carousels no standard condition monitoring solution exists. Self-contained wireless iBeacon sensors were used since cabling would not be feasible as the reclaim carousels in the public area are in operation 18 hours each day. It was expected that for every small improvement step the reliability of the reclaim carousels would improve. Technical action research combined with several engineering cycles continued until a measurable improvement in the maintenance quality was established, and the research schedule is shown in Figure 5.

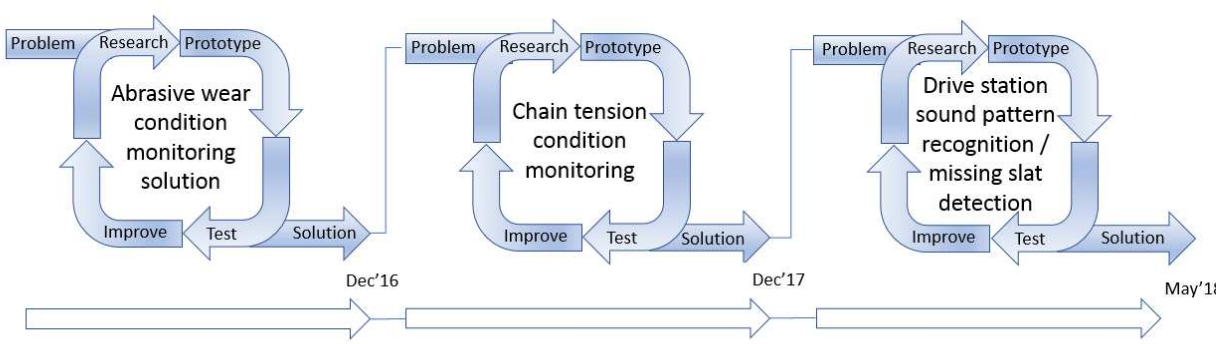


Figure 5: The planned engineering cycles

Detailed planning based on the stakeholder's requirements included:

- Solution to detect abrasive wear caused by objects blocking wheels
- Solution to avoid wear caused by over or under tensioned chains
- Solution to monitor if the threshold for track or wheel wear was reached
- Solution to monitor drive station and friction belt conditions
- Solution to detect missing slats

Wherever possible wireless sensor technology was used; BLE iBeacon sensors are battery powered, self-contained, easy to install wireless sensors with a life expectancy of 3 to 9 years (BLE datasheet), depending on data acquisition and transmission duty cycle. The vibration and temperature of the iBeacon sensors provides its internal status (ex. Battery life) to the signal processing units. The vibration of iBeacon sensors sends the internal and measured data for an assigned iBeacon sensor to WiFi bridges (Newman, 2014), with at least two WiFi Bridges present underneath the slats for each reclaim carousel. Each iBeacon sensor transmits the vibration and temperature data to the WiFi bridge via a 4G modem router to the signal processing server on the Siemens cloud. For each reclaim one 4G/WiFi router handles the TCP/IP data flow between the condition monitoring sensors and the signal processing server. The iBeacon/WiFi station and the 4G/WiFi routers were located underneath the slats where appropriate, and the signal processing unit was hosted on the secure Siemens cloud (Mindsphere) (Huber, 2016).

The prototype condition monitoring system was planned based on the following:

- Vibration measuring iBeacon sensors mounted on the rails to detect vibrations generated by objects blocking wheels (e.g. a luggage lock fallen loose onto the tracks)
- Wireless microphones facing the drive station detecting noise that deviates from a healthy drive
- Wireless load pin technology measuring chain tension
- Wheel axis distance to rail measurement using the gramophone principle
- Twilight sensor to detect light passing through a gap created by a missing slat

Data was planned to be pre-processed in a local server before being transmitted to the Siemens IoT Mindsphere platform, where the data were used to develop applications for use by O&M staff. The planned prototype principal is shown in Figure 6, and the solution takes advantage of the capabilities of the IoT as a toolbox.

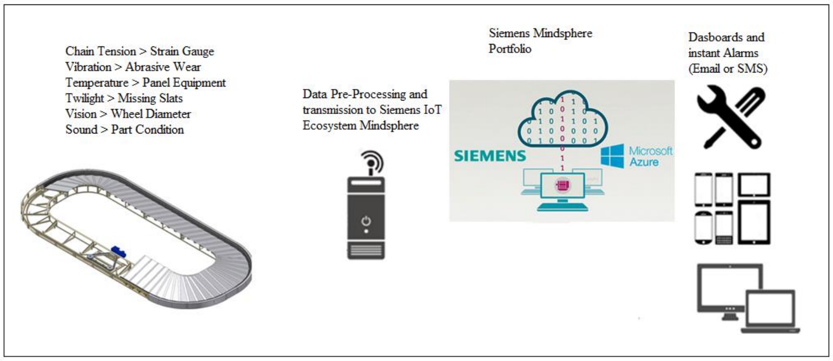
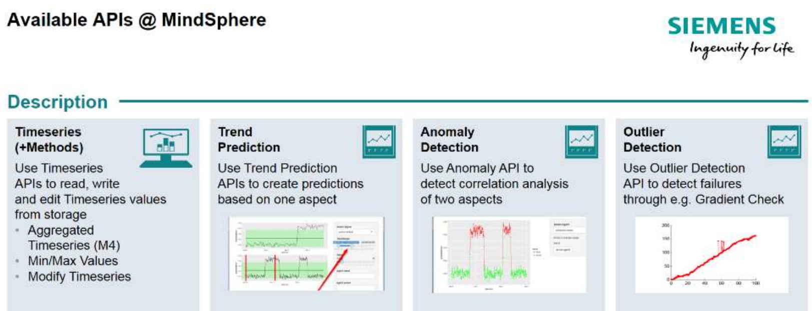


Figure 6: Modern 4.0 condition based monitoring system for arrival reclaim carousels

Available application programming interfaces, such as time series, trend, anomaly, and outlier detection were planned to be used (Figure 7).



(Huber 2016)

Figure 7: Modern 4.0 condition based monitoring App library

Findings

Following the engineering cycle process the research started with a problem analysis. An audit of the reclaims that frequently fail during operational hours was undertaken and continually tripping circuit-breakers were identified. A service crew dismounted sections of the slats to reveal the underlying components, which showed signs of heavy degradation due to wear. The clutter of debris shown in Figure 8 provides an impression of the findings.

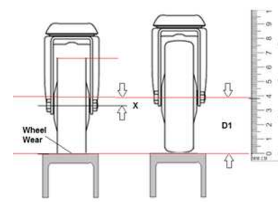
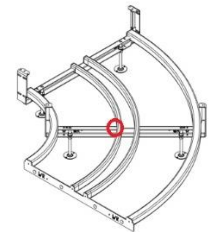
Figure 8: Reclaim carousel survey and items found underneath slats

The tracks showed signs of excessive wear, with the edges appearing highly polished, and especially along the curves, and the track thickness was worn from 4mm down to just 0.5mm, causing the track to lose stability and bow. The guide wheels had lost about 3mm in diameter, and the heavy rubber slats had been scraped, with rubber shavings, up to the size of a one penny coin observable everywhere. The concrete floor underneath the reclaim was entirely covered with debris, including lost IATA tags, locks, zippers and coins.

The maintenance manual calls for a yearly inspection, including cleaning, calliper measurement of the diameter of the rollers and a visual inspection of track wear. Some items present within the debris showed printed dates that were over 10-years-old, raising doubt that time-based maintenance had ever been performed on a yearly basis. The impression gained was that the reclaim carousels are only serviced using 'run-to-break' maintenance. Table 1 lists the findings of the surveyed reclaim carousel, the problem and the impact.

Table 1: Problems with Airport Baggage Handling and the Impact to entire system

System	Characteristic	Problem	Impact
Track wear	Tears or recesses up to a point where a hole in the rail arises		Medium to high. Depending on the grade of degradation, reclaim carousel frame can collapse under heavy load conditions. Slats can collide with metal frames and rubber scraped off until slats are instable and cannot hold enough load.
Wheel abrasive wear	temperature development, bad smell and increased noise		Medium. Depending on grade of wear, wheels with such damage generate noise should be avoided in an arrival hall.

Wheel common wear	Loss of wheel diameter over time		Medium to high. Lead to wear on slats, drive station Higher energy consumption caused by higher friction. Slats start scratching on supports with continues degradation risk for clashes with mechanical parts.
Chain tension	Unnecessary force on inner site or outer site of bends		Medium to high. Lead to wear on guide rollers as well as force on rails. Wrong chain tension reported as root cause with impact on roller and track life.
Missing slats	Gap on loading section		High. Bags can fall into gaps and block the carousel. Gaps where hands fit create major health and safety risks.

Following the phases of the research plan, the first abrasive wear detection condition monitoring was established by installing two iBeacon sensors on the tracks to measure the vibrations (Figure 9).

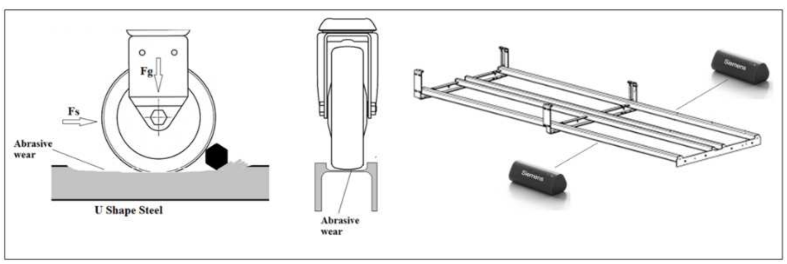


Figure 9 - Illustration showing track abrasive wear and iBeacon position on tracks

It was expected that the vibration generated by free spinning wheels would be low and the vibration of wheels blocked by an object higher. The installation was performed quickly with self-contained sensors placed on the rails (U profile), and since June 22nd 2017 both sensors have provided data to the Mindsphere cloud. The scenario of a wear-causing blocked wheel was created so that the functionality of the solution could be tested. Accordingly, a metallic object was placed in front of one wheel and with the reclaim moving at operational speed the blocked wheel passed by the wireless sensors, which picked up a vibration of 75 mm/s, by comparison, a free spinning wheel generates a very low vibration of just 5 mm/s. Figure 10 shows the digitalised signal generated by the test object and the blocked wheel.

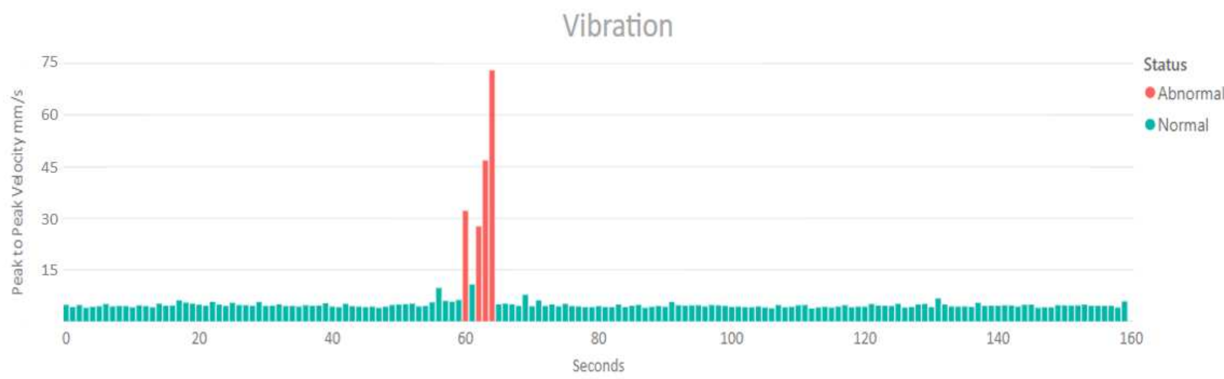


Figure 10 - Signal captured during site acceptation test

With the blocked wheel generating a higher vibration that was picked up by the sensors, the solution was proven to be functional. Following the controlled test the system remained operational with the aim of trying to detect real wear causing a blocked wheel event.

The second step was to find an automated solution for the measurement of chain tension. An essential part of this research was the process of identifying a sensor capable of measuring chain tension. The preferred solution was based on a wireless load measuring pin in double sheer, and in December 2017 the chain tension condition monitoring was incorporated. The sensor was tailor made so that it fitted to the type of chains used in reclaim carousels, and Figure 11 shows the chain drive station, the load pin and the principle of how the load pin was integrated into the reclaim carousel chain.

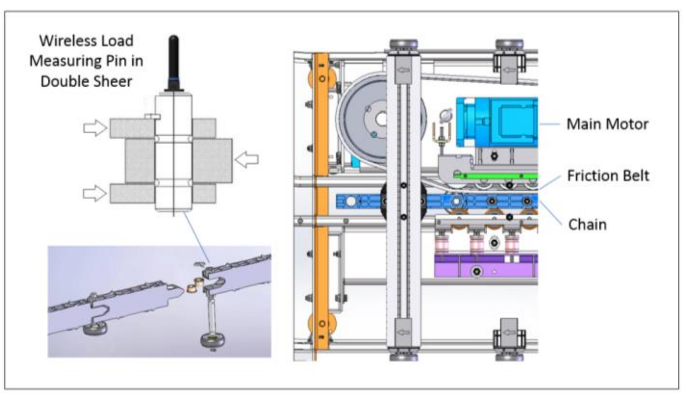


Figure 11 - Chain tension measurement using load pin in double sheer

According to the O&M manual, chain tension must be checked and adjusted each month, which requires the slats to be dismounted in order to gain access, before performing a pull test with a spring scale. The chain is supposed to start moving with a force of 10kN; however, chains stretch and extend in length over time, which leads to under tension. Excessive tension may also occur as a result of over tensioning during maintenance. As the load pin is able to measure tension during operational hours, monthly servicing is no longer required. The solution was installed and commissioned in December 2017, and prior to the test a service technician adjusted the chain tension to 10 kN. For the first month the system collected data of the restarting reclaim (in this moment there is no load on the reclaim), then in January 2017 the chain tension was manually released and data was collected for one week. All the measurements during this period were less than 8 kN, and at the end of the test the chain tension was re-adjusted to 10kN as required. The system collected data for another month and then in February 2018 the chain was manually over tensioned. All the measurements during this period were over 15kN, and after the test the chain was again re-adjusted to the required 10kN tension. The results are shown in Figure 12, and demonstrate that over and under tension can be measured with a wireless load pin sensor.

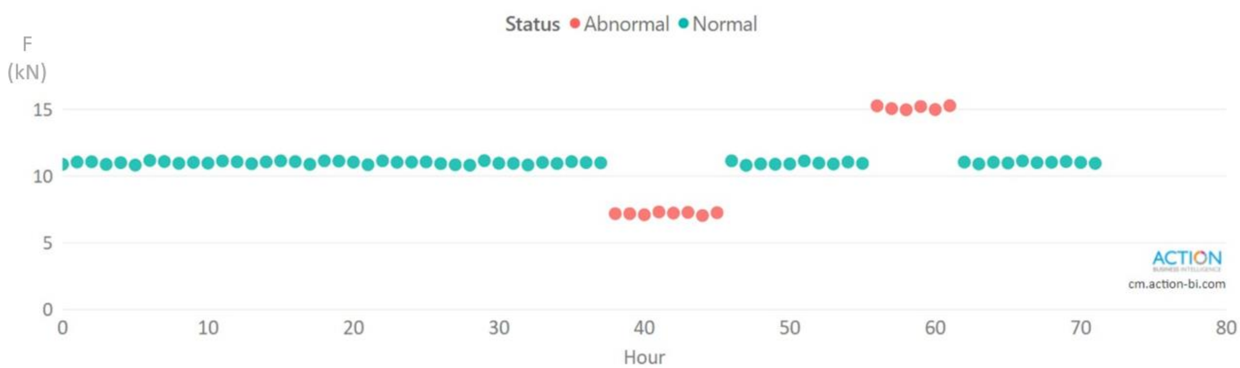


Figure 12 - Chain over and under tension test (unloaded reclaim)

With this chain tension solution in place, the chain tension of carousels is available at any time and the tendency over time can be easily visualised. Alarms can be set up to notify O&M staff if under or over tension is detected, meaning that monthly inspections are no longer required.

In June 2017 the so-called 'gramophone' solution was installed. This technical solution was based on the principal of an adjustable length needle mounted on the centre axis of one roller. By adjusting a thread and counter bolt, the needle was set to 1mm above the track surface. The needle moves around the reclaim circuit with the roller, and if any section of the track is worn in excess of 1mm then the needle touches the metal surface. The dragging of the needle along the metal surface generates a vibration that in turn can be detected by the wireless iBeacon sensor (Figure 13).

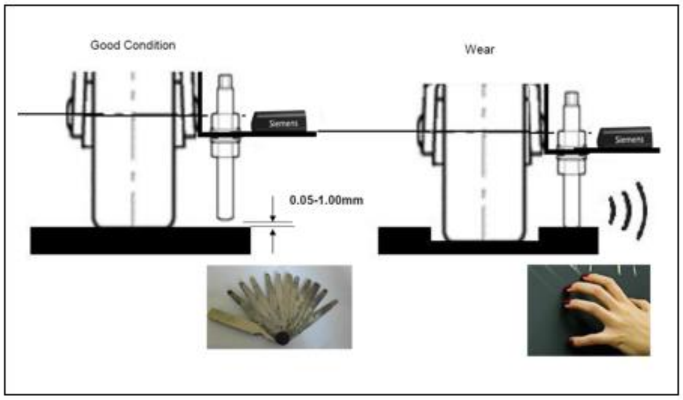


Figure 13: Reclaim track or wheel wear solution with iBeacon technology

In a controlled test the 1mm setup was reduced in 0.1mm steps with every round, and when the needle to metal surface distance was reduced to 0.2mm then the needle contacted the metal surface producing a vibration that the iBeacon sensor recorded as a peak to peak velocity of 80 mm/s. Further investigation confirmed that there was a 20cm section of one rail which had a depth of 0.2 mm (Figure 14).

Figure 14: Reclaim track or wheel wear solution with iBeacon technology

This is still well within the acceptable tolerance limits and so was not considered as demonstrating significant wear; however, the trial did prove the success of the wear measurement concept. Subsequently, the needle was reset to the 1mm threshold agreed by the stakeholders involved in the research.

The final part of the research commenced in December 2017 and was concerned with the automatic detection of a missing slat. This solution was simple to achieve as the space underneath a reclaim carousel is dark, so that missing slats let light diffuse through to the cavity beneath, and can easily be detected using an industrial twilight switch (Figure 15).

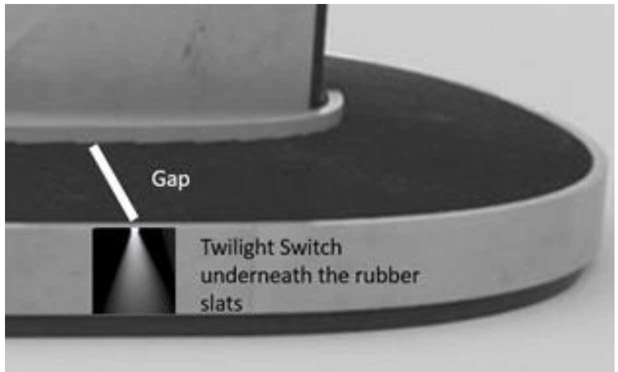


Figure 15: Missing slat detection with twilight switch technology

A reclaim carousel with a full complement of mounted slats should not let any light diffuse to the sensor, and the sensor was calibrated such that even small gaps that let light reach the sensor will generate a signal. The solution was installed and tested, and was found to function well with missing slats being reliably detected.

Analysis

In this paper a summary of the development of a condition monitoring system with the three elements of data acquisition, data processing and maintenance decision making has been presented. Based on a root cause analysis the condition monitoring solution was developed with the stakeholders involved using technical action research. The target was to improve the maintenance quality of the reclaim carousels, an important asset in baggage handling where all the wearing parts are hidden behind stainless cladding. The mechanical design of reclaim carousels established in the 1960s remains in operation, and those in Heathrow's terminal 2 are the first to which condition monitoring solutions are known to have been added.

The condition monitoring system was based on the evaluation of automated measurements, followed by the appropriate trigger of service or preventive actions. With the early abrasive wear detection system, objects blocking wheels are detected and can be taken out quickly which leads to less wear and damage, as well as optimised spare part storage. The gramophone solution in particular reduced the requirement for inspection by using an automated measurement to detect if a specific threshold of wear had been reached, while the chain tension monitoring solution now allows the automatic detection of over or under tensioned chains. Through a combination of solutions the arrival reclaim carousel is now subject to fully automated condition monitoring, which has led to less service personnel during operational hours and fewer high skilled and cost intensive specialists being required. Cost intensive time-based maintenance tasks have been replaced by modern condition-based maintenance methods.

Conclusions

The pilot test confirmed that condition monitoring using the IoT makes many maintenance improvements possible. Parts that are hidden behind cladding can be monitored reliably, so failure can be detected in the very early stages before heavy wear occurs. Even the high number of parts and several kilometres of track can be monitored and their status visualised via a single dashboard page, which is a huge benefit and a game changer for maintenance quality. Executive annual inspections, where several hundred heavy slats would need to be removed and replaced are no longer required. Wireless data transmission and cloud computing have been beneficial in this but the operational life expectancy of battery powered sensors remains uncertain, especially given their variety of usage and application. Airport brownfield projects would require several hundred critical assets to be monitored, and the logistics and maintenance for the condition monitoring system itself will be enormous if in a few years' time all of the iBeacon sensors need to be replaced due to depleted batteries; in itself this would be a full-time job as most are hidden behind cladding and are not that easy to locate.

The perfect sensor would have an external power supply, measure vibration and temperature, and be configurable for minimum idle time. It would also have a configurable measurement cycle time with a 'wake up' function for detected motion. Unfortunately, such a sensor does not yet exist, although it would be possible to design and build such a sensor based on the requirements listed. The prototype for a sensor like this could be the subject of future research and another pilot system.

Another factor that needs to be considered as a service cost in wireless beacon technology is the software. Together with the IoT ecosystem data hosting costs, the benefits of the low installation costs are quickly eroded by software service costs. Software as a service model for condition monitoring applications together with cloud computing is new and there are various models available. The situation is comparable to the first mobile phone contracts, where customers were obliged to purchase a handset, pay a basic monthly fee and in addition pay for the minutes they spent talking. As there is competition within condition monitoring and the IoT service market, it is assumed that the prices will continually drop, and it will be interesting for future research to reflect on whether competitive software service rates will become available.

Reflections

Within one year of operation the first iBeacon sensor failed due to a depleted battery, despite the specifications stating a potential lifetime of 8 years, although the level of usage was not noted. However, even with an optimised parameter setting, the iBeacon sensor still measured vibration and temperature at 10 second intervals and transmitted the data. Therefore, theoretically the 8 year battery life cycle was not achievable. Even though the wireless iBeacon technology pilot has yielded a significant increase in maintenance quality, the additional logistics and maintenance required for the condition monitoring system itself raised doubts regarding its adequacy in monitoring a high number of critical assets in baggage handling systems. Based on these findings, and together with the iBeacon manufacturer, new firmware has been developed, as for baggage handling system assets it is not necessary for vibration, temperature or chain tension to be measured at parametrisable intervals.

An additional parameter can be chosen for the minimum idle time: hourly, daily, or weekly. This second parameter defines the measurement cycle depending on the asset. For instance, one complete round for a baggage reclaim is 30 seconds; therefore if the vibration of one round is measured then sufficient data will be gathered for the condition monitoring system. For the chain tension measurement even a one-week measurement cycle is sufficient, as it is expected that tension change occurs slowly over time. Consequently, the iBeacon firmware was modified so that the sensors remained idle (12Hz) until motion is detected, whereupon measurements are collected for a defined period of time depending on the machine cycle. After sending its signal the sensor is switched to idle for a pre-defined idle time, and a new measurement is triggered after the minimum idle time expires and new motion detected. The advantage of this is that in periods when an asset is in an idle state, no battery power is wasted. With this new firmware the iBeacon sensor lifetime has been calculated to be a minimum of five years, which is acceptable. Figure 16 shows vibration data gained for eight consecutive days using this new firmware.

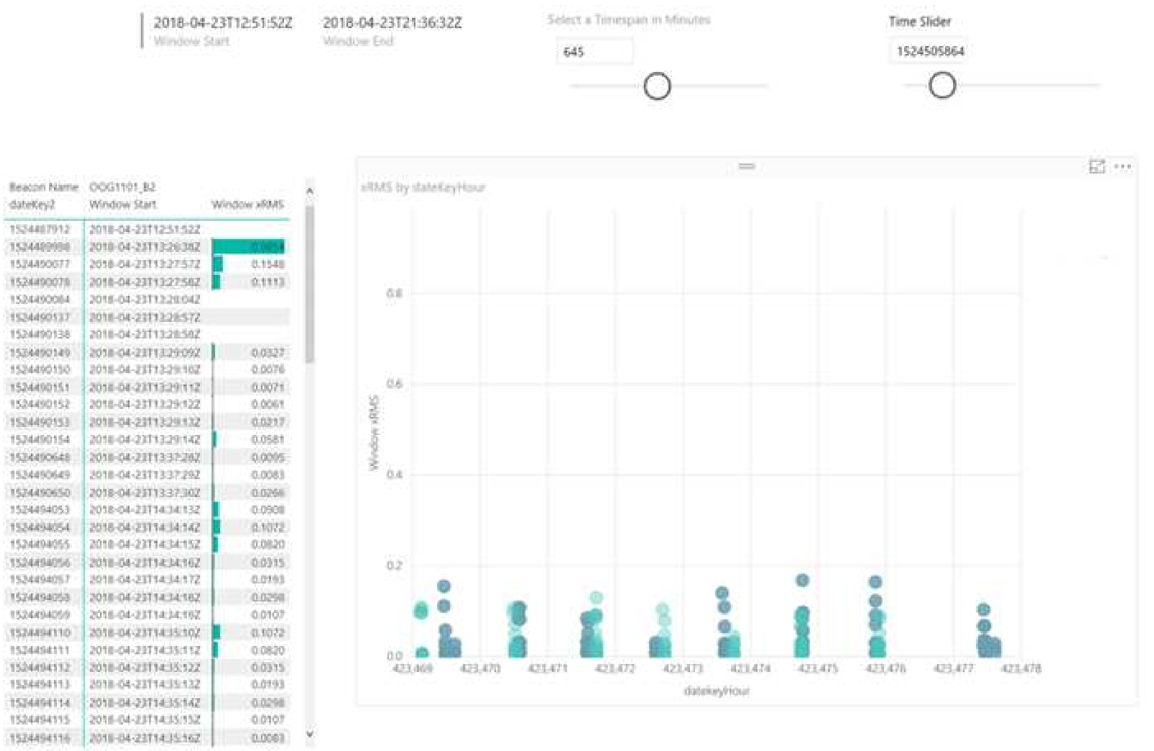


Figure 16: Beacon data diagram for 8 consecutive days

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Figure Legends

Figure 1: Airfield baggage tug traffic management system

Figure 2: The Delta Airlines luggage location tracker App

Figure 3: The technical action research cycle (Trist, 1980)

Figure 4: The Engineering Cycle

Figure 5: The planned engineering cycles

Figure 6: Modern 4.0 condition based monitoring system for arrival reclaim carousels

Figure 7: Modern 4.0 condition based monitoring app library (Huber, 2016)

Figure 8: Reclaim carousel survey and items found underneath the slats

Figure 9: Abrasive track wear and iBeacon position on tracks

Figure 10: Signal captured during the site acceptation test

Figure 11: Chain tension measurement using a load pin in double sheer

Figure 12: Chain over and under tension test

Figure 13: Reclaim track or wheel wear solution with iBeacon technology

Figure 14: Reclaim track or wheel wear solution with iBeacon technology

Figure 15: Missing slat detection with twilight switch technology

Figure 16: iBeacon data for 8 consecutive days