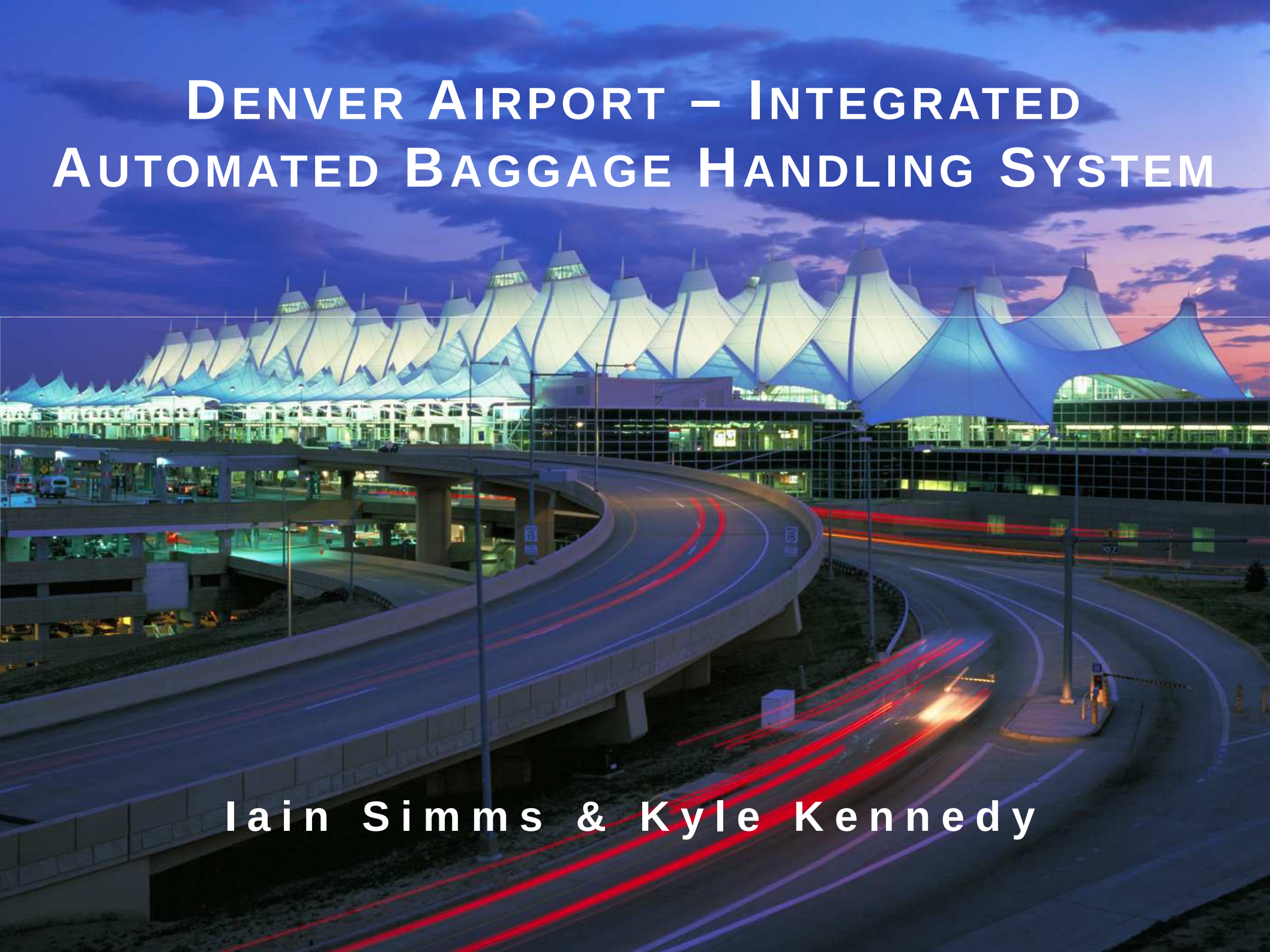
# Denver Airport – Integrated Automated Baggage Handling System



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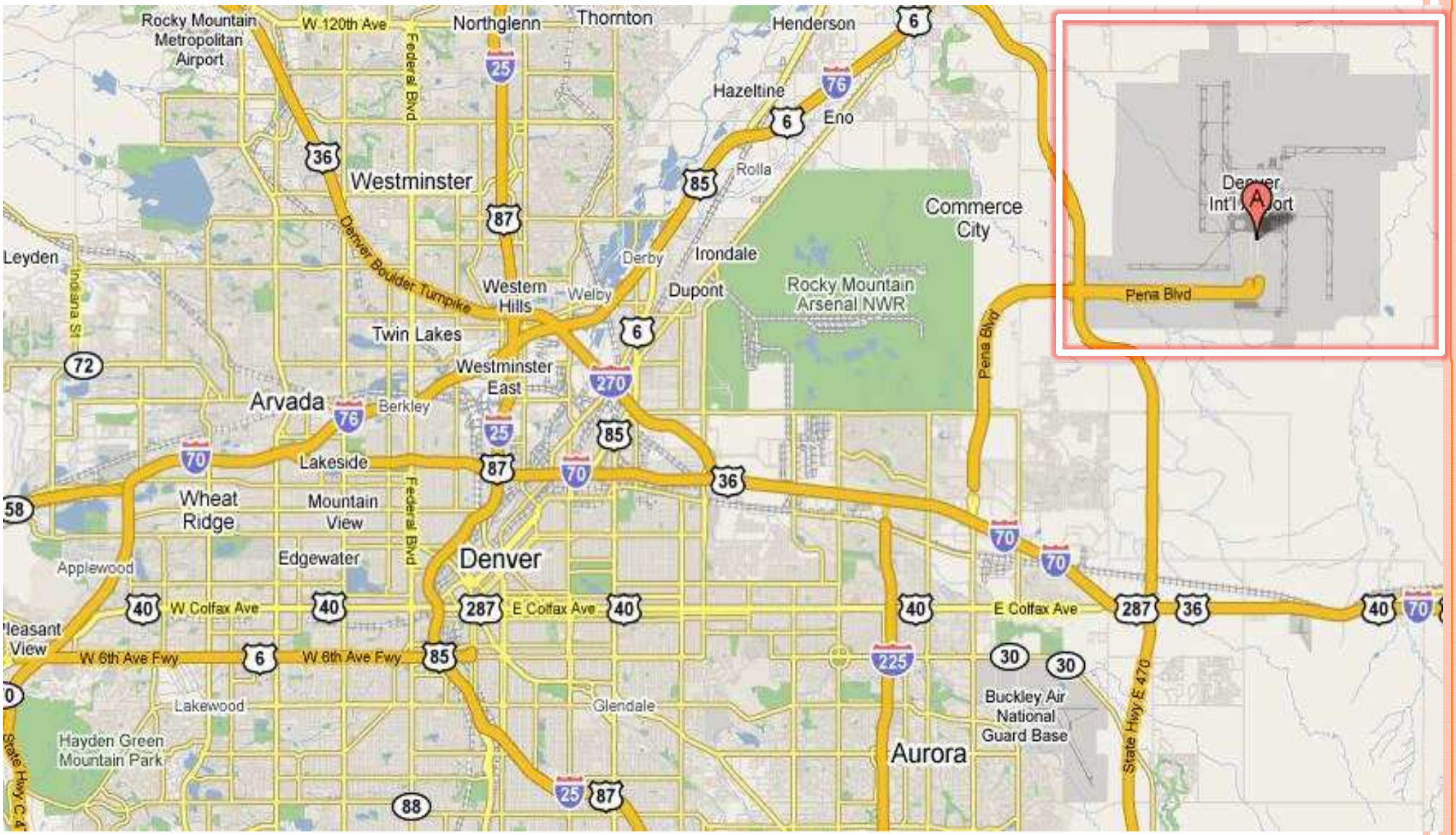
# Introduction

- We will discuss:
  - Background of the airport.
  - Baggage system functionality.
  - Why it was needed.
  - Project timeline.
  - Analysis of the project's problems.
    - Project management issues.
    - Failures to adhere to good software engineering principles.
    - How these problems could have been avoided.

# Background of Denver Airport

- Covering 53 square miles
- Twice the size of Manhattan.
- 5 full-sized runways.
- 120 planes land an hour with optimum weather conditions.
- 6th busiest airport in US, 10th busiest in the world.
- 22 airlines operate within.
- Denver Airport was used by 35 million travellers in 1997.


Rocky Mountain Metropolitan Airport
W 120th Ave
Federal Blvd
Northglenn
Thornton
Henderson
Hazeltine
Eno
Rolla
Westminster
Commerce City
Denver Int'l Airport
Leyden
Indiana St
Denver Boulder Turnpike
Western Hills
Welby
Derby
Irondale
Dupont
Rocky Mountain Arsenal NWR
Peña Blvd
Twin Lakes
Westminster East
Arvada
Berkley
Lakeside
Wheat Ridge
Mountain View
Edgewater
Denver
Applewood
W Colfax Ave
E Colfax Ave
Pleasant View
W 6th Ave Fwy
Lakewood
Glendale
Hayden Green Mountain Park
Buckley Air National Guard Base
Aurora
State Hwy E 470
State Hwy C-4

# System functionality

- Luggage checked-in and placed on conveyer belt.
- Barcode labels are read whilst luggage on conveyer belt.
- The luggage is loaded to a telecar and the barcode scanner informs the telecar what radio frequency to scan for.
- The telecar reaches its destination by following the defined radio frequency.

# System functionality 2

- Quickly move all baggage, including transfers, automatically between check-in, the aircraft and pick-up.
  - United Airlines wanted a 35 minute aircraft turnaround.
- Reduce labour costs.
- Be able to fit around the existing airport.
- Be fully automated.

# Why it was needed

- Moving the baggage by the traditional tug and cart system would not have been possible as they are diesel powered.
  - The exhaust fumes would have been trapped in the underground tunnels due to poor ventilation.
  - This would have caused the workers to become ill.
- The scale of the airport was incredible
  - The closest gate was 400 meters from the passenger terminal with the furthest being 1600 meters away.
  - It was essential that moving baggage was done efficiently and as quickly as possible – this could not be performed by a manual based system.
  - Also, the quicker they could move baggage, the less time aeroplanes would spend on the ground – increased airline profits.

# Project Timeline

- Autumn 1991 - BAE contracted to build baggage system.
- 31st Oct 1993 - Planned opening (missed)
  - Automated system incomplete/error-prone
- March 1994 - System demonstrated to several media groups
  - Absolute chaos, large quantities of luggage and systems destroyed.
- 2nd May 1994 - Faults blamed on lack of testing, not flawed design.
- 28th Feb 1995 - Actual opening
  - Three different systems in operation.

# Problem 1: Ignoring Logplan's help

- Logplan developed the Munich Airport automated baggage system.
  - They had great success.
  - They had the right skills for the job - getting help from Logplan would have been a big step in the right direction.
  - Key to project management: when selecting your team select the right people with the right experience and skills.
- Logplan, as outside consultants, would already have the verified knowledge in place.  By avoiding their use:
  - BAE had to pay for time for research to be done (and the research done wasn't verified as being correct).
  - As there was no previous experience there would have been no one in the team to guide them in the right direction.
  - BAE had no experience in dealing with baggage handling systems before.
    - They treated the luggage as though it was cement, passing it down paths with no concern for its wellbeing.
  - This means that it was not designed by a group of experts and was unlikely to conform to industry standards.
    - Adhering to industrial standards can help ensure accessibility, portability, usability, robustness.

# Problem 1: What they should have done

- The problems which resulted from the previous points could have been avoided as they were offered the help on a plate.
- Hiring Logplan as outside consultants and having them as key members of the requirements team, planning team and design team in particular.  This would have:
  - Given them the clear experience they were clearly lacking.
  - Given them clearer time estimates.
  - Given them much more appreciation for the difficult issues such as the line balancing problem.

# Problem 2: Poor Equipment

- Faulty latches caused telecars to dump luggage on the tracks and become jammed inside the tunnels.
  - BAE solves this issue by modifying every single telecar's latch.
- Strong airflow often caused the lighter suitcases to fly out of the telecars.
  - BAE pressure mapped the telecars in a full-sized wind tunnel to help discover why it was happening and modified the telecars accordingly.
- Some of tunnels required the telecars to take very sharp corners (as well as other navigational nightmares) which caused high-stress areas of track.
  - BAE resolved this issue by reinforcing the high-stress areas.
- These issues were caused by poor understanding on the designer's part.
  - This kind of poor initiation causes delays down the line through rework, errors and omissions.

# Problem 2: What they should have done

- Resisted starting far too early:
  - “Don't allow the customer to push you into starting the work on the assumption that it will result in an earlier delivery.”
  - This would allow time for correct design and the equipment testing which eventually follows.
  - A full simulation of the system should have been created, testing the full forces which could occur.
    - It would have also acted as a proof of concept, allowing BAE to ensure that the track and telecar design chosen was suitable for baggage transport.
- Carried out proper validation on the equipment chosen to ensure it was appropriate and could perform within the required limits.
  - The validation could have been performed by the Airlines and Logplan, both of whom have experience in luggage transport.
- The faulty latches problem could have been found out through prototyping rather than producing all the telecars, finding out their poor design then having to modify them all.

# Problem 3: Baggage system = add-on

- Its design had to fit it round existing airport.
  - Design begun after the Airport ‘s construction had begun.
  - The system had to fit around underground tunnels (and any other available space) as it was not planned for.
    - It created ridiculously sharp angles that the telecar cars had to navigate.
    - Had to demolish existing bits of the airport.
- Poor requirements gathering from the Denver officials.
  - It took a demand from United Airlines (7 years into Denver airport project) for them to decide to make all the baggage system automated.
  - Denver Airport assumed that each airline would design their own baggage system.
    - When they didn’t  produce the goods, Denver consolidated the baggage systems into one.
    - This was caused by poor communication between DIA and the airlines.

# Problem 3: What they should have done

- According to expert Bernie Knill:
  - They should have designed the baggage system at the same time as the building.
  - It should have been built at the same time too – preventing construction difficulties.
- DIA's poor requirements gathering prevented a firm foundation, from which to work, from being established.
  - "Never assume anything" – the foundation of requirements gathering.
- DIA and the airlines should have agreed a communication strategy.
  - By following this communication strategy the confusion over who would design the baggage systems would have been avoided.

# Problem 4: Bad Scheduling

- BAE claimed to be able to build the system in 2 years.
  - It really needed 3-4 years minimum.
- This tight schedule introduced a phenomenal amount of human error as:
  - A full simulation of the system was avoided.
  - Full testing of the complete system could not be completed.
  - The training schedule had to be cut right down.

# Problem 4: What they should have done

- Control the schedule by: defining activities and their resources, sequence and durations then putting these together into a schedule.
- They should never had committed to something they couldn't deliver.
  - "A considered response when you have had time to evaluate all the factors is much better. A date picked out of the air is good to no-one, least of all yourself."
  - Work break down structure should have been verified by a consultant as BAE had no previous experience of developing a baggage system – Logplan could have been consulted.
- Full training should have been planned for.
  - Training can identify issues that need to be dealt with
  - Be used to discover areas which need improvement.
- Full testing should have been planned for.
  - Reducing the testing means a reduced testing coverage and less scenarios are catered for.
  - Once you pick a testing strategy – you should stick to it.  By not doing so, some requirements may be ignored and not provide a system which the stakeholders require.
- They never accounted for slack time:
  - Tom DeMarco has proved people need approximately 20% slack time during their day to be effective.

# Problem 5: Changes

- Changes to requirements/design was carried out by DIA without consulting the airlines or BAE.
- The same situation occurred with the schedule.
- BAE failed to appreciate change impact – this was due to the complexity of the system and its tightly coupled nature.
- As the project was slowly implemented, it swelled in complexity . When design changes were made, this only made things worse.
- Centralized system faults, which ran through many of the baggage system's subsystems, were discovered.
  - To solve BAE decentralized all of the tracking and sorting computers.
- By far, the biggest change was caused by United Airlines penny pinching. They removed a complete loop of track; having just one loop.
  - Saved $20 million.
  - Required a complicated redesign at a critical phase of the project.
- Other major changes included relocating the outside stations, Continental Airlines larger baggage link and another mezzanine baggage platform.
- Due to time constraints, many of the problems which required substantial redesign were covered over by quick fixes.
  - No time was given to investigation of other solutions.

# Problem 5: what they should have done

- Established a communications plan:
  - All progress, successes, failures, risk and changes should be communicated to all members of the teams and stakeholders.
  - If something impacts the scope, time, cost, risk, or quality of a task it should be escalated up the appropriate communication channels.
- The system should not have been so tightly coupled and made as modular as possible.
  - If they had followed proper software development conventions and not relied on quick fixes on many occasions, they complexity could have been reduced.
- The additionally requested features could have been solved by better requirements gathering.  At no time did the airlines all sit down together BAE and brainstorm everything they'd need.
  - Having all the stakeholders together would ensured none of them forgot features another had requested.
- Quick fixes should not have been used:
  - Full investigation into fixes should have been carried out and then the chosen fix put through the development life cycle.

# Problem 6: Insufficient Testing

- No full computer simulation – why line balancing wasn't detected.
  - Line balancing problem discovered 6 months after airport opened.
  - The entire system consists of well over a hundred waiting lines that feed into each other.
- Munich had advised Denver to be very generous with the testing time.
  - Munich had devoted 2 years to testing.
  - BAE ignored this advice.
  - At Frankfurt am Main, getting the automated baggage system tuned to work fairly well took 2 years.
- As BAE had promised a system in far less time than was needed, the testing period was compacted.
  - Furthermore, they underestimated the time required to fix problems – again we see where complexity had run amuck.

# Problem 6: what they should have done

- Carried out a full computer simulation of the design, with many different scenarios, before moving on to the implementation.
  - This would have caught the line balancing problem.
  - It could have been used to model the redesign – making it easier to see change impact.
- More time should have been devoted to the testing stage.
  - They were given advice and chose to ignore it.
  - By working together with the Munich airport they could have discovered any parallels in the two systems and anticipated where problems could have lay.

# Problem 7: Reservation Systems

- Each of the airline's reservation systems had their own reservation language.
  - The baggage system had to translate to and from each of those languages.
  - This produced an incredibly complexity.
  - Any changes in the reservation systems had to be catered for.
  - The translation work itself was difficult to do successfully without testing for every different scenario.

# Problem 7: what they should have done

- These issues come under the heading of integration problems.
  - In order to prevent future problems the airlines should have developed their reservation systems to a common API or at least modified their systems to allow for a common API.
    - This would have made things far easier for the baggage system, eliminating the need for the baggage system to understand all languages.
    - Each of the airlines would only have to understand how to create a common API rather than BAE having to translate many different languages.
    - It ensures that tasks are delegated to the people with the most appropriate skills – the airlines will be in better stead to write APIs where as BAE were not in good stead to write translation modules.

# Problem 8: Timing

- Entire conveyor must wait till leading item can be removed.
- Timing of empty telecars to conveyors therefore is critical.
- Bags need to be distributed to conveyors evenly/sensibly.
- As traffic increases, efficiency can decrease.

# Problem 8: What they should have done

- Empty telecars need to be distributed to conveyers evenly/sensibly.
- Should have spent much more time on research/design.
- A simulation would have caught this problem.

# Problem 9: Poor staff training

- Agents issuing on-line baggage tags too quickly caused issues.
  - System incorrectly sending baggage to manual system(s).
  - Assumed the traffic was too busy for the system to handle.

# Problem 9: What they should have done

- Full training should have been planned for.
  - Training can identify issues that need to be dealt with
  - Be used to discover areas which need improvement.
- 'The more that employers invest in training and developing their employees, the more secure and successful their own businesses will be’.

# Problem 10: Reliability of the components

- Barcode readers can fail or misread tags
  - (initial 70% failure rate due to printing, 5% afterward).
- Telecars can have radio interference or fail, causing blockages.
- Photocells, even when working, can erroneously report telecar jams.
- Small misalignments can cause telecars to miss or destroy baggage.
- Conveyors can fail, leaving lots of luggage "stranded".

# Problem 10: What they should have done

- Should have investigated multiple redundancy and considered potential failure scenarios.

# Problem 11: Unreliable Power supply

- Large power fluctuations caused fuses to trip, stopping motors.
- Electrical engineers never found source of fluctuations.
- BAE had to install industrial power-filters to smooth power-flow.

# Problem 11: What they should have done

- Should have properly consulted the city council to try and resolve this issue.

# Problem 12: POLITICS

- In May 1992 Walter Slinger resigns as head of project.
- Gail Edmond becomes new project head.
- Gail Edmond is not given same power of autonomy as Walter Slinger.
- BAE access and involvement restricted, resulting in difficulties.

# Problem 12: What they should have done

- A more experienced management team with real decision making powers should have been assigned from the start.

# Problem 13: Disaster Recovery

- No back-up system existed.
- No way to relieve strain from overloaded system.
- No replacement for completely failed system.
- No alternate connecting routes for baggage.
- $50-75 million invested on a "tug and cart" system.
- They should have planned for a disaster recovery
  - “Of companies that had a major loss of business data, 43% never reopen, 51% close within two years, and only 6% will survive long-term.”

# Problem 13: What they should have done

- A real alternative system should have been built from the start.
- It should have been defined at the requirements stage.