Modeling the Linate Runway Incursion: Questioning Managerial and Operator Tolerance for Degraded Technical Infrastructures

Chris W. Johnson,
Department of Computing Science,
University of Glasgow,
Glasgow, G12 8RZ, Scotland.
+44 141 330 6053
johnson@dcs.gla.ac.uk
http://www.dcs.gla.ac.uk/~johnson

ABSTRACT

This paper uses Events and Causal Factors charts to reexamine the ANSV's report into the Linate runway incursion. The intention is not directly to identify new findings but to use the graphical formalism to trace the technical and managerial context for the errors made by individual air traffic controllers and aircrew. The analysis, therefore, looks beyond operator error as a cause of major accidents. However, the analysis also suggests that it is time to question the 'can do' attitude of air traffic personnel who are willing to find 'work arounds' even when technical changes remove critical elements of their safety infrastructure.

Keywords

Air traffic management, accident analysis, ECF charting.

INTRODUCTION

The Linate accident happened on the 8th October 2001 when a Boeing MD-87 was taking off from runway 36R at Milan's Linate Airport [1]. The MD-87 collided with a Cessna 525-A, which taxied onto the runway. The MD-87 carried two pilots, four attendants and one hundred and four passengers. The Cessna carried two pilots and two passengers. All occupants of the aircraft were killed along with four ground staff who were working in a baggage handling building struck by the MD-87 after the runway collision. The official ANSV report identified the human factors causes that led the Cessna's crew to mistakenly cross the active runway under, low visibility conditions. It also balanced these factors against a number of organizational and technical limitations in the systems in the airport's operational environment that created the preconditions for the accident. This accident had wider repercussions and prompted international initiatives in Europe and the US to reexamine the causes of and barriers against runway incursion. The following pages form part of these initiatives. An accident modeling technique is used to identify further insights from the original ANSV investigation into this collision.

Managerial and Organizational Background

Figure 1 uses a simplified form of Events and Causal Factors diagram to analyze the background to the Linate incursion. This notation was pioneered by the US Department of Energy. We do not claim that this is the only or even the best modeling technique that might have been used to support our analysis [2]. It was selected because it provides a graphical overview of the events leading to accidents and incidents. It is also one of the techniques recommended by organizations, such as NASA, for use in the analysis of aerospace accidents [3]. Ellipses denote contributory factors that combine to make events more likely. Events, as before, are denoted by rectangles. This diagram looks at some of the many ways in which the organizational structure directly affected the context in which the accident occurred. It records the observation that CASO, Airport Technical Safety Committee only met sporadically. This is represented by a contributory factor approximately mid-way down the diagram on the left-hand side. One of the factors that led to this was the need to improve the Safety Management Systems in operation at Linate prior to the accident. This apparent shortcoming also partly explains a failure to learn from previous incidents. These are shown as four separate events, including a very similar incident to the collision between the Cessna and the MD-87 which occurred only 24 hours before the accident. In this incident an aircraft taxied along TWY R5 instead of R6; the Controller was only alerted to the incident when the crew realized their potential mistake.

Figure 1 also records the ANSV's observation that most of the early concern about runway incursions came from North America rather than Europe. This may partly explain why transatlantic initiatives to address the problem began to make significant progress some three months before the collision leaving insufficient opportunity for many of the subsequent recommendations to be adopted at Linate. These factors combined with the issues that stemmed from the lack of effective Safety Management. Together they contributed to a situation in which there was no effective runway safety plan. The lack of a fully developed runway safety team may also help to explain the absence of runway safety awareness campaigns, of a failure to ensure compliance with ICAO runway requirements and for well integrated plans to deal with runway emergencies.

Figure 1 also includes a link between the need to improve Safety Management Systems and the lack of staff in the DCA (Airdrome Judicial Authority) and the UCT (Traffic documentation section). There would usually have been two UCT officers on duty but only one had turned up for duty. Fortunately, their colleague on the previous shift was still present even though they had worked a continuous total of 13 hours on duty. Such "failures to adhere to prescribed obligations" provide specific examples of the ways in which problems in safety management create the vulnerabilities that were exposed during the accident.

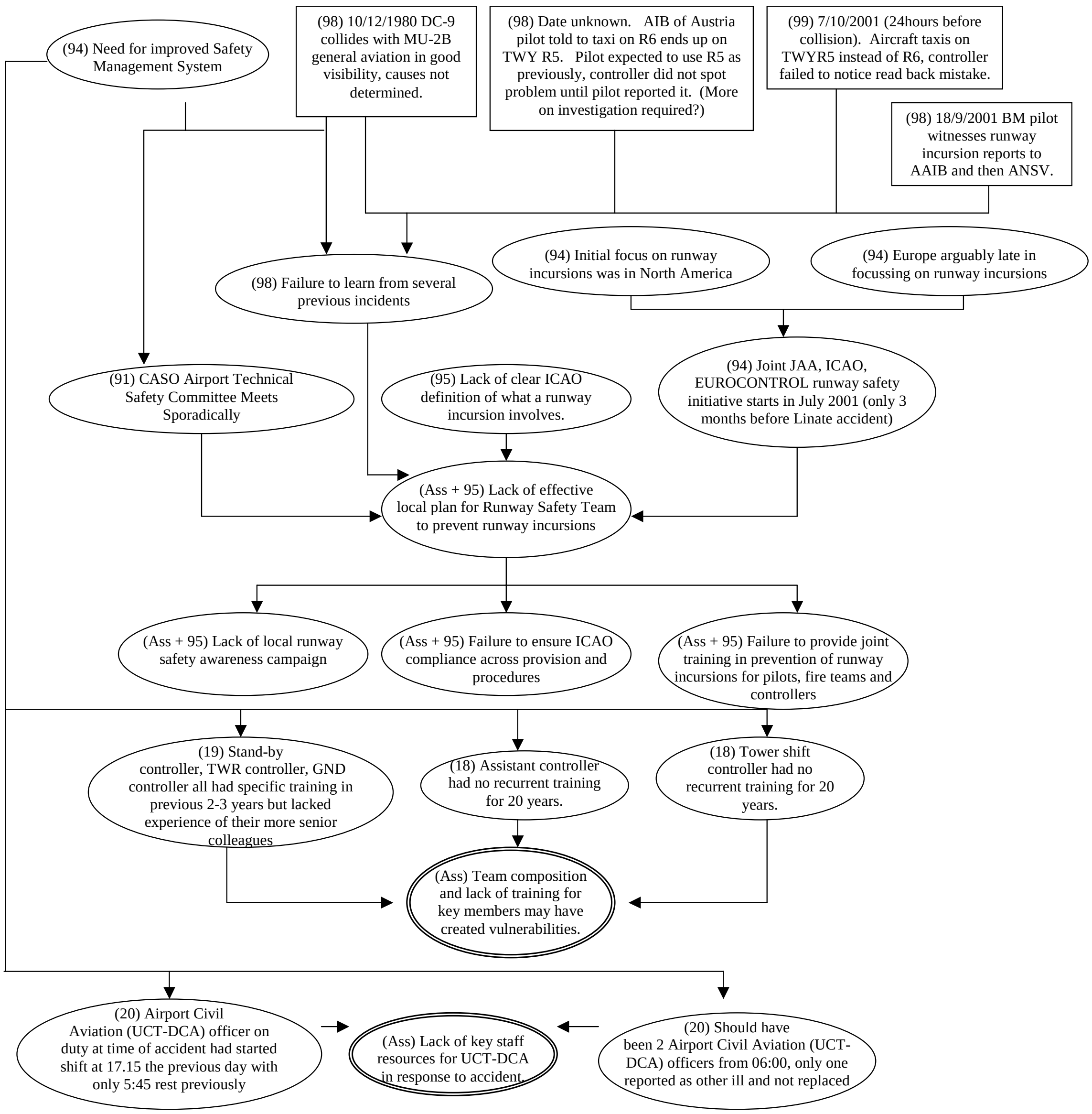

Figure 1: Contextual Factors Stemming from Organizational Issues Prior to the Linate Accident

Runway and Taxiway Infrastructure before the Accident

Figure 2 traces the ways in which the organizational issues in Figure 1 were influenced by and influenced the operating conditions at Linate. For example, the following ECF diagram shows that there was an unexpected increase in commercial traffic at the airport. One consequence of this was that many of the operational groups, identified in Figure 1, met to consider increasing the parking stands on the West Apron to accommodate the increase. The ANSV report criticised the lack of documentation to support the changes that were proposed by this meeting. There were also inconsistencies in the parking stands that were finally developed. For example, the stand S3 never seems to have been implemented and yet there were two S5s. This created the potential for confusion when crews reported their positions to controllers using these markings. These omissions were symptomatic of wider problems in the aerodrome documentation available to aircrews and controllers. For example, the Jeppensen charts did not reflect the yellow taxi lines on TWY R6. The right hand side of Figure 2 also illustrates the consequences of a further change in the operating environment facing ATM personnel before the accident. As can be seen, many of the flight slots at Linate were transferred to Malpensa in November 1998. This transfer meant that there was less need for the additional parking stands at Linate and were largely ignored. These changes combined with the lack of accurate and authoritative documentation left ATM personnel unaware of many of the markings that aircrew could see as they moved along the taxiways and onto the runways.

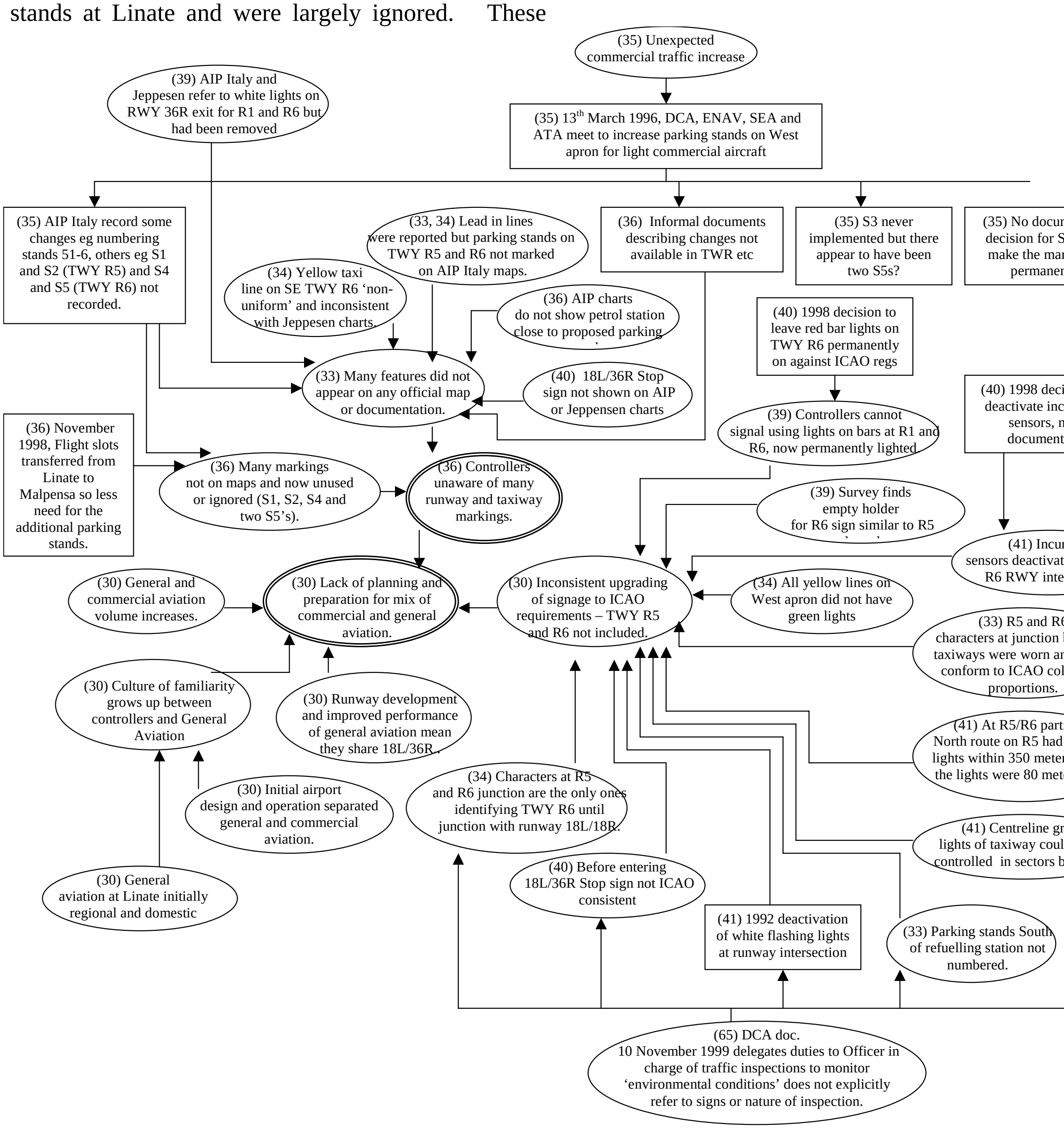

Figure 2: ECF Analysis of the Runway Infrastructure at the Linate Accident

Figure 2 also identifies inadequate planning for the mix of commercial and general aviation at Linate. Initially, the design and operation of the airport had separated these different forms of traffic. The general aviation had been largely domestic or regional and the ANSV refer to a 'culture of familiarity' between ATM personnel and the aircrews. However, as we have seen, there had been a gradual increase in traffic at Linate. Runway developments and the increasing power of aircraft used by general aviation pilots created a situation in which runway 18L/36R was shared by an increasingly mixed range of traffic. A further consequence of this was that ATM personnel gradually absorbed the additional overheads associated with synchronizing this mixed-use traffic as they moved from the parking areas, to the taxiways and the runways. These additional demands were exacerbated by the problems in signage mentioned above.

The previous ECF diagram also shows how a DCA document delegated responsibility to the officer in charge of traffic inspections to also monitor the 'environmental conditions' associated with the runways and taxiways. However, there is no explicit mention of the signage or of the types of inspections that might be appropriate to meet this objective. Partly in consequence, there was a range of modifications to the runway and taxiway infrastructure at Linate that did not meet ICAO requirements. These included the stop sign before 18L/36R, the 1992 deactivation of white flashing lights at the runway intersection, the 1998 decision to deactivate incursion detectors etc. It should be noted that this last modification was not properly documented and this reinforced the comments made in additional recommendation 8. The inconsistent signage created problems for the aircrews that had to navigate onto appropriate runways. It may explain the previous runway incursion incidents mentioned in previous paragraphs. Further problems were created by the lack of control over critical sections of runway and taxiway lighting. ATM personnel could no longer alter the configuration of these light sources to provide positional cues to aircrew. Some of the inconsistencies with ICAO regulations and wider safety provisions stemmed from decisions made 7 or 8 years before the accident. The fact that they had not been addressed after previous incidents arguably reinforces the need for improved Safety Management Systems. It also underlines the need to provide better support for the responsible individuals, such as the 'officer in charge of traffic inspections', and groups, including the 'runway safety teams' anticipated by the working groups on runway incursion [4].

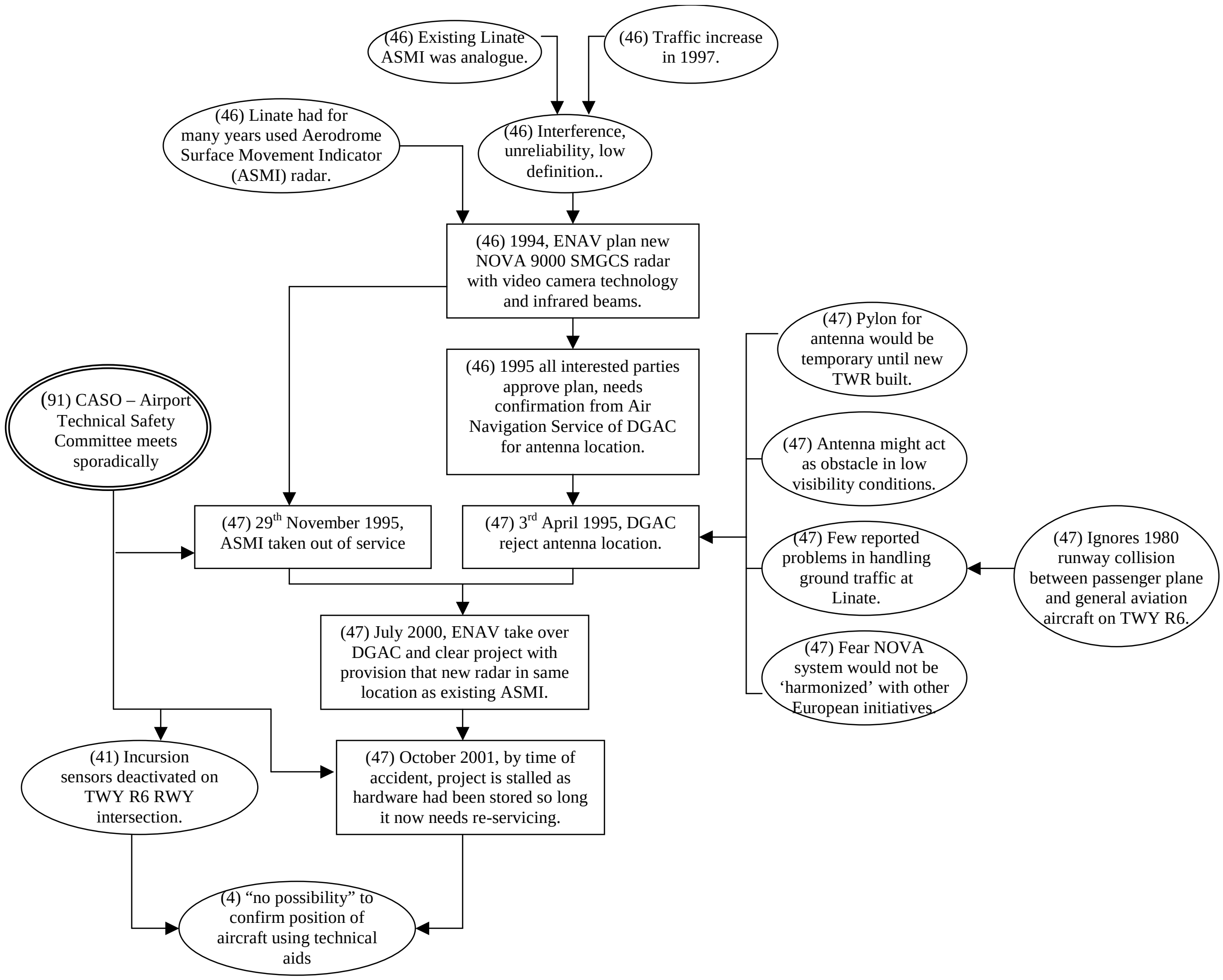

Figure 3: ECF Analysis of Technological Infrastructure at the Linate Accident

Technological Infrastructure before the Accident

Figure 3 examines the technological environment at Linate. As can be seen from events on the right of the extended ECF diagram, some of the decisions involving ground movement radar and incursion detection systems can be partly ascribed to the sporadic role of the airport technical safety committee, as described on page 91 of the ANSV report. As can be seen, the existing Aerodrome Surface Movement Indicator (ASMI) radar at Linate was analogue. The traffic increase mentioned in previous paragraphs exposed the reliability and low definition of this system to a point at which ATM personnel began to look for an alternative. There was a plan to introduce a NOVA 9000 Surface Movement Guidance and Control System (SMGCS) using video camera technology. The old AMSI system was taken out of service some 3 years before the accident. The plans to install the new system were jeopardized when the predecessor of ENAC objected to the antenna location. They argued that this would involve additional expense by constructing a temporary structure that would then be moved once a new Tower was built. It was also argued that the proposed structure might hinder visibility and that there were few reported problems in handling ground traffic at Linate. The ANSV do not explicitly consider the relevance or strength of this argument given the previous incidents noted in this report. Equally, the DGAC precursor of ENAC might not have been told about such previous incidents and hence would, from their point of view, have been justified in reaching this conclusion. The ECF diagram in Figure 3 notes this possible objection by showing the 1980 collision between a passenger aircraft and a commercial plane as a counter example. The previous diagram also illustrates the DGAC's concern that the new system would not harmonize with other European initiatives. This last point is particularly interesting as a reason to delay expenditure on a significant component of a ground-based safety net. It seems to be counter-intuitive that ATM personnel would be deprived of an important tool so that the eventual system would be consistent with a European initiative that was intended to harmonize safety provision.

The lower portion of Figure 3 uses the ECF formalism to continue the analysis. In July 2000, ENAV assumed many of the previous responsibilities held by DGAC. One side effect of this hand-over was that approval was finally granted for the development of the new Surface Movement Guidance and Control System. The antenna was to be located in the same position as the previous Aerodrome Surface Movement Indicator (ASMI) radar. The ECF diagram also shows that at the time of the collision this upgrade project was further stalled as mothballed hardware had to be re-serviced before the new system could be delivered. As we have seen from Figure 2, the runway incursion sensors had already been deactivated on TWY R6. In consequence, there was "no possibility" to confirm the positions of the various aircraft on the morning of the collision using technical aids.

Immediate Events Leading to the Incursion

Figure 4 illustrates the way in which ECF diagrams form a bridge between organizational, contextual issues and the events that led to the accident. It begins with the observation that there was an Automatic Terminal Information System (ATIS) broadcast at 04:50 advising of low visibility. Figure 4 also captures the observation that neither the aircraft nor the pilots were qualified to take-off under the Cat II/III conditions that held on the morning of the accident. It follows that the Cessna should not have started the flight. We consider two possible explanations, although there are others. Firstly, the crew may not have checked the ATIS announcements. This is marked as an assumption in the diagram and can only provide a partial explanation. The crews' own assessment of the prevailing meteorological conditions should also have alerted them to the possible dangers. Figure 4 also considers the possibility that they heard the ATIS announcement but failed to act on it, either because of the commercial and personal pressures mentioned above or because the ATIS announcement did not spell out the Cat status of the aerodrome under the prevailing meteorological conditions. It can be argued that ATM personnel should have checked the license conditions of the aircraft to ensure that they were permitted to operate in the low visibility conditions that currently held at Linate. As we have seen, however, ATM staff were working under a relatively heavy loading. In addition, Figure 1 has described how the initial dominance of local and regional general aviation at Linate may have led to the development of a culture of familiarity between ATM personnel and these crews. The reduction in traffic following the movement of slots to Malpensa may also have contributed to working practices that routinely cleared general aviation operations even though the controller's manual stated that ENAC was responsible for checking aircraft and pilots for low visibility operations.

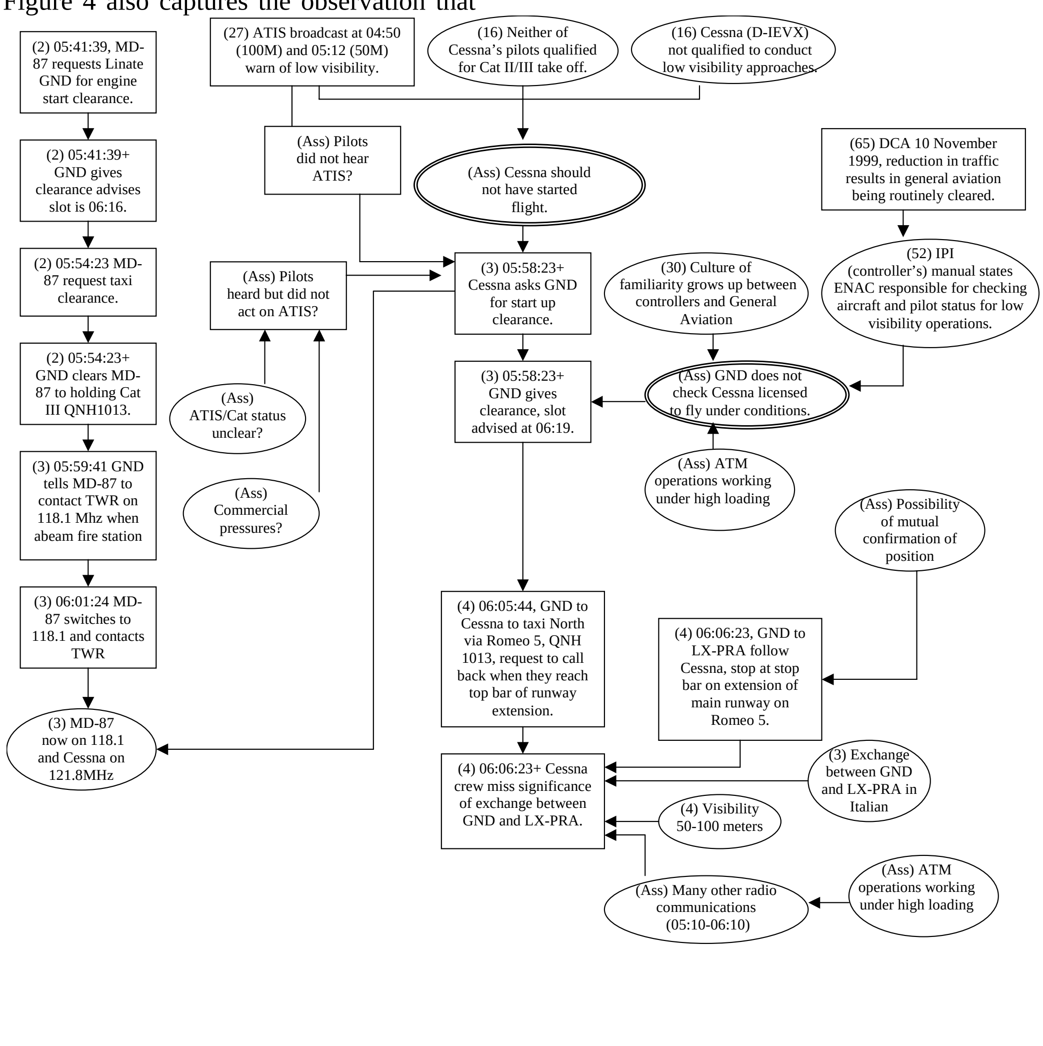

Figure 4: ECF Analysis of the Linate Accident – Initial Events on the Morning of the Accident

The left-hand sequence of events in Figure 4 describes how the MD-87 commenced its departure. This included the comment that the aircraft was to taxi to the 'holding position Cat III, QNH 1013". This analysis continues to the point at which the MD-87 transferred their radio frequency to the TWR on 118.1 while the Cessna continued to communicate with GND control on 121.1MHz. It is important to remember that some nine minutes elapsed between this handover to the TWR and the time of the collision. It might be argued that the protocols used for such handovers should be re-examined given that the opportunity for GND, TWR and the two crews to coordinate their actions was now significantly reduced. The common channel of communication between the GND controllers, the MD-87 and the Cessna diverged into two separate and distinct communications channels between GND and the Cessna and between the TWR and the MD-87 from 06:01:24 onwards. The previous ECF diagram also describes how GND personnel cleared another aircraft LX-PRA to follow the Cessna until the stop bar on the extension of the main runway on taxiway R5. As we have seen, this exchange was in Italian. This may partly explain why neither crew was able to use this clearance to provide information on their relative positions [5]. Equally, however, the crew of LX-PRA may not have been able to see that the Cessna was no longer in front of them given the reduced visibility on the taxiways.

Figure 5 builds on this analysis and includes the assumption that the Cessna's pilot and co-pilot did not question whether they were on the correct taxiway at this stage because the GND control had given them permission to continue taxiing. The ECF diagram again includes insights from the previous analysis of the environment at Linate. In this case, the crew did not question their position because there were no external prompts to indicate that they might have been on R6 rather than R5. There may have been a missing placard similar to one that was found for R5 and there were no other markings to indicate the identity of their taxiway other than the characters at the junction, mentioned previously. Figure 5 also shows that the Cessna's crew crossed the STOP markings 180 meters before RWY 18L/18R onto TWY R6. The ECF diagram reiterates points from Figure 2 that the STOP sign was not ICAO compliant. The sign was not shown on AIP or Jeppensen charts even though ENAV regulations required that the TWR should stop all aircraft at the signal on TWY R6.

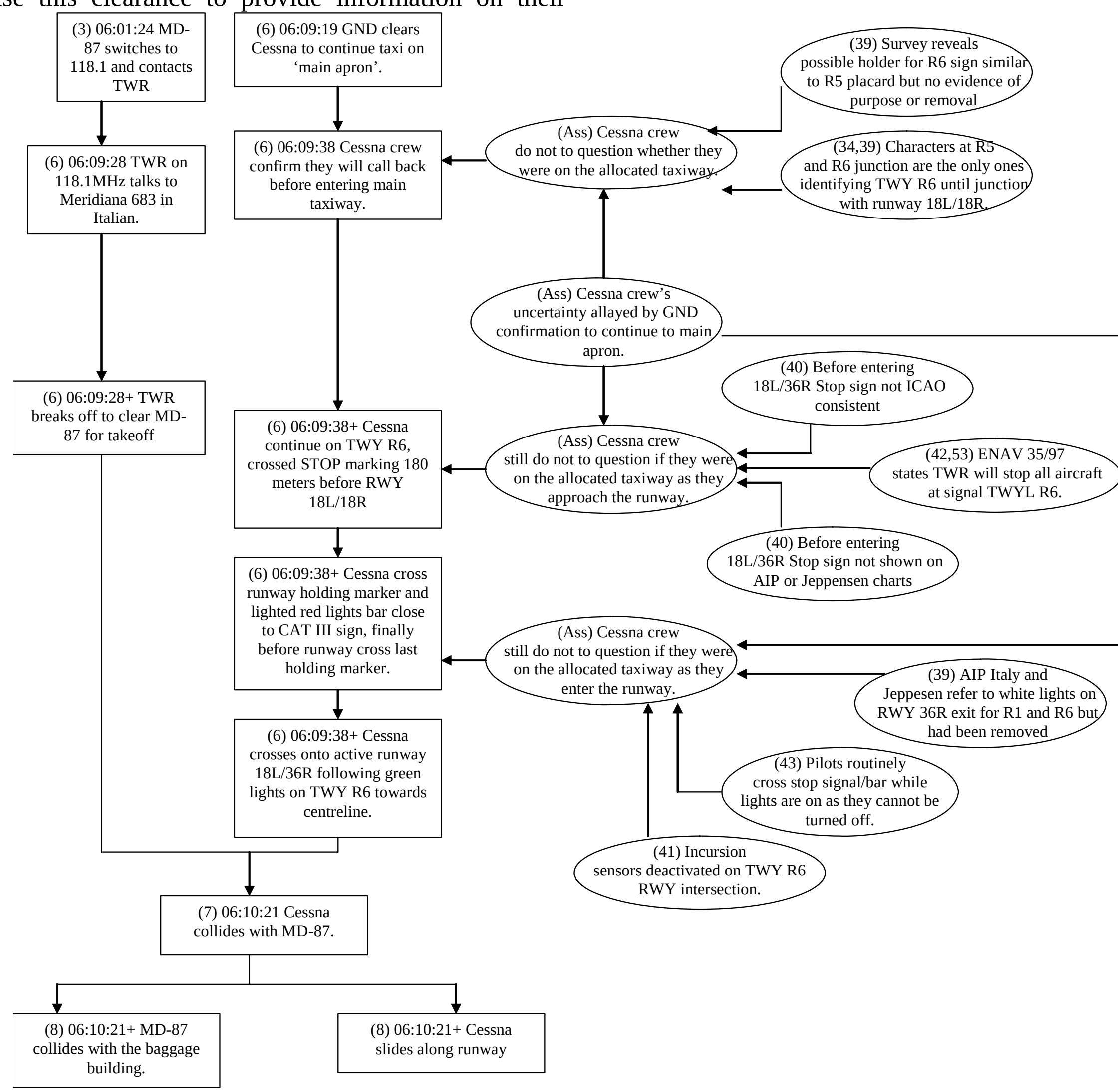

Figure 5: ECF Analysis of the Linate Accident – Events Immediately Prior to the Collision

At some time shortly after 06:09:38, the Cessna crossed the runway holding marker. They passed an illuminated red light bar close to a Cat III sign. Again it must be assumed that they were disoriented and did not at this stage question their assumed location on the appropriate taxiway short of the runway. The ANSV provide some information about the reasons why this final set of defences might have been broached when they argue that pilots routinely had to pass illuminated stop signals because ATM personnel could not routinely turn them off. This diagram also includes further observations on inconsistencies between the signage and official documentation. As before, however, it is uncertain whether there inconsistencies were immediate causes of the accident. There is no evidence that the Cessna crew attempted to use this documentation to trace their position on the taxiway at this relatively late stage in the accident. Their decision to cross onto the active runway may also have been influenced by the path of the green lights on TWY R6 that led onto the centreline of 18L/36R.

Events Following the Linate Collision

The Linate accident has many unusual and worrying features. One of these is the lack of coordination that characterized the immediate response to the collision. The adverse meteorological conditions that were an important cause of the incursion also served to exacerbate the problems of responding to the accident. Other organizational factors may not have helped. For instance, the response was hindered by a failure to learn from previous drills that had been organized to prepare for future incidents. Figure 6 provides an overview of the immediate response to the Linate collision.

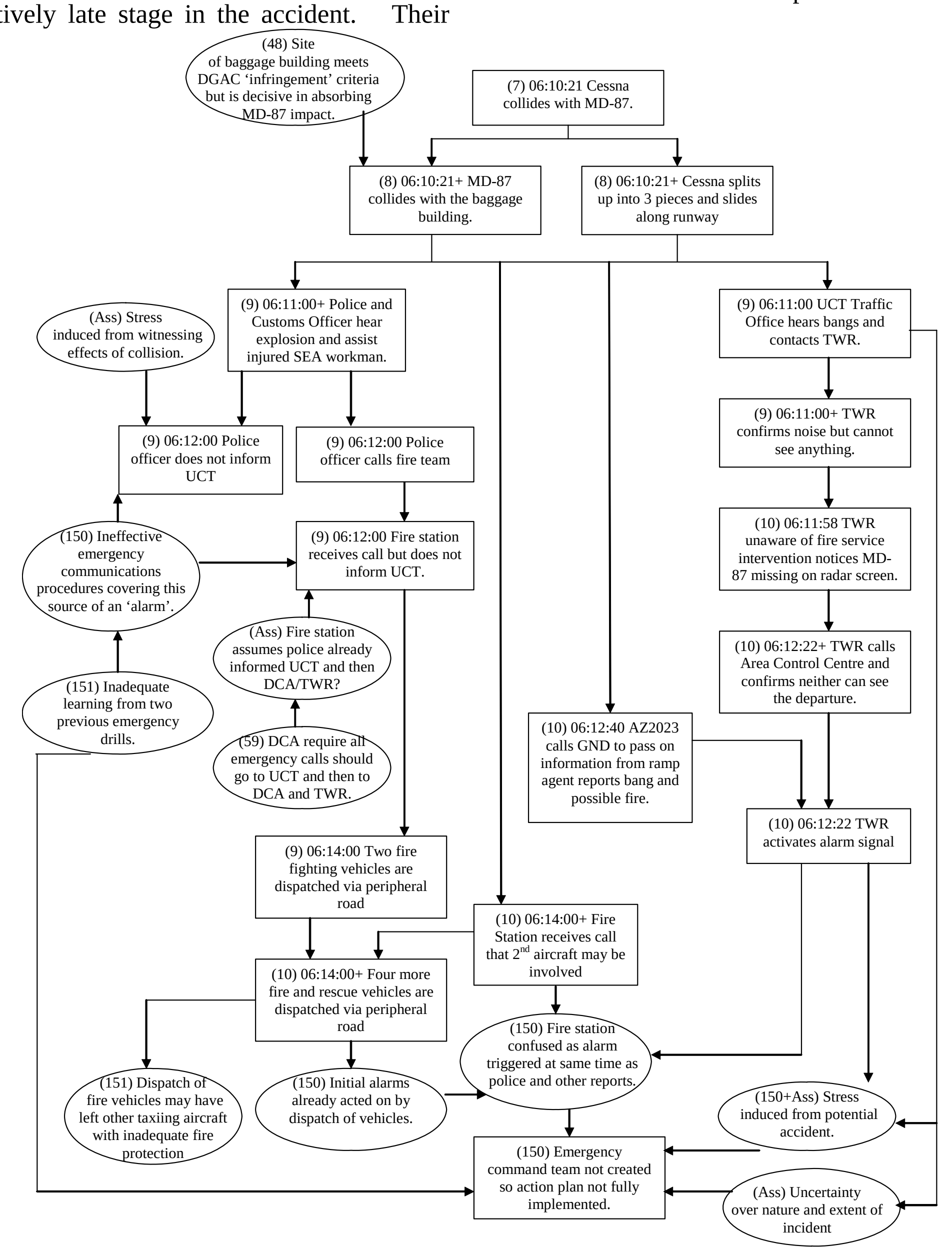

Figure 6: ECF Analysis of the Linate Accident – Events Immediately After the Collision

As can be seen, the MD-87 collided with a baggage building that was situated close to the runway. The location of this structure conformed to the relevant DGAC infringement criteria. A previous ENAV survey had shown that it encroached the permitted area by around 1 meter. Additional warning lights had subsequently been added to the structure. The ANSV concluded that the position of the building was 'decisive' in absorbing the violent impact of the aircraft (page 48) and was 'instrumental in the catastrophic sudden and violent stoppage of the aircraft' (page 160). The official report does not speculate whether the consequences of the incident would have been less severe if the baggage handling facility had not been placed so close to the runway. The ANSV report does not list the location of the baggage facility as one of the factors that caused the adverse outcome to this incident once the collision had occurred. None of the existing recommendations mention the location of buildings adjacent to runways.

Figure 6 extends the analysis of post accident events to consider communications problems that frustrated attempts to coordinate the response to the collision. A Police Officer who was close to the baggage facility heard the collision and rushed to assist the injured. They then contacted the fire station. However, he did not contact the UCT who should have coordinated the response according to the prearranged emergency plan. One consequence of this was that ATM personnel were not immediately alerted about this initial report. The officer's decision to call the Fire Service is entirely understandable given the stress that can be induced from witnessing the after effects of such incidents. The ANSV report also argues that a lack of organisational learning from previous drills had led to problems in the procedures and mechanisms that governed the reporting of incidents from such sources. The fire station received the officer's call and dispatched two vehicles via a peripheral road. It can be argued that even if the police officer, acting under the stress of the moment, had failed to contact the UCT to coordinate the response then Fire personnel should have reported to them. However, Figure 6 shows that the Fire Officers may have assumed that the Police had followed the DCA's recommended procedures and had already made this call. This assumption like the others that have been explicitly represented in previous ECF diagrams can be tested against witness statements and evidence not presented in the official report.

The failure of communications between the emergency service and the UTC coordinators may have hindered the establishment of an emergency team. However, UTC personnel were alerted to the incident even without calls from the Police and Fire Officers. The Traffic Office heard the collision and contacted the TWR. They then attempted to confirm which aircraft was involved. After subsequent calls with the Area Control Centre they realise that the MD-87 is missing and the TWR activates the alarm signal as required by the emergency plan. However, the stress and uncertainty of a potential incident can again be used to explain why neither the ATC not the UTC staff took the steps necessary to create an Emergency Command Team [6]. This emergency team was supposed to coordinate the response to such incidents. It was also intended to ensure that the pre-arranged emergency plan was fully implemented. A key issue here is that the same lack of coordination that led to the failure to convene the emergency team, also prevented the coordinated response that the emergency team was intended to address. This form of vicious circle had not been adequately addressed in the previous drills.

The fire station received a second call indicating that two aircraft may have been involved in the incident and, therefore, dispatched four more vehicles. The lack of coordination may have affected this decision as the ANSV argue the dispatch of so many appliances may have left other taxiing aircraft with inadequate fire protection (page 151). This is a significant concern given the uncertainty in the aftermath of the collision and the possibility of wreckage being dispersed across runways and taxiways. In the meantime, the alarm signal from the TWR may have added to the Fire Service confusion. They had already acted on two previous warnings. Hence, it is likely that they concluded they had taken sufficient actions without inquiring about the formation of the command team or explicitly communicating information about their actions back to the TWR. In particular, it seems likely that they assumed that TWR already knew the location and other information that they had received in the previous two calls that triggered the dispatch of their fire vehicles. These assumptions proved to be unwarranted.

Eventually, TWR received a report from I-LUBI that they have seen flames on runway R6. GND tries to confirm whether LX-PRA ever saw the Cessna that they had been requested to follow. They confirmed that they had not seen the Cessna and at about this time the ATA confirm that the Cessna had not returned. While all of this was going on, TWR asked the fire service if they could see two aircraft. There was no answer to this initial call at 06:29:27 and so after the confirmation from ATA, TWR asked the Fire Station to conduct an examination of the runway. The ANSV does not explicitly state whether such an examination should have been scheduled according to the airport emergency plan. However, in retrospect it seems likely that a more considered response to the emergency might have looked beyond the initial site of the MD-87 wreckage in order to ensure that they did not miss any injured survivors either from the aircraft or airport ground staff. Another issue here that was not considered by the ANSV was whether additional technological support could have been provided during this search. For example, the military now routinely make use of low cost night vision equipment, either based on thermal imaging or image intensification technology. This equipment is sufficiently robust now to be considered for deployment to fire service personnel. Thermal imaging devices would provide a useful means of locating burning wreckage on a runway in a relatively short period of time. It should be noted that certain meteorological conditions, such as fog and mist, can reduce the temperature gradients that are recognized by this equipment. However, in most cases this would not be sufficient to mask the heat generated by burning aviation fuel.

CONCLUSIONS

This paper had used Events and Causal Factors charts to reexamine the ANSV's report into the Linate runway incursion. The intention has not been to identify new findings but to use the graphical formalism to trace the technical and managerial context for the errors made by individual air traffic controllers and aircrew. In particular, we have shown that the lack of effective safety management techniques led to a degraded infrastructure both in terms of runway and taxiway markings but also in terms of the ground movement systems that might have helped ATCOs to identify the potential incursion before it occurred. It is important not simply to blame the operators, managerial factors exposed them to this error inducing context. However, it is equally important to ask why controllers were so tolerant of their degraded working environment. Our analysis suggests that it is time to question the 'can do' attitude that finds 'work arounds' when critical elements of a technology infrastructure are no longer available.

Acknowledgements

I would like to thank Tony Licu and Gilles le Galo for their comments and encouragement with this work and their insights into the Air Traffic Control issues in this incident.

REFERENCES

1. Agenzia Nazionale per la Sicurezza del Volo (ANSV), Milano Linate, ground collision between Boeing MD-87, registration SE-DMA and Cessna 525-A, registration D-IEVX, Reference A/1/04, 20th January 2004.
2. C.W. Johnson, A Handbook of Accident and Incident Reporting, Glasgow University Press, Glasgow, 2003.
3. NASA, NASA Procedural Requirements for Mishap Reporting, Investigating, and Recordkeeping, NPR: 8621.1A, Code Q/Office of Safety and Mission Assurance, Washington DC. 2004.
4. J. Rasmussen, Risk Management in a Dynamic Society: A Modeling Problem. *Safety Science* 27:183-213, 1997
5. E. Hutchins, Cognition in the Wild. Cambridge, MA, MIT Press, 1995.
6. D. Woods and R. Cook, Perspectives on Human Error: Hindsight Biases and Local Rationality. in Durso RS et al., eds., *Handbook of Applied Cognition*. New York: Wiley, pp. 141-171, 1999.