Analysis of the Denver International Airport baggage system

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THE DENVER INTERNATIONAL AIRPORT

AUTOMATED BAGGAGE HANDLING SYSTEM

by

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ABSTRACT

This document discusses events at the new Denver International Airport that resulted in opening delays of the airport. The scope is limited to the automated baggage handling system, which was the primary source of failure warranting the airport's several opening delays.

Analysis of the failing system is comprehensive. Research is conducted using a variety of sources. The final report is published on the worldwide web.

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INTRODUCTION

This research concerns the automated baggage handling system which was built by BAE Automated Systems, Incorporated of Carrollton, Texas for the Denver International Airport. The analysis of this system provides an important topic of study. From the baggage system's failure, principles of computer systems were clarified and many lessons were learned or relearned by those involved in the BAE project. While there are a variety of issues to learn from the many operations in the construction of the Denver International Airport, focus is placed on the baggage system itself. Some less relevant chapters serve to inform the reader of the occurrences that were influencing the timing and financial properties of the baggage system work as it was built.

Reasons For Automation begins by describing how it was decided that Denver International Airport would have an automated baggage handling system. A short review of the history of Denver International Airport in its planning stage illustrates the options that Denver had to choose from.

Functionality Of Original BAE Design describes how the baggage system was intended to work. It is a detailed explanation of what makes the system work. Here, parts of computer machinery are itemized, and specifications are explained.

Problems and Solutions is the largest chapter and describes what went wrong, and how the problems were solved. This chapter includes descriptions of mistakes made in both the design and construction of the system. Obvious problems such as paint covered optical scanners are explained. Less understandable problems such as the puzzling line balancing problem receive attention. Problems with scheduling and complexity are quickly reviewed, since both topics receive chapters of their own later in the report.

System Complexity was likely the predominant cause of the baggage system's failure. Surely many current control and information systems projects in the design phase could be simplified at great benefit to the construction and maintenance of them. The BAE design's failure provides more than enough incentive for other engineers to redesign or simplify a complex design when success of the whole system is at stake. Present industrial trends are horrific. By some estimates, 75 percent of all information systems projects are plagued with quality problems, and only 1 percent of them are completed on time.

Comparative Functionality explains how the baggage system really worked when the Denver International Airport finally opened on February 28, 1995. Needless to say, its performance was quite different from what the system's original specification called for. This chapter, in a sense, is a dream versus reality comparison.

Opening Delays tells how the project schedule was affected by the profound complexity of the design. The confusion resulted in a prolonged testing phase, reducing the process to solving by trial and error. Systems analysts and engineers hacked together solutions as they went. This unappealing course did the job at the expense of time.

Financial Hardship describes the way that the airport was initially funded and the direction of its financing after problems and delays affected its credit. This chapter explains what the city of Denver and airlines did to account for budget deficits and cost overruns.

Summary concludes the study with a review of the lessons learned, and how they can be constructive in avoiding similar failures or even worse, larger failures of catastrophic magnitude.

REASONS FOR AUTOMATION

United Airlines' Request

Early in the planning stage, United Airlines insisted on an automated high speed baggage system, like the one it operates in San Francisco. After some consideration, Denver agreed that not only would United have an automated high speed baggage handling system, but so would the rest of the airport's three concourses. Denver officials had sound reasoning in choosing to install an automated baggage handling system.

Before deciding on buying an airport-wide system, Denver officials had previously assumed that each airline would design their own system, according to its own needs. When the airlines failed to produce their own designs, Denver investigated the option of buying a system to service all airlines in a unified manner. When the planners considered a traditional manual baggage handling system using tugs and carts, it appeared to be inadequate for a few reasons. Moving baggage by the traditional system is a labor intensive and expensive process. The tugs are diesel powered and would not have been able to travel through the poorly ventilated underground tunnels due to the high volume of diesel exhaust that would have choked the tug drivers and other workers. Even if ventilation had been installed, the heavy volume of large tugs and carts would have jammed the small tunnels as they passed each other or turned corners.

Long Distances

An additional concern involved spanning the great distances of the airport. At the Denver International Airport, distance and speed of delivery have especially significant importance because the distances between passengers, planes, gates, ticket counters, concourses, and the terminal are much larger than at other airports. The closest concourse, concourse A, is 1,300 feet away from the passenger terminal. The farthest, concourse C, is a full mile from the terminal. Concourse B itself is .7 miles long. To keep flights on schedule, speed becomes critical in moving baggage. Furthermore, across such great distances the only direct route for baggage moving is through the underground tunnels, which are incapable of accommodating gas-powered tugs. Taking baggage on tug and cart by route of the runway aprons could take as long as fifty minutes, thereby missing most flights. Glenn Rifkin states, "For an airport this size, a conventional baggage system simply wouldn't work."

Increased Profits For Airlines

The airlines were as disappointed as the city in a traditional manual system. In general, airlines maximize their profits by keeping their planes airborne, not grounded and waiting for baggage. United knows this too well after enduring some of the worst gridlock and bottlenecking in the nation at Denver's Stapleton International Airport. Stapleton frequently ranked fiftieth out of fifty airports rated for on time performance according to Briggs Gamblin, a spokesman for Mayor Webb. United accordingly sought to keep their airplanes in flight and on time by insisting on an automated system in the construction of the new airport. Denver began researching the possibility of an airport-wide automated system, and with BAE's help, planned such a system and sent it to bid.

FUNCTIONALITY OF ORIGINAL BAE DESIGN

Savior Of Modern Flying

When the automated baggage system design for the Denver International Airport was introduced, it was hailed as the savior of modern airport design. Designed by BAE Automated Systems of Carrollton, Texas (previously Boeing Airport Equipment), it allows airport planners to design airports of larger size, using narrow corridors and tunnels for baggage where no tug and cart system can run. Furthermore, it requires none of the manual labor personnel, and can be used as easily in pinpointing the location of baggage as in moving it. The design truly fits its description as the world's most advanced baggage handling system. It is intended to run faster and more reliable than traditional technology. Its automation is so thorough, that in most cases, baggage offloaded from an aircraft doesn't see a human until it meets with its owner at the baggage claim. The system's speed outperforms even the airport's high speed trains. Flyers never have to hover around the baggage terminal waiting for their baggage as with traditional systems, because their baggage arrives at the claim before they do. On departure, their baggage arrives at the aircraft before they do.

Other Automated Baggage Systems

While the automated baggage system design of Denver International Airport is unique in complexity, technology, and capacity, it is not the world's first such system. The three other airports that have such systems are San Francisco International Airport, Rhein-Main International Airport in Frankfurt, and Franz Joseph Strauss Airport in Munich. The major distinctions that separate Denver's design are size and complexity. While Denver's design is integrated to sort baggage from all airlines throughout the whole airport and deliver over a thousand bags per minute, the other airports use systems that are localized to much smaller baggage loops and offer less capacity. San Francisco's system is ten times smaller and handles fourteen times less in speed and capacity. The system in Frankfurt runs on trays and conveyor belts rather than Denver's high speed telecars and is three times smaller in size. Munich's automated design is similar to Denver's but far less complex.

High Speed

Denver's baggage system design calls for replacing the traditional slow conveyor belts with telecars that roll freely on underground tracks at more than three times the speed. A telecar that is loading baggage rolls at 4.5 miles per hour. A telecar that is unloading its baggage rolls at 8.5 miles per hour. A telecar in transit rolls at a fast 19 miles per hour. Each track can handle 60 telecars per minute. It is the combination of using Denver International Airport's underground tunnel network and swift speeds that allows all baggage to move between any concourse and the airport terminal in less than nine minutes. In United's concourse B, transfer baggage moves between any two gates in under six minutes. According to Briggs Gamblin, a spokesman for Denver Mayor Wellington Webb, the system's high speed nature is intended to shave minutes off the turnaround time of each arriving or departing flight.

Components

The BAE design includes a number of high-tech components. It calls for 300 486-class computers distributed in eight control rooms, a Raima Corp. database running on a Netframe Systems fault-tolerant NF250 server, a high-speed fiber-optic ethernet network, 14 million feet of wiring, 56 laser arrays, 400 frequency readers, 22 miles of track, 6 miles of conveyor belts, 3,100 standard telecars, 450 oversized telecars, 10,000 motors, and 92 PLCs to control motors and track switches. With so much equipment serving such a large area, the Denver International Airport's baggage system is the world's largest. "This project is of the same magnitude as the Panama Canal or the English Channel Tunnel," said Mayor Webb. The system's total cost is $193 million dollars.

Baggage Handling Process

Because of the revolutionary automated baggage system, the process of handling baggage is unique at Denver International Airport. At check-in, agents stick glue-backed bar code labels on baggage, identifying the bag's owner, flight number, final destination, and intermediate connections and airlines. Instead of printed bar code tags, United's portion of the system uses photocells that serve the same purpose. The check-in agent then puts the bag on a conveyor belt. Since no baggage can move without a telecar holding it, a system exists for dealing with telecar allocation. Empty car management software is the heart of the allocation system, dispatching empty telecars to where the tracking computers anticipate they will be needed. The computers sense changes in demand by measuring the flow of passengers throughout the airport. During peak times, all 3,550 telecars are available for moving baggage.

When an empty telecar arrives, the conveyor belt holding the bag advances. Then a type of high-speed luggage bowling machine flings the bag at a T-intersection just as the telecar moves by, catching the bag in its fiberglass tray. Each telecar has a tray for this purpose that tilts into three positions for automatically loading, carrying, and unloading its baggage. In Denver International Airport's system, telecars do not stop for loading or unloading, they only slow. This type of "Dynamic loading" increases handling capacity and saves energy as well. Before the telecar speeds away, a laser scanner similar to those used in grocery stores reads the bar code tag on the bag's handle and associates the bag with its telecar. These laser scanners are triggered by photo-electric sensors that detect a telecar's presence. Telecars pass photo-electric sensors every 150 to 200 feet of track.

The computer that scans the bar code tags then sends information to a BAE sortation computer that translates it by using a look up table to match the flight number with the appropriate gate. A tracking computer guides the telecar to its destination by communicating with the hockey puck-sized radio transponders mounted on the side of each telecar. The telecars are able to move on the tracks by linear induction motors, or LIMs, which are mounted periodically on the tracks, and push the telecars along. A metal fin on the bottom of each telecar slides through each induction motor gaining impulse as it goes. Telecars merge with other telecar traffic and exit to unload stations by computers which control PLCs, or programmable logic controllers. The computer tracking a specific telecar directs it by communicating with PLCs that are responsible for causing track switches.

Tracking Baggage

As the telecars roll, the tracking computers monitor each of the system's thousands of radio transponderswhich emit millions of messages per second. The computers must also track all gate assignments so that the telecars can be re-routed if a change is made. The tracking computers can also re-route bags to special inspection stations, including one that is bomb proof. The same computers must keep track of obstructions or failures as well, so that telecars can automatically detour around a stalled vehicle or jammed track.

Oversized Baggage

In addition to standard-sized baggage, the system can also accommodate nonstandard-sized baggage on oversized telecars that measure 6.5 feet long by 4 feet wide. The oversized telecars are essentially double-length standard telecars. They are meant for non-standard size baggage which in Denver typically tends to be skis and golf bags. The oversized telecars navigate through twists, turns, and switches the same way the standard telecars do.

Security

Impressingly, the system can work in full capacity for 18 hours every day at a 99.5 percent efficiency rate. Two counter-circulating closed-loop tracks with multiple routing connections provide for future expansion and add redundancy to guard against unanticipated problems. To protect against malice that could theoretically shut down the whole airport by halting the flow of baggage, tight computer security is built into the baggage system. The system has strict access privileges for workers, and its command center is well guarded and locked behind steel doors. Despite BAE's conflicting advice, the entire automated baggage system is run by DIA's information systems staff of 18 employees, according to Ivan Drinks, director of MIS for both Stapleton and Denver International Airport.

Object-Oriented Architecture

Fortunately, the automated baggage handling system illustrates the principle of object oriented design beautifully. It sends messages to objects (the telecars), which respond by returning other objects (baggage and empty telecars) to the sender. Its real-time software was programmed in OS/2 and intended to run on OS/2 version 2.0. Decentralized computing allows the baggage system to operate independently of the airport's information systems department. The only dependence within the system involves coordination with the airlines' flight reservation and information systems.

PROBLEMS AND SOLUTIONS

Denver's Baggage Problems

The Denver International Airport's automated baggage system experienced such horrific problems that most with an opinion on the matter are thrilled to elaborate on their sense of what went wrong. It seemed that what could go wrong, did go wrong. Even the signs directing passengers to the baggage claim led to a concrete wall. Unfortunately, analyzing the true nature of the system's faults is not an easy task. Problems were so widespread, that possibly no small number of reasons can alone account for the chaotic performance in the system's early testing. Insight can be found in examining the accounts of some key people who were involved in the baggage project.

Expert Opinions

In response to criticism after the third opening delay, BAE president Gene DiFonso explained, "We simply ran out of test time" because of changes requested by the airlines, problems "working around other vendors," and failures in the airport's electrical power supply. Denver aviation director James C. DeLong maintained that baggage software glitches and electrical supply harmonics were late and unexpected obstacles to opening the Denver International Airport. According to David Hughes of Aviation Week & Space Technology, contributing factors to the baggage system's problems included concrete mechanical, electrical, and software flaws. William B. Scott of Aviation Week & Space Technology believed that the system's troubles originated in more fundamental miscalculations such as overall system complexity, underestimation of tasks, a steady stream of changes requested by both airline and Denver officials, and politics.

Politics

Political issues were a surprising obstacle in the progress of the automated baggage system design and installation. George Rolf, an urban planning professor from the University of

Washington, said that publicly run projects like Denver International Airport encounter problems because "you have two distinct processes going on, one political and the other technical, and they have little to do with one another." One example of this claim is Denver's refusal to award the job of operating the baggage system to BAE, the only company that well understood it. The basis of this decision revolved around political but impractical ideals. Essentially, Denver officials suspected that BAE would not hire enough minorities and women, although BAE said they would. Richard Woodbury wrote, "In the wake of political infighting over who should get the lucrative contract, it went to an outsider, Aircraft Service International of Miami, which has had to race to fathom the system in a few months." A Denver insider declared, "It was raw greed. Everyone wanted a piece of the contract moneys. The city lost control at the outset, and the project was destined to run amuck." Further political problems ran through the entire Denver International Airport construction in the presence of rhetoric and false assurances to the bond market. Some of the statements made by Denver in defense of construction delays and practices bordered the lines of legality. Mike Boyd, an analyst who heads Aviation Systems Research Corporation in Golden, Colorado said, "This is an airport built for politicians, not for airlines. When you look at the numbers and what they're telling bond houses, it is absolutely shocking. None of the significant numbers that the city has been putting out since the airport was started have held true." Other political troubles included Denver's alleged falsifying of temporary certificates of occupancy (TCOs) in the midst of the baggage system crisis to appease the airlines, and a lawsuit with the Park Hill Neighborhood Association barring a partial airport opening. Consequently, in January of 1994, both the Justice Department and the Securities and Exchange Commission subpoenaed key Denver International Airport documents. In February of 1994, the U.S. attorney's office sent investigators to Denver to interview city officials and probe into alleged wrongdoings. In August of 1994, a federal grand jury began investigating the Denver International Airport for fraudulent contracting, trading, testing, and construction financing practices. In late October of 1994, a congressional auditing agency became involved in Denver International Airport's financial woes. The General Accounting Office (GAO) reported that despite Denver's delays and losses, the city's chances of avoiding default were good.

Technologically Advanced

The BAE design is technologically advanced. According to Richard de Neufville, it is not the next generation of baggage system, it is more like a jump from third to fifth or sixth generation. Unfortunately, BAE misused its technological advantage by expecting spectacular performance from the system components, and not allowing them a proper margin of error. The components were expected to perform to their highest theoretical capabilities. Bruce Van Zandt, operations manager for the backbone communications network at Denver International Airport stated, "The system pushed the envelope of technology. The components that were put into the system were run right to the limit of what they were designed for." When any of the components failed in this respect, others failed as well due to the system's inherently tight coupling.

Planning

BAE, DiFonso said, was originally contracted by United in the fall of 1991 to build a baggage system specifically for United Airlines at the new Denver International Airport. The airline, he said, was concerned that after several years into the project, the city still had not contracted for a baggage system. Indeed, Denver's baggage system design was an afterthought to the construction of the airport. The BAE system was detailed well after construction of Denver

International Airport had begun. When construction of the automated baggage system finally began, problems arose due to the constraints of the buildings and structures which would contain the baggage system's tracks and other components. Unfortunately, the system had to fit into the underground tunnels and available space given the challenging and unrelated Denver International Airport construction plans. Tight geometry resulted in additional construction difficulties. Telecars had to make unreasonably sharp turns on tracks shoehorned into corners at considerable inconvenience. According to Bernie Knill, an obvious solution to such poor planning techniques entails designing the baggage handling system with the building, and installing the system as the surrounding structure is being built.

Schedule

BAE officials said that a timetable for the opening of the airport was never realistic and should have taken potential problems into account. When asked about the ambitious timeline, one BAE official responded, "We knew that was not long enough and we said so. It's a job that ought to take twice as long." While the media hammered BAE for their role in the delays, BAE vice president of engineering Ralph Doughty voiced his frustration. "Its a 3-4 year job we were asked to do in 2 years," he said. Denver Aviation Director James C. DeLong offered the explanation, "We had a project that should have taken seven years and we tried to do it in four years. We just misjudged. We'll probably do it in five." As the project fell more and more behind, human error became a factor due to a more truncated training and testing period.

Requirements Modifications and Other Changes

When BAE accepted the job, no changes to the project were anticipated, DiFonso said. However, once BAE's work had begun, Denver officials often altered plans and timetables without consulting either the airlines or BAE. Even worse, when changes were made to one part of the system, it was not clearly understood how the changes would affect the system as a whole. To reduce its construction costs, United decided to remove an entire loop from its own ambitious design for concourse B. Rather than two complete loops of track, United wanted just one. This change shaved $20 million off the system's price, but required a complicated and untimely redesign. Other changes were made such as relocation of outside stations, addition of a mezzanine baggage platform, and Continental's request for a larger baggage link. As the project matured, it grew in size and complexity. Design changes increased the system's technical difficulties that consistently hampered progress. When BAE learned that the centralized system's faults ran through the rest of its tightly coupled subsystems, they chose to decentralize all of the tracking and sorting computers. Such major design changes deserved review of alternate courses. However, due to the condensed development and testing schedule, on the fly design changes that typically require major design alterations were treated with minor patchwork

Chaos

The first time that BAE ran the baggage system for performance testing, the resulting chaos was sobering. In March of 1994, the installation staff ran the BAE system for several media groups. Faults throughout the entire baggage system destroyed bags and flung suitcases out of telecars. The next day, phrases like "bags were literally chewed up," and "clothing and other personal belongings flying through the air" hit newspapers. Telecars jumped tracks and crashed into each other. Suitcases went flying like popcorn kernels, some of them breaking in half, spewing underwear in every direction. When the telecars crashed into one another they bent rails and disgorged clothing from suitcases. Others jammed or mysteriously failed to appear when summoned. Telecars crashed into each other especially frequently at intersections. Many dumped their baggage off at the wrong place. Some telecars became jammed by the very clothing they were carrying. As the telecars flung their bags off or ripped them open, the clothing clogged the telecar rails, halting traffic and crashing other telecars in back. Most telecars holding bags with unreadable bar codes were routed to holding stations. Other telecars that knew were they were going collided with telecars that couldn't remember.

On May 2, 1994, DiFonso addressed the situation, and stated that the system was not malfunctioning, it just hadn't been fully tested yet. BAE officials blamed the mutilation and other problems not on a defective design, but on software glitches, and mechanical failures. They found one reason for baggage mutilation involved the airport personnel. When workers placed bags on the conveyor belts upright, the system frequently jammed or shredded the bags. When the bags were placed correctly, laying flat, the performance improved. BAE found many design culprits and appropriately made changes. Slowly, BAE improved the system's general performance.

Unfortunately, in August of 1994, the system's performance was still poor. Even during planning of the alternative tug and cart baggage system, telecars continued to collide and fall off their tracks. In late August, Glen Rifkin of Forbes wrote, "Throughout the day, workers are seen unclogging tracks lined with bags that have been cut in half." Morale was low among the installation crew. When asked how the test bags were damaged, one worker replied in mock horror, "It's not eatin' bags. A truck ran over these outside."

Software

Ginger Evans, director of engineering for Denver International Airport, claimed that BAE didn't pay enough attention to the programming issues early enough in the design process. She believed that alleged troubles with building access or mechanical issues weren't the problem. "It's that the programming is not done," she said. She faults BAE for this inadequacy. Others contend that many problems of mechanical nature originated in the buggy software. According to Glenn Rifkin of Forbes, software sent out carts too early or too late. Robert L. Scheier of PC Week alleged that it was the system's software problems that resulted in the airport's 3,550 baggage telecars crashing into each other or becoming stranded along its 22 miles of track.

BAE president Gene DiFonso contested allegations of faulty software playing the central role in the system's horrific performance by stating that "Software was not the major problem. It was an electromechanical problem. The system was stutter-stepping because the electromechanical side wasn't fully up to the software's capability." However, DiFonso admitted that program code had been a nightmare at times. He revealed that the burden of writing code for establishing and maintaining communication with the airlines' reservation systems was heavy. Particularly challenging was the duty of connecting with United's Apollo reservation computers. A definite element in the disarray of the communication software was the process of language translation, since BAE's computers had to converse in the same software language as of each airline. Such translation work is painstaking and often laden with bugs.

While writing code for the communication, tracking, and other numerous applications, the software grew more complicated. As a consequence, the code completion agenda experienced the threat of becoming unmanageable due to escalating levels of complexity. By principle, as program code grows in complexity, it becomes increasingly hard to track or understand (see

Complexity Of the System). Instances of systems code delaying the opening of large projects abound. For example, the English Channel Tunnel was delayed for about a year by problems with more than three million lines of code. Only adding to confusion, applications of such size typically borrow from a number of object code libraries and other resources. As Bjarne Strousoup noted in 1987, "No major program is ever written in the programming language as described in its basic language manual. Libraries of all sorts are used and often determine the structure of the program." Finding the origin of a glitch can consequently be nearly impossible. A giant project held hostage by troublesome software code and insufficient testing is the technologist's worst nightmare. When troubles arose with the Denver baggage system's complicated code, BAE programmers had to customize the software to handle each individual software related problem. This process rudely resulted in code hacking. "If the baggage handling system has all of its problems solved, it will be via hack-o-rama," wrote Larry O'Brian.

System Testing

According to John Dodge, 75 percent of all information systems projects are plagued by quality problems, and only 1 percent of the projects are completed on time. Dodge cites insufficient software testing as the most frequent culprit and describes it as "one of the thorniest client/server issues." Munich officials had advised Denver to leave plenty of time and resources for testing. At the Munich airport, where a smaller automated baggage system sorts baggage, engineers spent two years testing the system. In addition, the system was up and running 24 hours a day for six months before the airport even opened. The Munich officials said that the Denver staff did not heed their advice. Although BAE had tried to leave sufficient time for testing, they were constrained by their promises of a quick pace in developing the system. Moreover, troubleshooting the maze of software was a slow process. According to DiFonso himself, "Underestimating the time required to discover problems, fix them, and retest," was the main reason for the opening delays.

Testing the system's mechanical side was unsuccessful. One source of frustration involved radio communication between testers throughout the underground tunnels, concourses, and control rooms. Engineers using radio communication in the concourses couldn't talk to their colleagues during testing because of dead spots in radio transmission around the airport. Testing proved to be difficult and more time consuming than BAE anticipated. BAE's employees worked around the clock, rarely surfacing for air from the bowels of the system, as one BAE manager remarked. In September of 1994, BAE's parent company, BTR Plc. of London, brought in the British-based PA Consulting to help debug the system. In addition, BTR executives themselves began spending time in Denver working on the BAE design. The influx of engineers, programmers, managers, and analysts improved the pace of testing. According to Glenn Rifkin, that month, the 110 BAE employees got their first week off in two years.

Timing

Before timing problems were known, United Airlines ticket agents were generating on-line printed baggage tags too quickly. The timing gap led United's Apollo computer reservation system to communicate erroneous data to BAE's sorting computers, causing the baggage telecars to go to a manual sorting station, and not their proper destinations. The solution involved slowing the ticket agents' actions through additional training.

BAE altered system speeds when officials discovered significant timing problems in matching telecar and baggage arrivals as well. Denver Post staff writer Mark Eddy believed that BAE had to regulate more closely the speed of the telecars themselves. To ensure that bags would land in telecars, not ahead or behind them, BAE engineers revised telecar and baggage merge timing, and improved clutch brake reliability. Telecar speeds were smoothed by moving motor locations, adding magnets to tracks, and adjusting magnet gaps. To further improve accuracy in telecar and baggage merging, the release of empty cars from storage areas was tailored to better match demands. BAE constructed a new model, and changed to a new telecar reservation process. Adding redundant controllers to the baggage to telecar loader reduced misalignments and timing gaps. The system's general reliability was additionally improved by exercising time-critical elements each morning to warm the system's components.

Equipment

Some critics cite BAE's equipment choices as factors of the system's failure. Regarding the distributed 486-based PCs, Carl B. Marback states that, "when you combine DOS' quirks (my DOS PC still crashes regularly) and the uncertainty of PC software (I get lots that doesn't work) with third-party things like Novell and network hardware, where is the 'managing vendor' to sort it all out?" As he predicted, the computers became overwhelmed when tracking thousands of telecars in transit. This led to the system redesign called for by both the airlines and Denver. The new design reduced the system's complexity and far reach, and successfully bailed the computers out of their terrific workload.

Early in testing, laser scanning equipment that misread bar codes became a major problem. This was clearly a product of deficient planning, since anyone who has watched the checkout clerks in a grocery store with laser scanning devices has seen that they sometimes make mistakes. Continental had first experienced such problems with the system's poorly printed baggage tags when their laser scanners rejected about 70 percent of the tags, and sent the telecars to the manual sorting station. BAE found that part of the problem involved the baggage tag printers producing poorly printed bar codes that were easily misread. When the tags were reprinted clearly, the system only rejected 5 percent of the tags. Other difficulties in lasers reading bar codes occurred when airport workers erecting walls sometimes knocked laser scanners out of aim. BAE resolved some scanning difficulties by installing redundant laser scanners. Unfortunately, in BAE's case, it was difficult to pinpoint every manifestation of laser scanning error due to the number of possibilities inherent in the system. For example, when a laser scanning error occurred, it was possible that the baggage handler had placed the bag on the conveyor belt with the bar code tag hidden, or the bag may have had tags from earlier flights in view. The tag also may have been dirty or out of the field of view or focus of the laser scanner. Therefore, the complicated problems were laboriously dealt with one by one.

The scanning problem was compounded by the telecar to computer communication process. Even when the bar codes were successfully read by the laser scanners, the bar coded information was transmitted by radios on each of the telecars. This added a second opportunity for error, and decreased the reliability of the system in general. This can be expected since the reliability of two devices working accurately together is roughly the multiplication of their individual reliability, which is always less than either device alone. Conversely, if two devices are made to perform the same task, the built-in redundancy improves the combined reliability of both devices. This is an important principle, since the Logplan report made it clear that there was not enough redundancy to satisfy the system's reliability needs. Soon after Logplan's report completed, Denver decided to install the alternative tug and cart system for added redundancy.

When telecars that eluded the scanning and transmitting problems engaged in transit, other problems occurred. Some glitches in photocell quality and placement caused the tracking computers to mistakenly presume there was a telecar jam. To solve the problem, BAE reviewed the design and made sure that the motors and photo electric eyes were located where the computer thought they were. BAE added redundant photocells, and enlarged their diameter so they could 'see' more. Some photocells that couldn't detect cars going by were found coated with dirt or knocked out of alignment. The painting crews that had covered up some electronic eyes with paint went back and scraped them clean. Bumpers on the telecars had also been interfering with the photocells' tracking process, so BAE workers adjusted each bumper on all 3,550 cars.

Faulty latches were blamed for causing telecars to dump luggage on their tracks or becoming jammed against the side of a tunnel. When each of the car's latches was modified, the obstructions subsided. Another problem involved airflow flipping light or empty suitcases out of their telecars. To reduce the likelihood of this occurrence and to better understand the system's aerodynamics, BAE engineers pressure mapped the telecars in a full-size wind tunnel.

Some parts of the system required that telecars negotiated sharp turns and other abrupt conditions. Where high-stress areas of track frequently broke or bent, BAE added reinforcements for increased strength.

Power Generation

For some time, the system was experiencing unreliable power generation and electrical surges that no engineer could trace. "Even the electrical engineers don't understand completely what's going on," said Jay Button, BAE sales manager. The power surges tripped breakers on some of the system's 10,000 motors. Sometimes, the airport's erratic power generation shut down the system totally.

During detailed electrical tests, electrical power feed systems fluctuated, causing the surges that disrupted the system's operation. To solve the problem, BAE installed a series of special industrial power filters to smooth the flow of power.

Line-Balancing

To understand how a typical line-balancing problem can cause delays and inconsistent performance, think of the times that you missed a bus because it was so crowded with people that had boarded at earlier stops, that you were left behind waiting. Line-balancing problems are common and well known to many systems designers. Furthermore, just as with every other design issue, line-balancing solutions obey the law of complexity. The difficulty in solving such problems increases exponentially with the number of lines or cues in the system. The BAE system has hundreds of such cues. To gain perspective on the difficulty of understanding line-balancing, note the example of Atlanta airport's interior transit system. In this case, the problem involved the people mover between the five passenger buildings and was the subject of a doctoral dissertation at MIT (Daskin, 1978.) This was a two year long intensive effort on a system much less complicated than the BAE design. Ironically, the line-balancing problem is sometimes compounded by a general ignorance or disregard for its existence. BAE engineers seem to have discovered the line-balancing problem about six months after the intended airport opening date. A site manager giving a tour of the BAE system in July of 1994 explained the line-balancing problem and described it as a novel phenomenon that they had just started to work on!

BAE president Gene DiFonso revealed the system's line-balancing troubles during a tour in late February of 1995. "We had bags lined up and waiting for vehicles and empty vehicles going by with no bags," he said. "The problem was that we assumed we could release empty vehicles in some arbitrary quantity. Sometimes that number coincided with the number of bags waiting, but sometimes it didn't." Empty cars that were needed and summoned ended up instead being routed to waiting pens. Late in the testing period, the BAE staff finally curbed the system's dispatching problems. The solution came when programmers wrote new line-balancing related logic for both the OS/2 based car routing application and the PLCs that carry out the commands

Complexity

Admitting their ambition, Ralph Doughty stated, "We've done car-based systems before, but never this large." The project's size and comprehensive nature caused it to experience a many problems due to complexity. This is predictable when considering complexity theory (see "Complexity Of the System.") Typically, systems with more than 10,000 function points are canceled 65 percent of the time, according to Capers Jones. In Denver, the system's terrific workloads bogged down the network of distributed computers that track luggage on the 3,550 telecars. Computers were tracking so many telecars that they mistracked at times due to strict timing limitations. United believed that the tremendous workloads warranted drastically reducing the system's complexity. To begin reducing the complexity, Denver decided to completely cancel concourse A's automation design. The tracks and machinery serving concourse C were redirected to concourse B as well. The number of destinations in the system went down by a third when only one of the three concourses remained in the design. The number of destinations decreased by an additional third when Denver decided to consider only outbound traffic on the remaining baggage loop. Denver cut the system's track capacity rate from 60 to 30 cars per minute, when United argued that the computers needed to take more time to avoid mistakes. Along with the earlier changes, cutting the rate of sorting on each track caused the overall system complexity to shrink by a full order of magnitude. Unfortunately, the concept of a fully automated, high speed airport-wide baggage system deteriorated to a less complete system with drastically reduced complexity, speed, capacity, performance, and efficiency. This new system, however, worked well enough to open the airport.

Logplan

Denver conducted a worldwide search for consultants who could figure out exactly what is wrong and how long it would take to fix. Unfortunately, this was something that neither the city nor BAE could predict. Logplan, a German consulting company was hired for the job. Logplan had recently demonstrated its skills by performing similar troubleshooting and systems integration on the baggage system in Frankfurt. Denver and United then used Logplan's final report in deciding how to make the pieces of their system work.

SYSTEM COMPLEXITY

In studying the problematic design and construction of the BAE automated baggage system, the issue of complexity deserves attention. Most of the management involved with the baggage system have expressed their belief that the complexity of the BAE design outweighed other factors contributing to the system's poor performance. "I'd say most of the problems are because of the complexity of the system," said John Philp, director of public affairs at United in Denver. "It's the software to a degree, but also just the size of it." Engineers and material handling professionals have echoed this opinion.

Defining Complexity

Complexity can be described as a measure of how understandable a design is. A system with high complexity requires great mental effort to comprehend, while a system with low complexity is easily understood. Richard de Neufville, a professor at the Massachusetts Institute of Technology explains that "as you linearly increase size or complexity, the difficulties in making a system work increase exponentially. Basically, that means if a system is ten times more complex, you can expect that it is going to be one hundred times more difficult to deal with." Furthermore, while a complex system will require more effort to build, there is an even higher price to pay. This is because a majority of the amount of time and work on a system is typically spent in maintaining it rather than developing it. It is therefore important to build systems with complexity levels that are manageable not only in their construction, but in their maintenance as well. The original BAE design of the Denver International Baggage System was neither. More than twenty programmers worked undistracted for two years to write the software. Engineers took as long in their efforts of developing the electrical design and circuitry. What they ended up with was a highly coupled system whose points of failure were widespread and inconsistent. It was a recipe for a systems nightmare.

Heed Caution

In order to avoid such calamity, it pays to understand the concept of complexity. A careful review of the BAE design's complexity could have forewarned Denver of the terrific challenge of making such a system work. Richard de Neufville states, "the most fundamental problems with the automated baggage system designed for Denver had been predicted by theoretical studies and consulting reports, were avoidable, and should not be repeated." Unfortunately, the issue of complexity and its effects were most clearly confronted in the designers' hindsight, once the machinery had been installed and malfunctioned. Soon after the construction of the baggage system ended, it was turned on and expected to function as the design specified. To Denver's surprise, the system's performance was poor enough to deem it unusable. Even with the initial work done to overcome the system's troubles, its complexity was not addressed. Frequently with complex systems, correcting one small problem on part of the system causes two more to spring up in another part, which may not be detected for some time. Frank Kwapniewski, BAE site project manager affirmed this occurrence by stating, "This thing is 20 miles long, so you have numerous problems that are solved at one end and then have to be resolved on the other. You take two steps forward and one step back." In BAE's case, the baggage system's complexity overwhelmed engineers and technicians enough to reduce them to tedious trial-and-error debugging methods. During testing, situations where not a single BAE or Denver employee knew what was wrong prompted Mayor Webb to offer explanations such as, "We're dealing in areas we don't even understand." Soon after testing proved that problems with the system were increasingly complicated, Webb began searching for a NASA-level consultant to assist BAE in their plight.

Complexity Of the BAE Design

An example of the complexity in BAE's design is the act of summoning an empty cart from one place in the baggage track circuitry to another. This seemingly simple action must take place up to a thousand times a minute during standard airport operations. However, due to differences in empty telecar demand throughout the airport, empty cars frequently must change direction, jump tracks, or switch to another loop in the circuit. Because of the logistical difficulty of any of these maneuvers, special sequences can be ordered by the computers. For example, to bring one empty telecar to its neighboring station, it may need to merge with traffic going the opposite direction, exit at a special purpose intersection, avoiding other telecar pileups or stalls. It may then dive down beneath the tracks at a special crossover point in the intersection and merge with traffic running the correct way. It may then travel until it reaches its neighbor station destination and exit at the intersection, only to find that it must change tracks to reach the destination. There are countless variations of such traffic routines that the tracking computers must generate in lightening-fast, error-free operation. To make matters worse, the patterns of system loads are highly variable. The patterns depend on the season, time of day, type of aircraft, number of passengers, percentage traveling with skis, and other factors. At peak times, all of the system's 3,550 telecars are in motion. If a telecar interchange is popular enough, the telecars attempting to merge with busy traffic may wait in cues of other telecars. The cue tracks are of limited length. Should a cue fill to the maximum, the three hundred tracking computers must immediately detect the problem and transmit re-routing instructions to all telecars in danger of crashing. It's like taking a city with 4,000 cars and no drivers in them," says Ralph Doughty, vice president of engineering for BAE. "We have to be able to control all these cars when they come to an intersection." Control can be hard to achieve when so many connection points exist for the high speed telecars. Trying to predict the combinations of circumstances that the software must control is difficult. Deciding how the computers must respond to each of the combinations is difficult as well. When the wrong choices are made, the project can become a disaster.

COMPARATIVE FUNCTIONALITY

The Denver International Airport's automated baggage handling system fell short of its original design specifications by a large measure. Before the system was installed, most considered it to be the most advanced baggage system in the world. After its performance was known, critics called it "a national embarrassment for the city." Here is how the finished system compared with its theoretical design.

Completion

The anticipated completion date for the entire baggage system was October 31, 1993. The redesigned system finally worked on February 28, 1995, after delaying the airport's opening four times. Since the system's conception, the designers made increasingly large changes to it. When the system failed, Denver handed control over the project to United Airlines, who became the systems integrator. United declared that they would make the Denver system 'work' by reducing its complexity and performance.

Scope

While the system's scope began airport wide (serving concourses A, B, and C), it now serves concourse B only. Even though concourse C previously had its part of the automated system working, its components were scrapped and added to concourse B, which had failed testing.

Many airlines protested this move, and were informed that concourse A and C would receive traditional tug and cart systems.

Capacity and Efficiency

Design changes in the automated system cost it some efficiency. Because the tracks serving both concourses B and C were repositioned to serve only concourse B, the system's efficiency dropped. Additionally, each track's 60 vehicle per second capacity was limited to 30 vehicles per second, further affecting efficiency. Only half of the 84 airport's gates were served, and at only 12 percent of the system's capacity. Instead of handling originating, terminating, and transfer baggage, the automated system handled only baggage originating in Denver.

Alternative Tug and Cart System

The traditional tug and cart backup system was originally installed to serve the entire airport in case of automated system failure. Instead of its use as backup, airlines in concourses A and C relied on this system, since no automated system existed in their concourses. This traditional system cost $71 million, and was designed and installed by Rapistan Demag Corporation in Grand Rapids, Michigan. Even though the traditional system had none of the bells and whistles of the automated system, it was still quicker than the system at Stapleton International Airport. It was slower, however, than the theoretical speed of the automated system, since the traditional system relied on people rather than computers for handling baggage.

Financing

Both Denver and the airlines suffered losses because the automated baggage system did not deliver the productivity, efficiency, and cost-effectiveness as originally intended. Ironically, the system's original $193 million price increased to $311 million, including the Rapistan backup system.

OPENING DELAYS

Denver International Airport was scheduled to open on October 31, 1993 with all three of its concourses fully running on the BAE automated baggage handling system. On February 28, 1995, Stapleton International Airport finally closed its gates and terminal. Denver International Airport opened on the same day, absorbing all of Stapleton's traffic. Its opening came sixteen months late. Here are some of the milestones reached, and problems encountered in the history of Denver International Airport's making.

March 2, 1993 Denver Mayor Wellington Webb announces the first airport opening delay. The October 31, 1993 opening date is changed to December 19, 1993 to allow for a seven week debugging of hundreds of systems.

October 25, 1993 Mayor Webb announces the second airport opening delay. The December 19, 1993 opening date is changed to March 9, 1994 to accommodate changes made by the airlines, allow more time to test critical airport systems, train airline ticket agents and other workers, and complete installation of fire and security systems.

March 1, 1994 Mayor Webb announces the third airport opening delay. The March 9, 1994 opening date is changed to May 15, 1994 to accommodate problems of troubleshooting the airport's complex baggage system. Mayor Webb further asserts that the airport will open on May 15th "come hell or high water."

May 2, 1994 Mayor Webb announces the fourth airport opening delay. The May 15, 1994 opening date is delayed indefinitely to resolve more problems encountered while testing the baggage system.

June 20, 1994 The Webb administration announces that four steps are required in completion before a new opening date will be announced. First, BAE must submit a master schedule. Second, Logplan and the city must evaluate the BAE master schedule and conduct several tests to see how realistic it is. Third, Denver must consult with the airlines on their recommendations. Fourth, the BAE's baggage system must operate for an unspecified period of time at an acceptable level.

August 4, 1994 Mayor Webb announces that the city will spend an extra $50 million to build a conventional airport-wide luggage system using traditional tugs and carts.

August 22, 1994 Webb announces that Denver International Airport will open on February 28, 1995.

September 7, 1994 Denver and BAE sign an agreement that allows BAE to work directly with United Airlines to simplify the baggage system so it can be ready for a February opening.

September 21, 1994 Denver and BAE begin mediation over who is to blame for the cost overruns and problems with the baggage system.

February 28, 1995 Concourse A's opening is postponed indefinitely, owing to litigation between Denver and Continental Airlines, which has canceled its lease of 30 gates, and its operation of using Denver as a major hub. Concourse C, carrying Delta, American, TWA, USAir, Midwest Express, GP Express, Midway, Markair, Morris Air, Sun Country, America West, and Northwest opens with a traditional tug and cart baggage system. Concourse B, housing all of United's gates, opens using the BAE automated baggage handling system only on outbound, Denver-originated flights.

After the fourth delay in May 1994, Gene Di Fonso explained, "There's no question that it works. We just need more testing time."Mayor Webb used caution in scheduling a new opening date. Instead, he postponed the airport's opening indefinitely. BAE had promised completion dates before and missed them. Webb explained that "while deadlines do motivate some people, they don't work well for the computer programmers who must fix what's wrong at DIA." Denver Public Words Manager Michael Musgrave added, "Our approach no is establishing performance milestones rather than using calendar day scheduling."

FINANCIAL HARDSHIP

DIA Origin

United States Transportation Secretary Federico Pena was the previous Denver mayor who, in the mid '80s, got the Denver International Airport project started. He publicly called it "an airport for the next century, a critical investment for the country." Denver International

Airport planners originally anticipated a $1.7 billion dollar price tag. The final cost more than doubled to $4.5 billion.

Analysis Of Costs and Benefits

When questioned on the merit of enduring the enormous costs, problems, and delays, Brian Cary, vice president and senior economist of First Interstate Bank, Phoenix, replied, "The cost is being generated on the front end, but the benefits are on the back end." Some others feel that the nearly $5 billion dollar price will be laughed at by future generations as they watch other airports scramble to take the same direction as Denver. This point of view was not shared by Denver voters, who indicated in polls that they hypothetically would vote no on the Denver International Airport city proposal, could they go back in time. While united in this respect, few people in Denver agree on who is to blame for the missed deadlines and cost overruns caused by the flaky baggage system.

Owners Of Daily $1 million Debt

Even before voters were asked to cast their first vote on the airport project, Denver officials promised that no money would be taken from the pocket of a single Denver resident or business through increased taxes. The city of Denver, wishing to keep this promise, has since issued bonds several times to raise capital for the new airport. At the end of 1994, the bonded debt of Denver International Airport had reached $3.8 billion dollars. Even worse, with each new problem and delay, the ratings for Denver's airport stocks dropped. This made it difficult for Denver to issue new bonds when new delays and budget shortfalls occurred. Denver was forced to offer higher interest rates to investors to attract them to the new bond issuances. In the latest months of delay, the bonds had reached rates of near junk-bond status. Any further decline would have caused Denver to pay such high interest rates on future bond issues that it wouldn't have been feasible to attempt to borrow. Because it cost Denver about $33.3 million each month that the airport remained closed, critics began to fear the possibility of default. Even Michael Boyd, an aviation analyst working with Denver was skeptical. "It's highly questionable," he said. "United is bailing this thing out." While part of the debt was absorbed by the city and county of Denver, most of it was paid by the airlines, which were hard hit by the price of operating at Denver to begin with. Continental Airlines had recently filed for bankruptcy. Henry Dubroff of the Denver Post wrote, "Lead airline United is going through the Wall Street equivalent of a heart transplant. It can't support this project for very much longer." The total price tag for sixteen months of delay came to around $500 million dollars. Half of this enormous amount went to debt service, such as paying interest to bondholders. The other half was paid for operations and maintenance of Stapleton and Denver International Airport combined.

Litigation With BAE

To recoup some of its losses, Denver initiated a formal dispute with BAE regarding the alternative manual baggage system. Denver argues that the alternate system's $71 million dollar price should be paid by BAE, since its problems made the backup system necessary. Denver may have considered litigation with BAE for other delay incurred losses, but would likely have waited until BAE's work had finished to avoid spawning further delays due to legal struggle. At the time of this writing, no lawsuits have been filed between the two groups.

Passenger Flight Fee

To further ease its misfortune, Denver International Airport is charging all of the airlines a flight fee of nearly $20 per passenger. This has made the Denver International Airport the most expensive in the nation. Airports typically charge airlines between $5 to $10 per passenger for such fees. Stapleton's fee was $8 per passenger. This price hike has led the airlines to pass on the additional cost to the passengers through higher ticket prices. "At a time when airlines are taking lettuce leaves out of salads to save money, $20 is a big difference," said Michael Boyd. United Airlines has increased all of its Denver based round-trip ticket prices by $40.

SUMMARY

Lessons Learned

In ending any constructive narration of a project gone wrong, there likely are lessons to be learned. An appropriate conclusion to this study revolves around the notion that in planning a project of such scale as the BAE automated baggage system, great care must be placed in acquiring resources of information and expertise to help make important judgments early on in the design process. Developers should pay close attention to recommendations and advice of scholars as well as leaders of industry. Time-critical projects like the Denver baggage system require not only solid reasoning, but good anticipation of problems. It is of great importance that a timeline be built that allows for a generous testing phase. Technologically advanced designs perhaps deserve more development and testing time than may seem proper. However, the price of time will likely result in later payment in terms of improved accuracy and efficiency, just as the BAE design promised. For purposes of meeting a steeper learning curve in operating advanced non-traditional machinery, a good margin of error should be kept. Lastly, keeping the system's complexity down to manageable levels will save time of prolonged testing, and money for redundant parts and skills.

Baggage System Growing Pains

While many of the smaller hardships experienced in the baggage system could have been more efficiently resolved, in retrospect they seem to mark the system's technologically advanced growing pains. Larger failures certainly could have benefited from better insight, although a variety of special circumstances existed during their discovery. To discount the element of confusion or existence of many faults appearing at once would be unfair, since the designers and builders of the BAE system lacked the luxury of time.

More Than 10,000 Workers

Despite the poor reviews offered, the Denver baggage project has successfully emerged, and triumphed over the many setbacks regarding its initial failure. For the wealth of knowledge that came from the baggage system's affliction as well as more general airport trials, acknowledgment is due to the more than 10,000 people who devoted their time and energy to bringing the airport to a state of sound operation. In light of the dismal times when the baggage system seemed to be in a state of unknown fate, the final success deserves praise.

Prevention Of Crisis

In reflecting upon the automated baggage system's multitude of difficulties, United spokesman John Philp summed up his feelings of the system's completion. "There are a lot of 'shouldas' and 'wouldas' and revisionist history," he said. He is correct in hindsight. However, criticizing Denver, BAE, or United for the baggage system's problems and inadequacies would only serve to lay blame to many of the hard working employees who are responsible for bringing the system to its current state of operation. It is more appropriate to place the troubled baggage system's problems in the context of solid management and engineering principles. Hopefully, such analysis can reduce or prevent a system catastrophe from striking as control and information systems grow larger and more liable every year.

GLOSSARY

Automation - A process involving use of machines to automatically perform tasks otherwise performed or supervised by humans.

Complexity - A measurement used to describe the understandability of a system. Systems of high complexity are more difficult to understand whereas systems of low complexity are easier to understand.

Concourse - The outer buildings of an airport that house the airline gates. Airplanes typically park beside a concourse to embark or disembark travelers.

Dynamic loading - A process of loading where vehicles do not stop in loading or unloading. They just slow down. In contrast, vehicles of static loading systems must stop to load or unload.

Frequency reader - A radio wave receiver which reads signals emitted from a transmitter, transmitting at a certain frequency. Once it reads a signal, the frequency reader can decode it into information or send it onwards for use elsewhere.

Laser array - A laser intended to move its beam across a bar code and gain information from it. Laser arrays are familiar to anyone shopping in a grocery store equipped with them at the checkout counter.

Laser scanner - See laser array.

LIM (Linear Induction Motor) - A motor that propels its load in a linear direction by use of a magnetic coil. The motor's magnetic counterpart piece is attracted to the motor's coil when charged with opposite polarity. Very quickly as the piece passes, the motor's coil reverses its charge, changing to alike polarity. The piece is then repelled away from the motor's coil.

Line-balancing - A process which results in a system's balance of traffic. For example, a perfectly line-balanced city will have each of its streets used by the same amount of traffic, weighted by each street's intended capacity. No traffic jams could result in such a city.

Photocell - A circuit identifying an item by designated information. The information is transmitted by the photocell with flashes of light.

Photo-electric sensor - A sensor which detects movement by using a light emitter, and a light detector. When an object moves between the two, the circuit is broken, thereby signaling movement.

PLC (Programmable Logic Controller) - A computerized device which controls a switch, hinge or other piece of machinery. PLCs can be programmed to open a valve in a car, for example.

Radio transponder - A device which communicates information to another device, such as a frequency reader. When signaled, a radio transponder will respond by transmitting radio waves that can be read and decoded into useful information.

Telecar - A vehicle in a baggage handling system that can be loaded with baggage.

Tug and cart - The traditional type of baggage handling system which includes gasoline-powered tug vehicles that pull luggage-carrying carts.

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