Denver International Airport

Stapleton was a major airline hub[1] , was close to downtown, and had recently undergone $100 million in improvements. However, its capacity was reduced in bad weather, and nearby residents opposed expansion because of airport noise. In 1988, the City and County of Denver (both hereafter referred to as the City) made a preliminary agreement to acquire land for a new airport. In May 1988, voters in Adams County approved annexation of the land for the airport.

[1] This is an example of a keystone, the airport was high importance in that it connected many nodes.

With a design-build PDM[2], the City joined with a joint-venture engineering, architecture, and airport-design firm. Together, they coordinated and ensured the quality of some 61 design contracts, 134 construction contractors, and over 2,000 subcontractors[3] . These contractors and subcontractors would be responsible for building terminals, concourses, roadways, parking lots, and more than 33 miles of runways and taxiways.

[2] Design-build puts more on the construction manager, that is they advise and work with the project owner (the City) and advise them throughout the design process and then build it once the design is complete.

[3] We see coordination complexity here. It's a huge number of contractors and subcontractors, with complexity come more failure points.

In 1989, the City began to solicit bids for construction without obtaining formal **operator input**[4] on the airport's design from the airlines. In **negotiations**[5] with these major tenants to sign gate leases, the City agreed to some very large and significant **in-flight design**[6]. These decisions triggered far-reaching changes to the design and construction of DIA's buildings and systems, many of them in mechanical, electrical, and telecommunications systems that are complex and difficult to coordinate[7]. For example, at Continental Airlines' suggestion[8], the City moved the international gates away from the north side of the main terminal to its Concourse A and built a passenger bridge from Concourse A to the main terminal, duplicating the function of a below-ground "people-mover" system.

[4] For any project, getting operator input is necessary. This seems so obvious but I've seen this in project management of all kinds, not just construction.

[5] Since the airlines were signing long term leases and there were so few of them, they had leverage in the negotiations.

[6] Design changes in the middle of the project (or projects that mix design and construction) tends to cause significant construction costs and delays.

[7] More coordination complexity. With varied trades, there's increased complexity. Though they didn't have BIM meetings in the 80s and 90s.

[8] This *suggestion* is understated

United Airlines also requested substantial modifications when it negotiated an agreement with the City. Most significantly, United requested an automated baggage handling system for Concourse B to ensure that nearly all of its transferring passengers' bags reached flights very quickly. At that time, the City planned to allow each airline to develop its own baggage system as long as this system did not interfere with any airportwide automated baggage system that the City might wish to install in the future[9].

[9] It seems like it would be impossible to enforce this stipulation.

The City had already explored the feasibility of installing an airportwide automated baggage system. In August 1990, a study commissioned by the City indicated that the highly complex and technically difficult state-of-the-art[10] automated baggage system necessary for an airport of that size could probably not be built and tested in time to meet the scheduled opening date of October 1993 **new tech unique**

[10] State of the art gives me pause, first of their kind technology has a very high risk. In construction, how many times individuals (not the company) have built or installed a thing. That goes for how many times a manufacturer has built a thing, or how many an HVAC system has been installed, or

tech. Specifically, the consultant's report discussed the risks involved with five baggage system options. Following the consultant's report, the City decided to open the airport using a conventional tug-and-cart baggage system[11]. However, after United agreed to sign a 30-year lease in June 1991, the City decided to develop an automated system for the entire airport. According to the consultant's report, the automated system selected was the one option that posed the greatest **risk** for not meeting the airport's scheduled October 1993 opening date.

[11] This demonstrates lack of commitment to the solution, it was the best option of roughly equivalent options, but they were indifferent. Also an example of ignoring experts.

The opening of the airport was postponed at first because of construction delays and later because of problems with the automated baggage system[12]. The first delays–from October 1993 to December 19, 1993, and again to March 9, 1994, resulted because the construction of the airport was not complete. The airport's opening was delayed again from March 1994 to May 1994 and then postponed indefinitely[13] **credibility collapse**, solely as a result of problems in getting the baggage system to work properly. Recognizing that the contractor for the baggage system could not predict when the automated baggage system would be operating, the City decided in July 1994 to build an alternative baggage system. February 28, 1995, was established as the airport's new opening date.

[12] Problems seems to often grow, or cascading failure, more things follow along. My hunch is that this has to do with the fragility of construction and how interdependent activities are with one another.

[13] The Mayor's credibility collapsed. It was impossible for the Mayor to continue telling the public that the project was only going to be a few more months, no one trusted timelines anymore. Also an example of crossing the Rubicon.

DIA opened with the conventional baggage system providing service to all concourses, while a partially functioning automated baggage system served Concourse B. Specifically, the automated system was only operating for the luggage of United passengers on Concourse B–and only for normal size bags on outbound flights and large size bags, such as skis on inbound flights. The City expects the automated system to be fully operational for Concourse B in July 1995 and for Concourse A in August 1995. A decision on whether to extend the automated system to Concourse C–the most distant concourse from the terminal–will be made later. According to City officials, the carriers operating from Concourse C are satisfied with the alternative baggage system. The total construction cost of the baggage handling system–both the automated and conventional systems–is about $300 million to date[14].

[14] Building the alternative baggage system is also a Rubicon moment. This is almost 1/10th of the total cost of the airport. The schedule delay also cost Denver international at least 12 months of leasing their space to the airlines.

Costs

In November 1988, before selecting a site for the airport, the City developed a "conceptual estimate" of $1.3 billion for constructing a new airport. The earliest firm estimate for the cost of design and construction of the airport was contained in the May 1990. A bond series prospectus prepared by the City.

The City estimated that construction costs would abet at about

$2.08 billion, excluding planning, land, interest, and finance charges. This estimate was revised in February 1992 to $2.7 billion. The principal reason for the growth in the cost was the additional requirements(**operator input**[15]), facilities, such as tenant finishes in increasing apron sizes in the aircraft parking areas, widening and lengthening a concourse, expanding the parking structure, and adding the automated baggage system.

[15] All the following requirements were based on the operator inputs they received after construction started (9/1989). They had already started construction at this point, I believe.

In February 1994[16], the City revised the estimated cost of construction to $2.92 billion. Two factors made up this increase: (1) $30 million, mainly for the terminal, electronic systems, and tenant improvements in concourses A and B, and (2) $194 million for additional facilities requested by the airlines. In September 1994, the project's estimated cost was increased to include $51 million for a back-up baggage handling system and about $24 million for additional capital projects. As shown in table 1, the updated costs for the baggage systems brought the final construction cost at the airport's opening to about $3 billion.

[16] This is months after the original deadline and at this point they are still $80 million dollars off from the final number that they land on. Forgive the wordplay but the City is bankrupt of trust on this project at this point.

Financing costs were another major expense. These costs included about $958[17] million for capitalized interest and bond financing incurred before the airport's opening. These expenses brought DIA's estimated total cost to about $4.2 billion. When other costs, including those for air traffic control facilities, special airline facilities, into account, and rental car facilities, are taken into account total cost is estimated to be over $4.8 billion.

[17] This cost isn't part of the initial public facing costs. As far as I can tell, the only thing that's been discussed is construction costs.

About half of the total federal funds for the project–$327 million–have been or will be spent on the construction of airfield pavement. Federal funds are also used for the construction of some airport buildings, land purchases, and support and engineering.

Quality Assurance System Is Late

DIA'S total airfield pavement, 135,000 concrete panels, required placing approximately 5.3 million square yards of concrete. Construction work was performed simultaneously on 3+ runways and airport structures quality assurance inspectors were responsible for many different and aspects of the airfield's construction[18] **cascading failure**.

[18] QA was likely overwhelmed or understaffed. With a google map I measured the area of the airport itself of 20 square miles. I don't know what to call this concept except find a better way to vet the contractors. This could be an example of cascading failures, but I don't know for sure.

We reviewed the City's construction reports and project records for 3 of the 5 runway systems. These three systems comprised about 32,000, or 24%, of DIA's 135,000 panels. These records showed that about 14,400, or 45%, of the 32,000 panels inspected did not conform to the contracts' specifications when the concrete was initially placed by the contractors. About 3,000 contained clay and cracking, the remaining 11,300 were improperly installed by a contractor.

In most cases, the City required contractors to repair or replace panels that had problems at their cost per the contracts.

On one runway, concrete was contaminated with clay. This occurred because inspectors did not inspect the batch plant where the contractor was mixing concrete and the contractor failed to notice that a critical screen was missing. As a result, clay went into the mix for 10 days while paving continued. The contamination was discovered when clay was found on the pavement's surface approximately 3 weeks later **cascading failure**.

According to the City, the problems with the tie bars occurred because it was not always evident to contractors or inspectors that the machines installing the tie bars had not spaced them properly or that workers were not operating the machine properly **skill deficit**. In July 1993, the City tested two runways and sections of other pavements on the airfields where it suspected that the contractors had improperly installed the tie bars. The tests, using special ground-penetrating radar (GPR) instruments, showed that the contractor had not installed tie bars in thousands of panels according to specifications, had installed too few or too many tie bars or had installed tie bars at the incorrect depth[19]. The City allowed the contractor to make repairs by inserting additional tie bars. The City told us that all repairs related to the tie bars had been completed.

[19] The skill deficit caused more cascading failures, this added to the schedule and cost increases. Although the contractor "charged nothing additional" there were costs associated with it.

Quality Assurance Process Missed Some Problems

We found some instances in which the City–through its quality assurance program–did not ensure that the contractor corrected the 10,374 identified problems with the pavement as required[20]**correction fatigue cascading failure**. To verify that the contractor had completed repairs related to the tie bars, we examined portions of two runways and taxiways on February 24, 1995. Many of the nonconforming panels we inspected had not been repaired. According to the design engineer for the taxiway, if tie bars are not properly installed, the joint between the panels could widen enough to cause settlement, faulting, and failure of the concrete on each side of a joint.

[20] Here is one of the costs that the City incurred, they have become fatigued with ensuring that the contractor is doing their job and did not QC their work again.

As a result of our examination, the City performed a 100% visual inspection[21](**credibility collapse**) of both runway systems on February 26, 1995, less than 48 hours before the airport opened. After determining that the 762 panels with too few tie bars had not been repaired, the City will require the contractor to begin repairs in June 1995[22]. However, the City is not going to repair about 400 panels

[21] Another symptom of lack of trust in the contractor, they have lost all credibility. Rarely does an owner require an inspection of all like material installed. Having to go back a 3rd time, the City wanted this to be the *last* time.

[22] This is 3 months after the airport is fully open.

we identified as having too many tie bars. The City is not requiring the contractor to repair these panels because the City's design engineers concluded that the performance or life of the runways will not be affected by the presence of too many tie bars. However, an FAA pavement expert with whom we discussed the issue told us that the presence of too many tie bars could cause panels to break and crack[23] (**cascading failure**, **correction fatigue**).

[23] Another symptom of correction fatigue and or cascading failures.

In addition to these unresolved problems, questions remain about whether problems exist on another runway and taxiway system. For example, GPR tests conducted at seven locations on the runway system identified a shortage of tie bars in each location. Specifically, 63% (210 of 334) of the panels tested did not conform with the contract's specifications. The City told us that the panels had been repaired by the responsible contractor. While the City plans no additional tests, it does plan to visually inspect all the pavement (**correction fatigue**).

In May 1995, FAA requested that the City provide its inspection records so the agency could ascertain how extensive DIA's pavement problems are and whether the City's GPR tests included an adequate sample of panels. FAA plans to use this information to determine if additional testing should be conducted (**credibility collapse**) .

FAA Is Correcting Construction Problems

DIA's principal air traffic control facilities–the TRACON building and the 300-foot air traffic control tower–have been subject to allegations of poor design and workmanship or substandard construction. Except for some problems with cracks and water damage at the TRACON facility that FAA is addressing, we have not found support for these allegations[24].

[24] My guess for part of the reason of these allegations is that there was so much trust lost that even when things weren't bad, people expected them to be and when there was one problem, though I'm not sure as some of the problems found in the TRACON building were earlier than the other problems.

The $19 million TRACON building was completed in September 1992[25]. By December 1992, FAA's project engineers found several cracks along non-weight-bearing walls. According to FAA officials who have since reviewed the construction plans for the facility, a slip joint –a critical design element necessary to compensate for expected expansion and contraction of the soil underneath the building–was overlooked (**skill deficit**) during design and construction. The soil has expanded beyond the 2-inch limit that the building's foundation was designed to accommodate. FAA's engineers assume that this movement is causing the building's walls to crack. According to FAA, the floor's movement has not affected the operations or safety of the facility. Repairs, to be paid for by FAA, are under way and are estimated to cost between $150,000 and $175,000; $150,000 had already been obligated as of March 1995.

[25] Airport fully open Feb 1995.

FAA's project engineers also found water damage on some of the TRACON facility's walls where cracks had appeared because the contractor installed rain gutters that were too small[26](**skill deficit**). As a result, water backed up and seeped into several non-weight-bearing The contractor's l-year warranty on the work had expired. Action is being taken to install exterior gutters at an estimated cost of between $90,000 to $100,000.

[26] A design flaw, I'm not sure what to call this other than skill deficit. For many instances, I have ideas about how I might mitigate risks or what I might do if a certain situation arises, I don't know how I would see or notice this ahead of time, obviously the solution is to have larger gutters, but how do you know this ahead of time? And knowing about gutters is such a narrow use case.

FAA examined the air traffic control tower after allegations were made that it was leaning. In March 1993, FAA surveyed the tower shaft and verified that it was standing straight as designed. In January 1995, FAA again surveyed the tower shaft and found that it was straight.