PROJECT MANAGEMENT

CASE STUDY #2: The Baggage System at Denver

Due: Nov. 21st @ 17:00h

READINGS:

The Baggage System at Denver: Prospects and Lessons

DISCUSSION/EXERCISE:

Objectives:

- Introduce students to real world problems
- To experience synthesizing a broad view subject into a one page executive style memo that clearly and effectively discusses aspects related to planning problems due to bad scope and requirements management.

Assignment:

1. Individually, from a project management view, what were the top three issues involved with the development of the baggage system at Denver. Take special attention to aspects related to the requirements and scope.
2. The paper will be 1 page maximum, with a minimum of 12 pitch font, and 1 inch margins (use the word header/footer section for your name, assignment name, etc). Consider the paper from the point of view of senior management that has limited time to digest what you will write. You will probably not be able to include all the above in 1 page, so pick the most critical items. If you write less than 1 page, then you probably have not properly answered the question.
3. Spelling, grammar and "readability" count in the grade: **both Portuguese and English can be used**.
4. Be prepared to discuss the case in class immediately after the due date.

THE BAGGAGE SYSTEM AT DENVER: PROSPECTS AND LESSONS

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This article discusses the fundamental design difficulties of the fully automated baggage system originally planned for the New Denver Airport, and their implications for airport and airline management. Theory, industrial experience, and the reality at Denver emphasize the difficulty of achieving acceptable standards of performance when novel, complex systems are operating near capacity. United Airlines will thus make the Denver system "work" by drastically reducing its complexity and performance. Automated baggage systems are risky. Airlines and airports considering their use should assess their design cautiously and far in advance, and install complementary, backup systems from the start.

Ref: "The Baggage System at Denver: Prospects and Lessons," <u>Journal of Air Transport Management</u>, Vol. 1, No. 4, Dec., pp. 229-236, 1994.

Background

The City and County of Denver have built a massive new airport, the New Denver International Airport. It extends over 13,568 hectares (about 53 square miles); has 3 parallel North-South runways, 2 parallel East-West runways, and room for a total of 12 major runways. In many ways the New Denver Airport represents a model of the airport of the future (de Neufville, 1995).

At opening, the Airport will have cost about US $ 5 billion including the US $ 685 million contribution of the Federal Government and the over US $ 400 million investment of airlines in fitting out their passenger buildings, catering facilities and cargo centers (US Government Accounting Office, 1994). At the end of 1994, the bonded debt of the municipally owned Denver Airport System was more than US $ 3.8 billion (City and County of Denver, 1994b).

A mechanized baggage system is at the heart of the New Denver Airport, as for all major new airports. In the case of Denver, this was to be something unique: the "Integrated Automated Baggage Handling System", originally designed to distribute all baggage -- including transfers -- automatically between check-in, the aircraft and pick-up on arrival.

Unfortunately, massive problems plagued this automated baggage system. (See Henderson, 1994, for example.) Consequently, the New Denver Airport did not open in October 1993 as scheduled. After missing later opening dates in April and May 1994, the Airport seems -- as of January -- likely to be open in March 1995. The delay would then be around 16 months.

This delay costs the owners a lot. The interest on their bonded debt exceeded US $ 271 million for the single year of 1994 (Deloitte and Touche, 1994). The costs of maintaining the new airport are extra. A commonly accepted estimate of their costs of delay, endorsed verbally by officials in Denver, has been US $ 33 million a month. By March 1995, the delays may thus have cost them around US $ 500 million. A year after the original opening date for the airport, the City and County of Denver borrowed a previously unscheduled US $ 257 million (City and County of Denver, 1994b).

This delay is also expensive for the airlines. United Airlines invested about US $ 261 million, and Continental 73 million, in peripheral facilities in anticipation of the 1993 opening (United Airlines, 1993; US Government Accounting Office, 1994). FedEx likewise created a sorting center for around US $ 100 million. By the time the airport opens, the opportunity cost of the idle investments may have cost the airlines around US $ 50 million.

Both the airport owners and the airlines will also suffer losses to the extent that the automated baggage system does not deliver the productivity and efficiency that they had bargained for.

Airline and airport management can learn much from this unfortunate experience. As indicated by the discussion that follows, 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. The basic lesson is that automated baggage systems are risky, and therefore that airlines and airports considering automated baggage operations should assess their design and performance cautiously, and should implement them with the insurance of backup systems from the start.

Design of the Automated Baggage System

The fully automated baggage system originally planned for the New Denver Airport was unique in its complexity, its novel technology, and its anticipated capacity. It was designed to deliver each bag, including transfers, individually from check-in or the unloading of the aircraft to the outward bound aircraft or baggage reclaim. The delivery mechanism consists of about 9 km. (5.5 miles) of conveyors and over 27 km. (17 miles) of track on which circulate 4000 individual, radio-controlled carts, the so-called "destination coded vehicles" or "DCVs" (US Government Accounting Office, 1994). The capacity of each track was supposed to be 60 DCVs per minute, one a second.

The essential layout of the automated baggage system at Denver is that conveyor belts feed the central network of DCVs. The bags do not flow continuously from the conveyor belts, however, as they do in traditional systems. Each bag must independently be placed on its exclusive cart, and thus the delivery of the bags from the conveyor belts must be carefully controlled. Furthermore, the conveyor belt can only advance when there is an empty cart onto which the leading bag on the conveyor belt can be placed. The speed at which the conveyor belts can advance -- and thus the performance of the entire system -- depends on the rate of delivery of empty carts to each conveyor belt. This is a crucial point, at the root of the deeper difficulties with the original design.
The destination of each bag and its individual cart is defined by bar-coded labels, and transmitted by radio to tags (the "radio frequency identification" or "rf ids") on the constantly moving vehicles. The operation of these vehicles is to be entirely controlled by a network of about 150 computers (Myerson, 1994; US Government Accounting Office, 1994).

Speed in handling baggage is critical to achieving acceptable boarding and transfer times at Denver, since the distances are much greater those at other airports. The space between the midfield concourses provides for two taxiways (one is standard) between the tails of the aircraft parked at the concourses, and the terminal building in which passengers check-in and pick up their bags is separated from the first concourse by an office block, a garage, and the Customs and Immigration (FIS) facilities.

Speed has been considered crucial to the commercial success of the New Denver Airport, which the owners have marketed to the airlines as a highly efficient platform for hubbing operations because of its multiple parallel runways and prospective ability to turn around aircraft flights very rapidly. United Airlines, the dominant airline at Denver,[1] insisted on a rapid baggage handling system before signing its lease with Denver (Flynn, 1994b).

The Denver system was thus originally designed to deliver bags much faster than current norms at major airports -- at up to 38 kmh (24 mph) (US Government Accounting Office, 1994). The maximum delivery time was apparently set at 20 minutes for narrowbody and 30 minutes for widebody aircraft (Leigh Fisher, 1994). The installers are quoted has having planned a "design that will allow baggage to be transported anywhere within the terminal within 10 minutes" (Airport Support, 1993).

Despite the central importance of the automated baggage system, its design was largely an afterthought. This is a common practice, unfortunately. The Denver system was detailed well after the construction of the airport was under way and only about two years before the airport was to open.

Being late, the design was thus subject to two important constraints. First, the geometry was tight. The automated system had to fit within the confines of the airport passenger buildings and the underground tunnel connecting the concourses and the terminal; in many instances it was shoe-horned in at considerable inconvenience. Second, the schedule was tight. The system was to be implemented within 21 months, since Denver executed the contract only in January 1992. This schedule precluded extensive simulation or physical testing of the full design.

Remarkably, the design of the fully automated baggage system at Denver did not include a meaningful backup system. The planners provided neither a fleet of tugs and carts that could cope with the level of baggage expected, nor even access roads between the check-in facilities and the aircraft.

Obvious Problems

Highly visible mechanical problems have plagued the automated baggage system at Denver. As shown by television and widely reported in the trade and popular press, the baggage carts have jammed in the tracks, misaligned with the conveyor belts feeding the bags, and mutilated and lost bags (Flynn, 1994; Henderson, 1994; Myerson, 1994).

[1] In 1994, United Airlines accounted for well over 60% of the passengers at Denver. Continental Airlines, which was the launch tenant for the New Airport and which used to operate a considerable hub at Denver, has largely canceled this operation: as of November 1994 it closed its crew base in Denver and cut its daily departures to 23 -- about a tenth of the number offered by United. The airport consultant to the City and County of Denver predicted that by 1995 the United System will account for 90% of the passenger traffic at Denver (Leigh Fisher, 1994).

To deal with these difficulties, the contractors are installing additional equipment. For example, more laser readers will reduce the probability of misreading the destination of each bag. More controllers will slow down the carts, reduce misalignments with the conveyors feeding bags, and minimize the momentum that tossed bags off the carts. Overall, solutions to the mechanical problems come at the price of increased costs, reduced performance, and lower cost-effectiveness of the system.

Deeper Problem of Reliable Delivery

The blatant difficulties with the automated baggage system designed for the New Denver Airport are almost certainly only the tip of the iceberg. There is a deeper, fundamental problem associated with all complex systems of handling baggage, cargo or materials.

The more extensive and long-term difficulty is that of "reliable delivery times". The fully automated system may never be able to deliver bags consistently within the times and at the capacity originally promised. This difficulty is a consequence of the extreme complexity of its design combined with the variability of the loads.

The entire system consists of well over a hundred waiting lines that feed into each other. For example, bags can only be unloaded from the aircraft and put into the system when the unloading conveyor belt is moving, this belt will only advance when there are empty carts on which to place bags, empty carts will only arrive after they have deposited their previous loads and have proceeded through the system, and so on. In short it is a complicated "cascade of queues".

The patterns of loads on the system are highly variable. These depend on the season, the time of day, the type of aircraft at each gate, the number of passengers on these aircraft, the percentage traveling with skis, etc., etc. There may be over a thousand reasonable scenarios!

Managing a complex network of interacting, fully loaded queues efficiently for any single scenario is complicated. Managing these flows under all the realistic scenarios is exponentially more difficult. Learning how to do this appears to be a major, long-term research project.

Both airports, such as Frankfurt am Main, and companies attempting to automate their materials handling, have routinely spent years trying to make their systems work correctly under all circumstances (Auguston, 1994; Zitterstein, 1994). It is not clear that anyone, anywhere, is currently capable of managing a fully automated baggage system -- one without any backup system or use of tugs and carts for transfers -- to ensure full capacity, on-time performance, or is likely to be able to do so anytime in the near future (Knill, 1994).

Causes of Reliable Delivery Problem

Any automated baggage system is subject to risk. The difficulties at Denver are not due to any obvious bad luck or incompetence. On the contrary, the contractor responsible for the installation (BAE Automated Systems) had enjoyed the reputation of being among the best and, on the strength of its good work, has been responsible for most of the major baggage systems recently installed in the United States.

Enormous Increase in Complexity

The development of a fully integrated, automated baggage system, such as the one originally designed for Denver, represents an enormous technological leap over current practice. No airline, for example, has used a fully automated system to deliver "hot" or time sensitive baggage for passengers transferring between aircraft in 45 minutes or less. The individual elements of the baggage system at the New Denver Airport have each, separately and on a much smaller scale, been used successfully -- but they have not functioned together in such a large system. This enormous increase in complexity is the root of the problem.

It is a truism in systems design that as you increase the complexity, the difficulties in making the system work increase "exponentially". If the system is 10 times as complex, the difficulties could be 100 times as great.

The fully automated system at the New Denver Airport is far more complex than predecessor systems. It features about 12 times as many carts as in the existing comparable systems in San Francisco or Atlanta, which are also very much simpler in layout and the number of connections. The speed of its carts is about 10 times as great as on conventional conveyor belts.

As reported in the New York Times:

> "The Denver system represents a leap in scale, with 14 times the capacity of San Francisco's. It is the first such system to serve an entire airport. It is also the first where the carts will only slow down, not stop, to pick up and drop off bags, the first to be run by a network of desktop computers rather than a mainframe, the first to use radio links and the first with a system for oversized bags, which in Denver tend to be skis." (Myerson, 1994)

If relative complexity is measured by a factor of the increases in the salient dimensions of a system, the fully automated system originally designed for Denver would be 100 times as complex as comparable systems elsewhere. This crude estimate factors speed (10x) and the number of destinations (~10x). Massive problems and therefore extensive delays should have been expected from the start.

The enormous increase in complexity, that distinguishes the fully automated baggage system attempted at Denver from all others, represents much more than a simple evolution of technology. It is not just a change from a third to a fourth generation of technology, say; it is more like an attempted leap from the third to the fifth or sixth generation of baggage systems.

Implementing an advance so much more complex than anything existing must be viewed as a major research and development project. As with any research project, success cannot be guaranteed -- certainly not in a short time. According to the expert consultants on the conceptual design study for the baggage systems at Denver:

> The DCV concept..."is the only alternative subject to a high degree of development risk.... At this point the prototype tests are ... in no means conclusive or representative of the complexity of a system which would be employed at Denver International Airport. Therefore ... on the development risk alone, sufficient time must be allocated to allow the development to be furthered prior to commitment to this type of system..." (Breier Neidle Patrone, 1990, p. 1-7)

Note that this statement dates from just the year before Denver committed to the fully automated DCV system.

Difficulties in "Line Balancing"

The complexity of a fully automated system leads to tremendous difficulties in trying to achieve reliable delivery times. To guarantee acceptable delivery times under all circumstances in a network of queues such as at Denver, it is crucial to control the capacity of the system so that all lines of flow have balanced service. This is the "line-balancing" problem.

Conceptually, the problem of "line balancing" is simple, once one thinks about it. As the name suggests, the issue is to provide equally good service to all lines, in the case of Denver to provide sufficient empty carts to each of the conveyor belts that feed bags onto the system of carts. The point of this is to avoid situations where some lines get little or no service, to avoid the possibility that some connections simply do not function. This kind of failure can easily happen in any system where a common artery serves many demands.

Most people have experienced the difficulties that arise when line-balancing has not been achieved. Think of the times you could not get on a bus because it was crowded by people who had boarded at earlier stops. The problems of line-balancing are common and should be well-known to all systems designers.

The solution to the line-balancing problem is to control the "empties", to make sure that there is enough space available, at the right time, to all users of the system. Specifically for the fully automated baggage system originally planned for Denver, the crux of the solution is to devise control systems that will deliver enough empty carts to all the conveyor belts delivering bags to the system.

Solving the line balancing problem efficiently can be very difficult. This is especially true for complicated systems such as Denver, with highly variable flows on close to 100 independent lines of access. This is where the complexity of the fully automated baggage system originally designed for Denver has a major impact. The difficulty in solving the line balancing problem increases exponentially with the number of lines or queues requiring service. (Auguston, 1994, discusses examples, and Gibbs, 1994, the problems in computer control of complex systems.)

To put the degree of difficulty into context, an analysis of the line balancing problem associated with the people mover between the 5 passenger buildings at Atlanta airport was the subject of a doctoral dissertation at MIT (Daskin, 1978). This was a two-year intensive effort on a system far, far simpler than that at Denver.

The line-balancing problem is complicated by the fact that any automated baggage handling system is a "cascade of queues", a network of flows that must each wait for each other. When the loads are near capacity, the performance of queuing systems is highly variable and service is often terrible, either overall or for particular connections. (Formally, the delay and its variance depend approximately on [1/(1-p)] where p is the ratio of traffic to capacity. As loads near capacity, this ratio nears 1.0, and the delays increase dramatically.) As in driving through a busy city at rush hour, everything can be fine, but traffic jams and gridlock generally occur for one small reason or another.

Short Term Fixes

In the short term, novel, complex automated baggage systems can be made to "work" by drastically reducing their performance and cost-effectiveness. The recent developments at Denver illustrate what can be done. These feature:

* Installation of a complementary, backup system that constitutes the insurance necessary for the inherently risky automated design; and
* Drastic reduction in the complexity and the loads on the system.

Complementary, Backup System

The City and County of Denver have given up on relying exclusively on the automated baggage system. At a cost of between US $ 50 and 75 million, Denver has installed an alternative system based on "standard conveyor belt technology with delivery of bags to concourses by tugs and carts" (Leigh Fischer, 1994; Johnson, 1994; US Government Accounting Office, 1994). This will be labor-intensive and expensive to operate.

Given the distances at Denver, a conventional system can hardly handle within acceptable times the bags for airlines at the further midfield concourses. United Airlines, located at the second or B concourse at Denver, "has stated that it is uncertain that the Backup Baggage System will provide timely operations to its satisfaction" (Leigh Fisher, 1994: see also Flynn, 1994c).

Reduction in Complexity and Loads

To make the automated baggage handling system "work" at Denver, it has been necessary to reduce its complexity and loads. The concept of a "fully automated", airport-wide system is gone. United Airlines has been aggressively reworking the original design. Henceforth, the system focuses on United Airlines and its single concourse, B. The track serving the furthest concourse, C, has been redirected to concourse B. Concourse A, the nearest to the landside passenger building, is now to be served by the complementary, backup system of tugs and carts.

In the new, simplified configuration, the automated system will:

* serve only 1 midfield concourse instead of 3;
* operate at half the planned capacity on each track;
* handle only outbound baggage at the start;
* handle inbound bags later, perhaps in the summer of 1995; and
* not deal with transfer bags.

United Airlines will transfer baggage between aircraft with tugs and carts. Airlines normally use these vehicles in transfer operations to back up mechanical systems in any case, even at the most modern transfer mid-field concourses, such as Pittsburgh and at the United Airlines facility at Chicago/O'Hare. This kind of operation is relatively easy at Denver because -- in an arrangement almost unique in the United States but standard at busy airports in Europe and elsewhere -- there are separate roadways for apron vehicles, located between the aircraft positions at the gates and the concourse building. Using tugs for transfers is, however, a labor-intensive, expensive operation.

These changes drastically reduce the complexity of the original design. The number of different destinations goes down by about a third when the system is focused on only 1 of the 3 concourses, and down by a further third when only outbound traffic is considered. Because the speed of the sorting process on each track is also being cut in half, the complexity of the system may be thus be reduced by an order of magnitude.

Reducing the loads on each track significantly increases the reliability of the system. According to a senior representative of United Airlines, the system is unstable at its design capacity of 60 bags/minute on a track, but performs satisfactorily at 30 bags/minute (Lantner, 1994). This improvement is exactly what theory predicts. (Formally, as the ratio of loads to capacity drops from about 1 to about a 0.5, the delays decrease by several orders of magnitude.) This redesign of course dramatically reduces the cost-effectiveness of the automated system: 3 tracks are now be required to do the work originally intended for 2.

These changes also increase the capital cost of the automated system by at least US $ 35 million on top of the 191 million already spent (Lantner, 1994; US Government Accounting Office, 1994). The costs of operating and maintaining tugs and carts for transfer bags are additional.

Long Term Solutions

Efficient solutions take much longer and require much attention to detail. The development of fully automated baggage systems, including transfers, is a major research project in which progress will occur incrementally.

Efficient solutions require time

An efficient control system for any automated baggage system is likely to take a long time to develop successfully. Rapid efforts seem bound to fail. In particular for Denver, it is difficult to have confidence that the system as originally planned would ever be able to guarantee the adequate delivery of empty carts, at the proper time and proper place (Knill, 1994).

The problem is difficult to solve in practice. Getting a control system to deal effectively with the line balancing problem requires extensive testing for the specific loads prevailing at a site. At Frankfurt am Main, getting the automated baggage system in Terminal 1 to work reasonably properly reportedly took several years of operation -- and this work does not apply easily to Denver since the German system and pattern of loads are different. By comparison, testing of the full Denver system under realistic loads had not taken place as of December 1994. As of that date, only the much simpler, significantly reconfigured system serving just one mid-field concourse had been successfully tested, and that only for outbound baggage (Hensel Phelps Construction Company, 1994).

The problem should be checked out in advance by computer simulation. Doing this properly requires a simulation of essentially every bag, over an extended period, under hundreds if not thousands of scenarios. This is an arduous task for a system as complicated as Denver, requiring many months just to organize, let alone to run through powerful computers (Breier Neidle Patrone, 1990). It is a major research project. Yet it is a fairly routine approach, and was already used in the 1970s to simulate the operations of the train system at Dallas/Fort Worth before this airport opened.

For Denver in particular, there is no available evidence of effective alternative testing of the capability of the system to provide reliable delivery times to all destinations under variable patterns of load -- and there was hardly any time available to do this. On the contrary, the outside experts brought in by Denver have specifically indicated that what they saw was inadequate (Frenz, 1994).

The theory for solving the line-balancing problem has furthermore not been worked out. It seems clear however that the analytic solutions will be complex and require great sophistication. Practical solutions have had to be worked out situation by situation according to the specific patterns of activity. A major technical review of Denver's fully automated baggage system could not find evidence of appropriate solutions to its line balancing problem:

"The IABHS *control system* and the *operation strategies* have yet to be investigated, due to the lack of the necessary information" (Logplan/Fukuma, 1994). As it is perfectly possible to talk about the strategies of a control system without revealing proprietary information about the software itself, this reticence corroborates the conclusion that the strategies for dealing with the fully automated system as originally designed, were neither impressive nor adequate.

The line-balancing problem is compounded by a general ignorance or disregard for its existence. Even knowledgeable designers and operators of automated systems seem not to focus on this issue. For example, the installers of the fully automated baggage system at Denver seem to have discovered the line-balancing problem six months after the original opening date for the system. A site manager giving the tour of the system in July 1994 referred to "car starving" (because conveyor belts are "starved" of empty carts onto which they could deposit their bags when the lines are not properly balanced) and described it as a novel phenomenon that they had just started to work on!

... and Extensive Detailed Work

Achieving reliable delivery times also requires very high mechanical and computer reliability. Not only must the system be able to be in operation a very high percentage of the time (which has been the immediate focus of attention at Denver), but it must also operate accurately. However, sufficient accuracy is not easy to achieve, either in reading information, or in managing it in the computer.

Any system of identifying bags makes mistakes in reading or transmitting information about destinations. These happen for all kinds of reasons. The baggage handler may place the bag on the conveyor with the label hidden; the bag may have two labels, one left over from a previous flight; the label may be dirty, out of the field of view or focus of the laser reader; the laser may malfunction, and so on. Anyone who has watched check-out clerks in a super-market read bar codes with laser guns has seen that laser readers do not work right all the time.

Superior systems operating under maximum control, such as those of FedEx, currently aspire to over 98% accuracy. A more usual well-proven, well-maintained system of laser readers can boast of 96 to 97% accuracy, which still means that 3 to 4 bags out of 100 go to the misread pile or the wrong destination.

The effect of misreads can be great, both on cost and on performance. At Denver, the usual problems of identifying bags properly are compounded because the baggage system requires two distinct kinds of readings: the destination of each bag must first be read by lasers and then this information must be transmitted by radio to devices on each of the baggage carts. This duality compounds the errors. The reliability of two devices working accurately together is, roughly, the multiplication of their individual reliabilities: that is, always less than either alone.

To deal with the inevitable misreads, the most important thing is to have a backup system. This is standard, but costs money and time, and degrades performance. The complementary solution is training of personnel and continuous improvement of the system -- this comes with experience and may take years to acquire.

Managing the information accurately is also difficult. The database needs to track tens of thousands of bags, going to hundreds of destinations, all in real time. The problem is further complicated at Denver because it uses a distributed system of about 150 computers. The software must, in addition to the usual error checking codes that guard against electrical disturbances in the communications, have multiple levels of redundancy and be able to recover from errors very rapidly. Getting this right can take many expensive programmers a lot of time (Gibbs, 1994).

Medium and long-term implications for Airlines and Airports

Issues

The obvious lesson to be drawn from the experience at Denver is that novel, complex automated baggage systems are risky. Put simply, they may not work well.

This conclusion should not come as a surprise. Airline and airport professionals with experience should remember all the experiments in automating cargo movements which were operational failures, as at Amsterdam, London and Paris over the past 20 years. This experience continues to be replicated by various attempts to automate materials handling within factories, such as at the General Motors Plant at Oshawa, Canada. Managers of new baggage systems know that they face start-up problems that can last years.

Airports and airlines considering the use of such systems -- such as at the second airports for Bangkok, Hong Kong, Kuala Lumpur and Seoul, and for the Third Terminal at Singapore -- should thus pay careful attention.

The medium to long-term consequences of not being able to rely on the automated baggage system at an airport may have rather important implications for the financial success of its operations.

Backup baggage systems based on current technology will be expensive to install and operate. Most importantly, unless the alternative system is designed generously, it may not be able to handle within acceptable times the very large number of bags originally projected at peak hours.
To the extent that neither the automated nor the alternate baggage system can guarantee reliable delivery times within original specifications, airlines are likely to limit operations below the level for which the airport was designed. Fewer flights and passengers increase the cost per passenger, thus encouraging airlines to route connecting traffic through alternative, competitive hubs.

Relatively higher charges and poor performance are certainly problems for the airlines. The airlines can protect themselves from unlimited costs by their ability to reduce the number of flights, by entering into relatively short-term leases, and insisting on limits to the price increases. At Denver for example, United Airlines' lease specifies a maximum charge of US $ 20 per passenger, in 1990 dollars, subject to certain conditions (City and County of Denver, 1994).

The financial situation is potentially worse for airport management and, behind them, for investors in any airport bonds. Despite a conservative financial analysis and apparent prospects, over the longer term the revenues generated by the airport might not be able to cover the costs as scheduled.

Ways to avoid the Problems

Recognition that the successful implementation and operation of a novel, complex automated baggage handling system is difficult, and is likely to take a long time, provides the basis for avoiding the problems with automated systems.

Airlines and airports considering automated baggage systems should start out by assessing their design and performance of these devices cautiously and far in advance of their use. They should certainly do this before they allow architects to fix the layout of the airport passenger buildings. This is because a realistically conservative estimate of what automated systems can achieve should influence the design of these facilities.

Unfortunately, airlines and airports generally violate this precept. For example, planners chose the layouts of the new airports for Kuala Lumpur, Hong Kong and Seoul before designers began to consider seriously the details of the baggage systems. Unless designers now engage this issue rapidly, serious problems may occur.

Airlines and airports proposing to install automated baggage systems should also, in recognition of their inherent risk of poor performance, plan on installing adequate backup systems from the start. Experience demonstrates that this insurance is necessary.

These precepts really amount to saying that airlines and owners should not progress to more complex automated systems until researchers do a lot more work with prototypes and demonstrations. The cost of installing both an automated system and a satisfactory backup may be so great that it would seem preferable simply to design one complete system using fairly conventional technology, as was done by United Airlines at its midfield concourse at Chicago/O'Hare, and by the County of Allegheny in developing the new midfield complex at Pittsburgh Airport.

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References

Airport Support (1993), "Denver turns to Texan Telecar," April, pp. 17.

Auguston, K. (1994), "The Denver Airport: A lesson in coping with complexity," Modern Materials Handling, Oct., pp. 40 - 45.

Breier Neidle Patrone Associates (1990) DIA -- Denver International Airport, Baggage Handling Systems, Conceptual Design Study Final Report, BNP Doc. Ref. 9016R.008, 19 Oct.

City and County of Denver (1994a), discussions with airport officials in July and August, both at Denver and through broadcast conference calls.

City and County of Denver (1994b) Official Statement for Airport System Revenue Bonds, Series 1994A.

Daskin, M. (1978), "Effects of Origin-Destination Matrix on the Performance of Loop Transportation Systems," Doctoral Dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA.

Deloitte and Touche (1994) "Independent Auditor's Report," Appendix B to City and County of Denver, 1994b.

de Neufville, R. (1995) "Designing Airport Passenger Buildings for the 21st. Century," Transport Journal, UK Institution of Civil Engineers, in press.

Flynn, K. (1994a) "Baggage System was behind from the very beginning," Rocky Mountain News, May 1.

Flynn, K. (1994b) "Delays began with United's demand for automated system," Rocky Mountain News, June 5.

Flynn, K. (1994c) "Webb picks backup system -- airlines resist solution to baggage problem, say it's 30 years out of date," Rocky Mountain News, Aug. 5.

Frenz, M. (1994) Statement on behalf of Logplan consultants, in response to direct questions during the Denver conference call to investors Aug. 5.

Gibbs, W. W. (1994) "Software's Chronic Crisis," Scientific American, Sept., pp. 86 - 95.

Henderson, D. (1994) "It's in the bag(s) -- the balky, $ 193 million luggage-delivery system continues to hold up the opening of Denver's ultramodern airport," Air Transport World, September, pp. 54-58.

Hensel Phelps Construction Co. (1994) "United Airlines Enhanced Baggage System, Denver International Airport," Weekly Status Report 012, Dec. 9.

Johnson, D. (1994) "Late Already, Denver Faces More Delays," New York Times, Sept. 24.

Knill, B. (1994) "Flying Blind at Denver International Airport -- DIA can't open until its automated baggage handling system works, and nobody knows when that's going to happen," Materials Handling Engineering, July, pp. 47-49.

Lantner, Gary (1994) Personal communication, Dec. 19.

Leigh Fisher Associates (1994) "Report of the Airport Consultant on the proposed issuance of City and County of Denver, Colorado, Airport System Revenue Bonds, Series 1994A," Appendix A to City and County of Denver (1994b), Aug. 18.

Logplan/Fukuma (1994) "Assessment of the Integrated Baggage Handling System IABHS, Denver International Airport," July 29.

Myerson, A. (1994) "Automation Off Course in Denver," New York Times, April 18, pp. D1 and D2.

United Airlines (1994) "United Denver," publicity brochure, Nov.

US Government Accounting Office (1994) New Denver Airport: Impact of the Delayed Baggage System, Briefing Report to the Hon. Hank Brown, US Senate, GAO/RCED-95-35BR, Oct.

Zitterstein, G. (1994) "Frankfurt maintains fast trains with T2," Airport Review, Vol. 6, No. 9, Nov., pp. 22, 25.