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Managing disruption risk in express logistics via proactive planning

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Abstract

Purpose – The purpose of this paper is to carry out a comprehensive review for state-of-the-art works in disruption risk management of express logistics mainly supported by air-transportation. The authors aim to suggest some new research directions and insights for express logistics practitioners to develop more robust planning in air-transportation.

Design/methodology/approach – The authors mainly confined the research to papers published over the last two decades. The search process was conducted in two dimensions: horizontal and vertical. In the horizontal dimension, attention was paid to the evolution of disruption management across the timeline. In the vertical dimension, different foci and strategies of disruption management are employed to distinguish each article. Three keywords were used in the full text query: "Disruption management", "Air transportation", and "Airline Operations" in all database searches listed above. Duplications due to database overlap, articles other than those from academic journals, and papers in languages other than English were discarded.

Findings – A total of 98 articles were studied. The authors categorized the papers into two broad categories: Reactive Recovery, and Proactive Planning. In addition, based on the problem characteristics and their application scenarios, a total of 11 sub-categories in reactive recovery and nine sub-categories in proactive planning were further identified. From the analysis, the authors identified some new categories in the air-transportation recovery. In addition, by analyzing the papers in robust planning, according to the problem characteristics and the state-of-the-art research in recovery problems, the authors proposed four new research directions to enhance the reliability and robustness of air-transportation express logistics.

Research limitations/implications – This study provided a comprehensive and feasible taxonomy of disruption risk management. The classification scheme was based on the problem characteristics and the application scenarios, rather than the algorithms. One advantage of this scheme is that it enables an in-depth classification of the problem, that is, sub-categories of each class can be revealed, which provides a much wider and clearer horizon to the scientific progress in this area. This helps researchers to reveal the problem's nature and to identify the future directions more systematically. The suggestions for future research directions also point out some critical research gaps and opportunities.

Practical implications – This study summarized various reasons which account for the disruption in air-transportation. In addition, the authors suggested various considerations for express logistics practitioners to enhance logistics network reliability and efficiency.

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Originality/value – There are various classification schemes in the literature to categorize disruption management. Using different algorithms (e.g. exact algorithm, heuristics, meta-heuristics) and distinct characteristics of the problem elements (e.g. aircraft, crew, passengers, etc.) are the most common schemes in previous efforts to produce a disruption management classification scheme. However, the authors herein attempted to focus on the problem nature and the application perspective of disruption management. The classification scheme is hence novel and significant.

Keywords Air transport, Express logistics, Disruption management, Proactive planning

Paper type Literature review

1. Introduction

In recent years, express logistics is playing a critical role in logistics and supply chain networks. Striving for high efficiency to increase the once time-based competitiveness in the business, companies rely more and more on express logistics. Although in the economic view, air-transportation is relatively much more expensive than any other transportation form, it has already been widely adopted. Air transport bears the most critical function in the modern logistics structure, especially when alternative transportation is relatively slow, such as by ship, train, and truck. It is estimated that the global increase of air-cargo will be about 5 per cent per annum in the coming 20 years. However, despite the fact that air transport has become more prevalent and provides a much more efficient way of transport, any disruption may result in severe delays and negative impacts.

Air-transportation disruption management is receiving increasing and detailed attention from airlines, express logistics providers, and governments nowadays. The importance of air-transportation disruption management is motivated by the fact that executing air-transport-related operations according to a planned schedule is extremely difficult since there are many uncertainties frequently occurring in reality, known as disruptions. Although development of the aviation industry can bring huge benefits to a country, any disruptions such as flight delays and cancellations would bring huge negative impacts to passengers, airlines, shippers, and the country's economy. Every year, the total direct disruption cost is reported to be billions of US dollars (Ball *et al.*, 2010). In addition, because of the nature of this problem complexity, it has attracted many researchers and practitioners. Disruption management is critical and crucial to airlines because of the huge economic impact induced, its practical needs, driven by the airline industries, and research complexity (Liu *et al.*, 2008, Petersen *et al.*, 2012).

Disruption can be defined as "an event that prohibits an airline from operating as scheduled" (Rosenberger *et al.*, 2002). It is indeed almost impossible to predict anything that may interrupt the continuity of the schedule (Chan *et al.*, 2015). If it is not managed in a timely and proper manner, it will relentlessly affect customer satisfaction, operation efficiency and revenue performance (Jafari and Zegordi, 2011). Disruption management can be applied in many areas, such as flight scheduling, airline crew scheduling, machine scheduling, logistics scheduling, inventory, production planning supply chain coordination, and project scheduling (Archie, 2014). A general description of disruption management was described as the revision of the original plan or creation of a new plan in the execution phase under constraints to minimize the adverse impact of the disruption, and other objectives as a result of internal and external uncertainties that induce deviations to the original plan obtained by the optimization models and solutions (Yu and Qi, 2004).

In fact, disruptions in airline operations (e.g. flight delays) often impact on airlines in terms of extra expenses (e.g. food and lodging) and lost revenue. In addition, it causes inconvenience and misery to passengers. Moreover, it induces a propagation effect, and causes revenue loss to the rest of a company, directly or indirectly (Li *et al.*, 2007). This is similar to the situation in supply chain management (Durowoju *et al.*, 2012), and significantly reduces the profitability of those companies that depend on air-transportation, such as express logistics (Ball *et al.*, 2010). As a result, there is a strong need by the industry on effectively tackling the problems of air-transportation disruptions to minimize the effects brought upon. It is necessary to investigate more effective approaches to keep flights on schedule, as well as to get the disrupted schedule back to the original schedule as soon as possible, with a minimum number of stakeholders being affected. The term "Disruption management" therefore emerged.

In the literature, there are many papers mentioning different causes of disruption, for example, bad weather, crew absence, mechanical failures, airport congestion, etc. Among them, both Yu and Qi (2004), and Sinclair *et al.* (2014) gave very detail discussion on this, as summarized in Table I. To be specific, Yu and Qi (2004) stated that the sources of changes can be system environment changes, unpredictable events, system parameters changes, changes in resource availability, new restrictions/considerations, or system performance uncertainties (Yu and Qi, 2004). All these cause deviations to the planned schedule. Sinclair *et al.* (2014) further stated three causes of disruptions specifically related to airline operations, namely aircraft disruptions, airport disruptions and flight disruptions (flight delays and cancellations). Aircraft disruptions refer to all the disruptions related to the availability of an aircraft. Airport disruptions refer to the disruptions at the airport, for example the closure of a runway due to accidents. Flight disruptions can also be caused by the reasons mentioned above. In practice, three kinds of disruptions may occur simultaneously in one scenario. Among all the possible reasons, inclement weather accounted for 75 per cent of disruption causes (Sinclair *et al.*, 2014). These provide some information for practitioners to prepare for during the planning.

Disruptions in airline operations affect not only the resource availability of one single flight in real world operations, and its propagation effect can be fatal. Aircraft and crew are also usually considered as major resources, and have to be recovered and returned to normal operations as soon as possible (Abdelghany *et al.*, 2008). In the case of a flight cancellation, crew will be required to fly as passengers for the next flight or a duty swap with available crew or call for a standby crew, if available, at the station. Some EU airlines maintain 30 per cent of standby crews for operations (Ehrgott and Ryan, 2002). It would significantly increase the operation costs. On the other hand, the airline has to consider its reputation and customer service. The disruptions cause

Causes	Examples
System environment change	Snowstorm
Unpredictable events	Terrorist attack
System parameters change	Delay in arrival of newly purchased aircraft
Availability of resources change	Crew sickness
New restrictions	New government law on noise control
System performance uncertainties	Baggage system breakdown
New considerations	Travel alert to the Philippines
Aircraft disruptions	Aircraft malfunction
Airport disruptions	Runway closure
Flight disruptions (delays and cancellations)	Diverted flight

Table I.
The summary of causes of air-transportation disruptions

inconvenience to passengers. Though it is not compulsory to offer compensation to passengers, except in EU regions, most airlines voluntarily offer meal vouchers and water to disrupted passengers. In addition, Airline Operations Control Centers (AOCC) have to arrange a vacant aircraft for the subsequent flights or consider re-routing the flight (Bruce and Newman, 2010).

A minor disruption can also initiate a series of chain reactions in the entire planned schedule (Liu *et al.*, 2008). A flight schedule consists of numerous constrained resources, such as aircraft, crew and airport facilities. These resources are closely linked together through the network. Each resource moves from one flight leg to another. Though every flight, more or less, needs the same types of resources, individual resources do not necessary link together. For instance, crew member A is assigned to flight 001 to Beijing and crew member B from the same initial flight is assigned to a later flight 002 to Japan independently; and the same applies to aircraft. The domino effect of disruption amplifies the damages and magnifies the associated costs. The ramification of this kind of connection is the key element in the propagation.

The remaining part of this paper is organized as follows. Section 2 presents the survey methodology. Section 3 presents paper classification mechanism. Section 4 discusses the review papers published in air-transportation disruption management. Section 5 gives a detailed review regarding recovery problems, while Section 6 describes proactive issues. Section 7 discusses the future work in enhancing air-transportation express logistics. Lastly, Section 6 concludes the paper.

2. Survey methodology

2.1 Source of literature

The objective of this paper is to carry out a comprehensive literature review on the current state of research related to disruption management in airline operations and an in-depth analysis to explore the future trends in order to identify new research directions and value-added applications. The literature surveyed in this paper was mainly selected from six sources: Emerald; IEEE/IEE Electronic Library via IEEE Xplore; Science Direct – Online Journals by Elsevier Science; Springer LINK Online Libraries; Taylor & Francis; and ProQuest. This survey is based on articles in journals and a small number of conference proceeding papers, working papers, technical reports, and theses/dissertations.

As we intend to survey studies on recent trends on disruption management related to proactive planning, we mainly confined our search to papers published in the last two decades. The search process was conducted in two dimensions: horizontal and vertical. In the horizontal dimension, attention was paid to the evolution of disruption management on the timeline. In the vertical dimension, different focuses and strategies of disruption management are employed to distinguish each article.

Three keywords were used in the full text query: “Disruption management”, “Air transportation”, and “Airline Operations” in all database searches listed above. Duplications due to database overlap, articles other than from academic journals, and papers in languages other than English were discarded. The full text of each paper was read to screen and identify its relevance to the field. The papers that matched with the query but did not focus on disruption management in air-transportation were also rejected. For example, some only mentioned air transport as an example for disruption management but no research was actually conducted in the domain. This left 98 articles, among which, there were 72 journal papers, 20 conference proceedings papers, one book chapter, and five technical report paper. The distribution of papers by publication year is summarized in Figure 1 and in Table II. As shown Figure 1, research on disruption management in airline operations as a promising research area, grew significantly in recent years, especially after 2006.

2.2 *The philosophy of the review work*

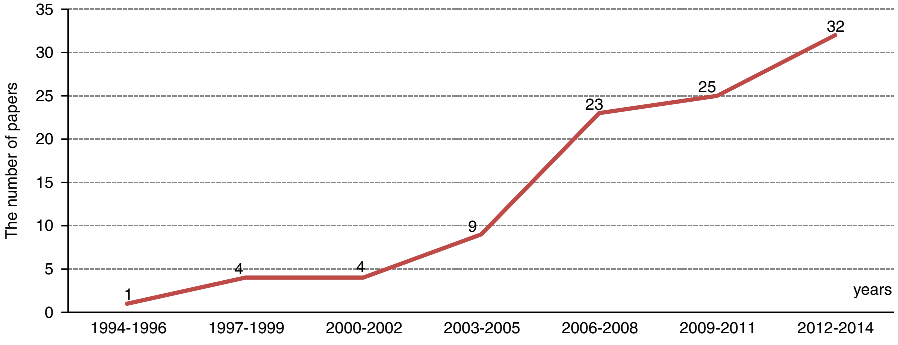
We conducted the review work in three steps. Step 1 focused on the review of the traditional disruption management variants in the literature, aiming to provide a landscape of how different classes of problems evolved and varied in diverse application domains and operational constraints. Step 2 focused on the state-of-the-art research of proactive planning in disruption management. Based on the traditional disruption management variants we identified in Step 1, we discuss how the proactive planning interacts with the traditional disruption management variants to formulate more practical and complex models in Step 3. Then we suggested the next wave of research on proactive planning in disruption management.

2.3 *Classification schemes*

A comprehensive and feasible taxonomy of disruption management is essential to reveal the problem's nature and to identify the future directions. There are various classification schemes in the literature to categorize disruption management. Using different algorithms (e.g. exact algorithm, heuristics, meta-heuristics) and distinct characteristics of the elements of the problem (e.g. aircraft, crew, passengers, etc.) are the most common schemes in previous efforts to produce a disruption management classification scheme. Since we herein attempt to focus on the nature of the problem and the application of disruption management, our classification scheme is based on the problem characteristics and the application scenarios, rather than the algorithms. One advantage of this scheme is that it enables an in-depth classification of the problem, that is, sub-categories of each class can be revealed, which provides a much wider and clearer horizon to the scientific progress in this area. Using this scheme, we identify the categories and the respective sub-categories.

3. Distribution of publications by classified categories

According to the nature and implementation stage in practical air-transportation operations (with reference to the airline operations), the key research areas can be classified into two broad categories focusing on two different time frames in real



Note: (three years as a period)

Figure 1. Distribution of papers over time

References	No. of papers	Disruption management variants
Yan and Yang (1996)	1	R-FA
Wei *et al.* (1997); Argüello *et al.* (1997)	2	R-C, R-FA
Clarke (1998); Grandeau *et al.* (1998)	2	R-F, review
Filar *et al.* (2001); Løve *et al.* (2001)	2	R-FA, review
Ehrgott and Ryan (2002); Rosenberger *et al.* (2002)	2	R-C, P-C
Yu and Qi (2004); Abdelghany *et al.* (2004); Dorneich *et al.* (2004); Andersson and Värbrand (2004); Rosenberger *et al.* (2004)	5	R-F, R-C, R-IS, R-FA, P-AF
Guo *et al.* (2005); Castro and Oliveira (2005); Ehrhoff *et al.* (2005); Schaefer *et al.* (2005)	4	R-C, R-FAC, P-C, P-F
Nissen and Haase (2006); Berge *et al.* (2006); Liu *et al.* (2006); Andersson (2006); Malucelli *et al.* (2006); Bratu and Barnhart (2006); Wu (2006); Smith and Johnson (2006); Schaefer and Nemhauser (2006); Shebalov and Klabjan (2006); Sohoni *et al.* (2006)	11	R-C, R-FA, R-FAC, R-FACP, P-F, P-A, P-C
Kohl *et al.* (2007); Castro and Oliveira (2007a,b); Liu *et al.* (2007); Bierlaire *et al.* (2007); Abdi and Sharma (2007); Dorndorf *et al.* (2007)	8	R-C, R-FA, P-D, P-FG, review
Abdi and Sharma (2008); Abdelghany *et al.* (2008); Liu *et al.* (2008); Sohoni *et al.* (2008)	4	R-IS, R-FA, P-FP
Kuster *et al.* (2009); Acuna-Agost *et al.* (2009); Janic (2009); Castro and Oliveira (2009a,b); Castro *et al.* (2009);	6	R-Airport, R-FAP, R-FACP, P-D
Clausen *et al.* (2010); Bruce and Newman (2010); Marks and Jenkins (2010); Cohn and Lapp (2010); Darlay *et al.* (2010); Zegordi and Jafari (2010); Eggenberg *et al.* (2010a); Castro and Oliveira (2010); AhmadBeyhgi *et al.* (2010); Yang *et al.* (2010); Burke *et al.* (2010); Aloulou *et al.* (2010); Weide *et al.* (2010)	14	R-FR, R-P, R-FAP, R-FACP, P-F, P-A, P-AF, P-AC, review
Le *et al.* (2011); Aguiar *et al.* (2011); Ionescu *et al.* (2011); Bisaillon *et al.* (2011); Jafari and Zegordi (2011); Makhlouf and Waheed (2011)	6	R-FAC, R-FAP, review
Jeng (2012); Gao *et al.* (2012); Wu and Le (2012); Li and Wallace (2012); Waheed and Makhlouf (2012); Makhlouf and Waheed (2012); Petersen *et al.* (2012); Castro *et al.* (2012); Landry *et al.* (2012); Dück *et al.* (2012); Şeker and Noyan (2012); Dorndorf *et al.* (2012); Lapp and Cohn (2012)	13	R-F, R-FA, R-FAP, R-FACP, P-A, P-AC, P-FG, P-FM
Xiong and Hansen (2013); Quansheng *et al.* (2013); Kontogiannis and Malakis (2013); Jozefowiez *et al.* (2013); Chan *et al.* (2013); Le *et al.* (2013); Mou and Zhao (2013); Arıkan *et al.* (2013); Atkinson *et al.* (2013); Muter *et al.* (2013); Aloulou *et al.* (2013)	11	R-FR, R-ATC, R-FAP, R-Cruise, P-A, P-C, P-FP
Visentini *et al.* (2014); Sinclair *et al.* (2014); Lei and Zhao (2014); Aktürk *et al.* (2014); Lu and Gzara (2014); Soykan and Erol (2014); Castaing *et al.* (2014)	7	R-FAP, R-Cruise, P-C, P-FG, review

Notes: R-F, Recovery; R-C, Crew Recovery; R-P, Passenger Recovery; R-Airport, Airport Recovery; R-ATC, Air Traffic Control Recovery; R-IS, Information System; R-FA, Flight and Aircraft; R-FAC, Flight, Aircraft and Crew; R-FAP, Flight, Aircraft and Passenger; R-FACP, Flight, Aircraft, Crew, and Passenger; R-Cruise, Cruise Speed; P-F, Robust Planning of Flight; P-A, Robust Planning of Aircraft; P-C, Robust Planning of Crew, P-D, De-peaking; P-AF, Robust planning of integrated Aircraft and Flight Planning; P-AC, Aircraft and Crew Planning; P-FP, Flight and Passenger Planning; P-FG, Flight and Gate Planning; P-FM, Flight and Maintenance Planning

Table II.
The papers reviewed in this study

air-transportation operations: Reactive Recovery, and Proactive Strategies (Robust Planning), as shown in Figure 2 (Clausen *et al.*, 2010).

Reactive Recovery can be further divided into two main categories, named as Non-Integrated Recovery and Integrated Recovery, according to the airline operations involved in the problem, as summarized in Table II. Reactive Recovery measures refer to the approaches to be adopted during a disruption. It concerns the re-scheduling of the original plan once a disruption occurs. The generation of recovery plans is complicated, involving many highly interrelated operations, such as flight, aircraft, crew, passengers, cargo, catering, etc. They have to be carefully re-planned for efficient and effective coordination, with the goal of getting the disrupted schedules back to the original plan as soon as possible. As a common practice, to deal with disruptions, large airlines usually adopt a sequential approach by re-generating the aircraft schedule, and then the crew schedule. After that, there is re-scheduling of all the operations related to the ground issues, and passengers recovery comes last. The process will be iterated until a feasible recovery plan is obtained. The solution can be the re-timing or cancelling the flights, reassigning standby crew, and re-accommodating passengers involved to a later flights.

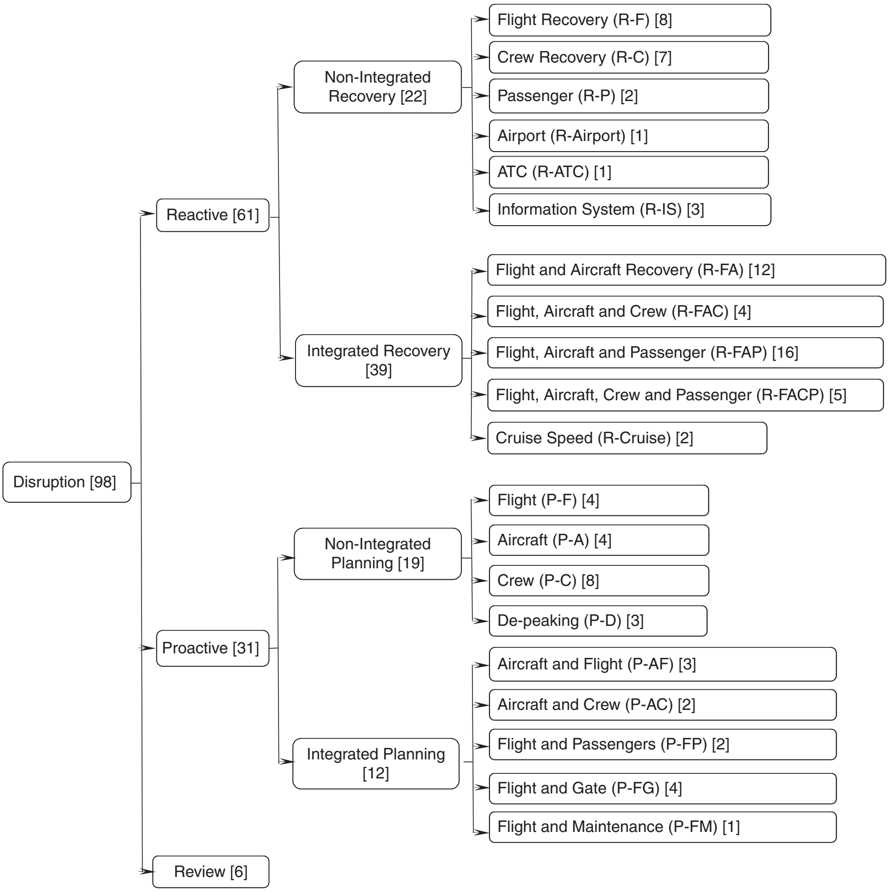


Figure 2.
Classification of the air-transportation disruption management problems

The Non-Integrated Recovery category includes the key research areas in Flight Recovery (R-F), Crew Recovery (R-C), Passenger Recovery (R-P), Airport Recovery (R-Airport), Air Traffic Control Recovery (R-ATC), and Information System (R-IS). Meanwhile, the Integrated Recovery category includes the integration of airline operations with Flight and Aircraft (R-FA), Flight, Aircraft and Crew (R-FAC), Flight, Aircraft and Passenger (R-FAP), Flight, Aircraft, Crew, and Passenger (R-FACP), and Cruise Speed (R-Cruise).

On the contrary, Proactive Planning is used antecedently to the occurrence of disruptions in the planning stage rather than in the operations stage. It aims to build a plan that can remain feasible and is less vulnerable in the case of disruptions. It is a "sense and response strategy", and requires less cost and simpler recover solutions can be applied to recover the operations. The first one focuses on flight scheduling before the aircraft departs, with the main concern of establishing a flight schedule with adequate buffer time for each flight to cover any unexpected disruption events, such as late arrival of previous flights, crew rearrangements, etc. The challenge at this stage is the buffer time optimization, as any excess buffer time reserved would increase the turnaround time of an aircraft, and lead to a waste of standby time. It is essential for airlines to strike a balance between the risk of delay and utilization of aircraft turnaround time when establishing the flight schedule.

Similar to the Reactive category, Proactive Planning can also be further divided into two categories, Non-Integrated Planning and Integrated Planning, as summarized in Table II. Non-Integrated Planning includes Robust Planning of Flight (P-F), Robust Planning of Aircraft (P-A), Robust Planning of Crew (P-C), and De-peaking (P-D). Meanwhile, the Integrated Planning includes the robust planning of integrated Aircraft and Flight Planning (P-AF), Aircraft and Crew Planning (P-AC), Flight and Passenger Planning (P-FP), Flight and Gate Planning (P-FG), Flight and Maintenance Planning (P-FM).

4. Review paper in air-transportation disruption management

In the last decade, there have been a few review papers on air-transportation disruption management. An early review paper was completed by Clarke (1998), in which the author conducted a review of about 19 papers focusing on the work related to AOCC during disruptions. At that time, the review focus was on the operation process after disruption in AOCC, discussing information systems and flight re-scheduling approaches. A few years later, one can see that recovery becomes the main focus of the related review studies. Filar *et al.* (2001) carried out a review on Airline and Airport recovery, such as those induced by aircraft unavailability, crew planning, diminishment in airport capacity. It is interesting to note that by that time, there was only one paper reviewing the feasibility of the integrated recovery model. Another review paper appeared several years later, by Kohl *et al.* (2007), who carried out a review on about 16 papers in air-transportation disruption management. They focused on reviewing non-integrated recovery, including aircraft, crew, and passengers. Recently, Clausen *et al.* (2010) carried out a review on disruption management on aircraft, crew, passengers, and integrated recovery. They further classified the papers into sub-categories, such as Aircraft Recovery (sub-categorized by Solution Approaches), Crew Recovery (sub-categorized by disruption nature), and integrated passenger recovery. In addition, they also briefly discussed robustness but without further classification.

There were a couple of other review papers, which were also related. Le *et al.* (2011) presented a conference paper reviewing about 29 papers in the area of air-transportation recovery, mainly focusing on mathematical programming studies. They reviewed the models in Aircraft Recovery, Crew Recovery, Passenger Recovery, and Integrated

Recovery. Another recent work by Visentini *et al.* (2014) was not specifically focused on an air-transportation disruption. They carried out a review on recovery methods in transportation services, including aviation. They studied about 19 papers between 2000 and 2012 related to reactive problems and summarized the problem content, objective, functionality, real-life instances, and solution methods.

5. Reactive recovery

Traditional recovery arrangements are based on the costs associated with recovery. Flights have the greatest impacts on the airline so it comes in the first stage. The second leading aspect is the crew costs, including salary, allowances and benefits. Hence, the second stage will cope with the crew recovery. It is important to note that crew costs are more manageable than the other associated costs. After receiving the repaired flight and aircraft schedules from the operations dispatch and aircraft control units, the crew control unit needs to assign crew members to fit the respective flights and aircrafts. However, recovery for passengers and air-cargo has the lowest priority in operations recovery, as they are mainly affected by the repaired flight, aircraft and crew schedules. Figure 3 summarizes the development of each subcategory throughout the past years in reactive recovery.

5.1 Non-integrated recovery

5.1.1 Flight recovery. In the earlier years, some models were presented that mainly focused on flight-related issues, such as re-timing and cancellations simultaneously, without aircraft consideration. Flight legs cancellation was the main research focus on hub-and-spoke networks in flight recovery to maintain aircraft balance. Flight legs assigned to the same crew are cancelled first to reduce the magnitude of the disruption, and then flight legs with crew finishing their duties are also considered for cancellation (Grandeau *et al.*, 1998). Yu and Qi (2004) proposed three different models to manage flight re-scheduling including a Time-Space Network Model, a Time Band Model, and a Set Packing Model. An integer programming problem was formulated with the aim of minimizing the total costs in the new schedule, including all the flight arcs and protection arcs costs, and the flight cancellation costs.

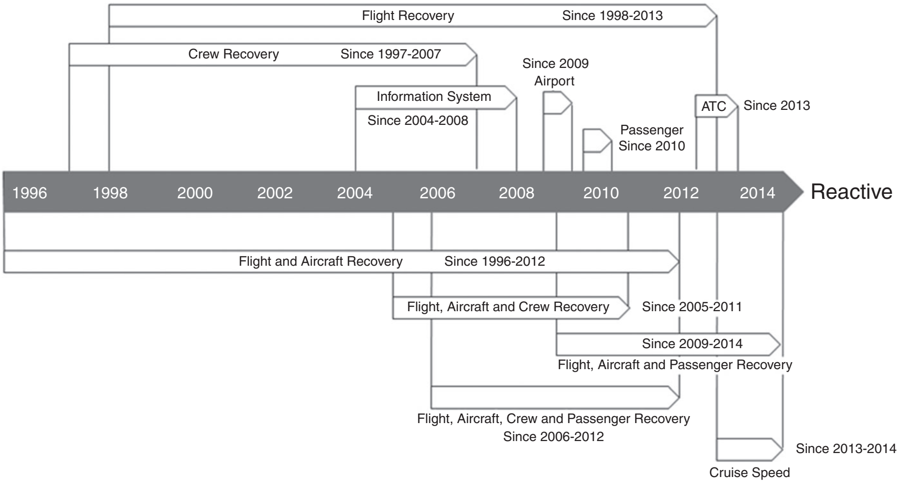


Figure 3.
Timeline of reactive recovery papers for each subcategory

In recent years, the studies became more specific and focused on particular areas, e.g., flying time/distance, scale of disruption, etc. Jeng (2012) studied disruption scheduling of short-hauls with the characteristics of quick turnaround flights. They proposed an inequality-based multi-objective genetic algorithm to schedule real-time airline schedules. Similarly, Xiong and Hansen (2013) explored flight cancellations that would lead to corresponding delay savings to other flights to support flight cancellation decisions. They concluded that larger, fuller, less frequent, shorter-distance, and spoke-bound flights are less likely to be cancelled. Gao *et al.* (2012) focused their study on the impact of large-area flight delays, aiming to reduce the risk and economic losses due to re-scheduling flights. They proposed an analytical model and developed an optimal polynomial algorithm. Makhlouf and Waheed (2012) studied the monitoring of flights preparation and punctuality, and proposed an airline flight preparation management system for recovery. Le *et al.* (2013) examined a multi-commodity flight network problem for air-transport to minimize the total disruption cost by using column generation.

5.2.2 Crew recovery. In disruption management, since the crew is relatively more controllable, and the related cost is significant, a lot of studies have been done in this area. However, crew recovery is very complicated because of the strict legal regulations and politics in regard to the airline crew, such as the maximum flying hours, minimum resting hours, etc. It is known to be one of the bottlenecks of the whole system recovery process (Wei *et al.*, 1997). The crew schedule and the repaired schedule have to completely comply with all the related rules and regulations, otherwise, penalties will be imposed. In severe situations, deadhead crews need to be ready to fulfil the duties, meaning that a crew member will fly as a passenger to the particular station. Normally, a duty swap of crew members with the same qualifications is applied here, similar to the flight recovery problem. Rosenberger *et al.* (2002) proposed a stochastic model for daily airline operations by using the semi-Markov process, and proposed recovery policies. A decision support tool was proposed to allow automatic crew recovery and to solve problems induced by the disruption. It included options for using standby crew, deadhead crew, and duty swaps (Abdelghany *et al.*, 2004). Solutions using genetic algorithms were also applied for unpredicted delays to solve real world crew recovery problems. The model was capable of performing searching step by step for better solutions. It customized the problem instance so that broader investigations could be conducted (Guo *et al.*, 2005). Nissen and Haase (2006) proposed a duty-period-based formulation, which was tailor-made for European airlines for airline crew re-scheduling. Their approach specialized in efficiently covering various labour regulations. Similarly, Castro and Oliveira (2007a, b) proposed a Distributed Multi-Agent System (MAS), representing different roles in the AOCC, to deal with crew recovery.

5.1.3 Passenger recovery. In air-transportation studies, distribution in passengers is also one of the focal points. However, as our focus is in express logistics, only a very brief explanation will be included here. For example, Marks and Jenkins (2010) proposed a Passenger Displacement Model to estimate the impact of flight cancellations on passengers. They concluded that cancellations induce a huge impact on passengers. Later on, Cohn and Lapp (2010) briefly summarized the papers in passenger recovery. For more studies, please refer to Clausen *et al.* (2010).

5.1.4 Other non-integrated recovery studies: airport/air traffic control (ATC)/ information system. One can see that in non-integrated recovery papers, Flight, and Crew are the major topics. Nevertheless, a few papers addressed some other interesting recovery topics, which are in fact very significant. For example, there was a paper focusing on Airport-related aspects. Kuster *et al.* (2009) proposed an Extended Resource-Constraint Project Scheduling Problem to support the decision for maximizing the aircraft turnaround in the airport ground process. Similarly, Kontogiannis and Malakis (2013) studied the problem of ATC. They proposed control strategies to maintain the control of actions, transfers, and coordinates, and the choice of a new model of the function when control breaks down.

Applications of Information Systems are also one of the important topics. Dorneich *et al.* (2004) proposed a Diversion Off-Gate Management Assistant to support the decision of diverting arriving aircraft to another airport with the objective of minimizing the impact on the downstream operations. Abdi and Sharma (2008) proposed a Management Information System to support flight disruption management. Abdelghany *et al.* (2008) proposed a decision support tool that simulated a list of disrupted flights in the system to support the generation of a recovery plan. They aimed to minimize the flight delays and cancellations.

5.2 Integrated recovery

Despite the complexity of integrated recovery, researchers later on started to discover that the method of solving the flight delays in sequential manner with separate resources recovery is defective.

5.2.1 Integrated flight and aircraft recovery. Common techniques in Flight recovery are flight delays and flight cancellations, while in Aircraft recovery are aircraft swapping and aircraft positioning (ferrying flight). Simultaneously applying all of them for recovery can further improve the efficiency and quality of recovery. In this section, we review those papers applying all these techniques in recovery.

Early work can be found in Yan and Yang (1996), which was done even earlier than Non-Integrated Flight Recovery. By that time, they proposed a model that can handle flight re-timing, cancellations, and aircraft swaps simultaneously. Argüello *et al.* (1997) studied the disruption induced by flight delays and proposed a greedy randomized adaptive search procedure to re-construct the aircraft route with the aim of minimizing the deviation cost induced. Similarly, Løve *et al.* (2001) also proposed a heuristics approach to recovery of the flight schedules by reassigning aircraft-flight, delaying flights, and cancelling flights. They implemented the heuristics in British airlines and were able to obtain a good quality solution in less than 10 sec. Andersson (2006) proposed a Tree-Search algorithm to determine a new aircraft schedule and then applied his proposed Path Re-linking strategy to determine new paths between different solutions. Berge *et al.* (2006) studied the ground delay, flight cancellation, and pre-departure re-routing with consideration of a convective weather event by using the Boeing National Flow Model simulator. Wu and Le (2012) investigated the aircraft recovery problem by using Iterative Tree Growing with a node combination method.

Regarding recovery by using a computational approach, Andersson and Värbrand (2004) proposed a mixed integer multi-commodity flow formulation to re-construct aircraft schedules by flight cancellations, delays, and aircraft swapping. Bierlaire *et al.* (2007) considered a more complicated situation with a heterogeneous fleet of aircraft and consideration of maintenance constraints. They proposed a column generation-based method using a multi-commodity network flow modelling approach for solving the case problem in Thomas Cook Airlines.

Multi-objective decision making is another focus. For example, Liu *et al.* (2006) proposed a multi-objective recovery plan by using the Evaluated Preference Genetic Algorithm. They considered five objectives: flight delays cannot exceed 30 minutes, minimize total delay time, minimize number of delayed flights, minimize duty swap, and minimize flight connections. Later on, Liu *et al.* (2007) studied flight delays and flight swapping simultaneously to minimize the propagate effect on the later flights. They proposed an Inequality-based Multi-objective genetic algorithm to solve an instance of a temporary one-hour closure of two airports, immediately after re-opening, and generated alternatives to avoid additional costs and minimized passenger inconvenience. Liu *et al.* (2008) studied another five objectives: flight delays cannot exceed 30 minutes, minimize total delay time, minimize ground turnaround time, minimize duty swap and minimize flight connections. Yaowiwat *et al.* (2007) also proposed a Multi-objective Micro Genetic Algorithm to combine flights and re-route them. They stated that their proposed algorithm can obtain the optimal solution within a few seconds for a problem scale of 100 flights and eight aircraft.

5.2.2 Integrated flight, aircraft and crew recovery. The integration of aircraft and crew can further minimize the cost of aircraft routes and crew pairings such that every flight leg is assigned with one aircraft and one crew (Mercier *et al.*, 2005). This is similar to the integration of aircraft and crew recovery. However, the integrated problem becomes more complicated, and a heuristic approach can be more appropriate. Castro and Oliveira (2005) proposed a Distributed MAS, with collaboration in different airline operations. In addition, they applied learning to define and develop crew member profiles. Malucelli *et al.* (2006) proposed the applications of the information obtained from the e-market to interact with the airline's own recovery solution to generate a final recovery plan. They proposed that the e-market information can be shared by different airlines. Aguiar *et al.* (2011) developed a multi-agent-based approach to model aircraft recovery and crew recovery. Ionescu *et al.* (2011) studied and compared the recovery strategies between re-optimization (e.g. column generation) and rule-based (heuristics) recovery approaches and concluded that rule-based recovery performs better.

5.2.3 Integrated flight, aircraft and passenger recovery. In the past, studies on airline recovery mainly focused on integrated flight and aircraft recovery with the aim of minimizing the induced deviation cost. A limited extent and lower priority is given to passenger recovery. However, after recovery, passengers may usually are affected due to flight cancellation, flight delays, aircraft swapping, etc. Accordingly, there is a stream of papers further integrating passengers in the recovery with flights and aircraft.

Janic (2009) studied the effect of large-scale disruption to airports, flights, aircraft, and passengers in terms of cost. More specifically, the author focused on disruption due to snow, with consideration of snowfall intensity, snow melting rate, snow accumulation, etc. Zegordi and Jafari (2010) integrated passenger recovery as a part of the objective function, with flight and aircraft recovery, which was solved by using the Ant Colony algorithm. Eggenberg *et al.* (2010b) proposed a Column Generation approach to determine recovery for integrated aircraft recovery with maintenance and passengers. Later on, Jafari and Zegordi (2011) proposed a formulation of recovery by considering flight re-timing, aircraft swapping, ferry fight, reserved aircraft, flight cancellations, and the cost of passenger re-accommodation, reassignment during recovery and solved the problem by using LINGO. Bisaillon *et al.* (2011) developed a large neighborhood search heuristic to construct a repair schedule considering aircraft and passengers. Their heuristic included three stages, namely, construction, repair and improvement.

An initial solution was created in the construction phase, and was tested to see if it was functionally and operationally feasible. In the last stage, a large change to the schedule was made to see if better solutions would be obtained. Recently, Mou and Zhao (2013) aimed to minimize the total delay minutes of passengers, as its main objective, by reassigning aircraft to disrupted flights, meanwhile minimizing the total cost induced. There were also some conference papers in this area, such as by Waheed and Makhlouf (2012), Makhlouf and Waheed (2012), Chan *et al.* (2013), and Le *et al.* (2013).

There was a stream of papers focusing on the disruption model from the Challenge ROADEF 2009, titled "Disruption management for Commercial Aviation", which was proposed by Amadeus. Acuna-Agost *et al.* (2009) proposed a Mixed Integer Programming formulation and applied their own developed algorithm, named Statistical Analysis of Propagation of Incidents, to reschedule trains under disruption. Darlay *et al.* (2010) decomposed the problem into aircraft recovery with maintenance and passenger reassignment on operated flights. Li and Wallace (2012) proposed a Flight Sequencing Model for aircraft re-routing, flight re-timing, and flight cancellations. They studied and tested the algorithm on various instances by ROADEF 2009. Jozefowiez *et al.* (2013) developed an algorithm that considered aircraft and passengers with the same priority by reassigning passengers and creating a limited number of flights. Recently, Sinclair *et al.* (2014) proposed a large-scale neighborhood search to produce new aircraft routes and passenger itineraries, with refinements in each phase, in order to improve the search ability. They obtained the best known solution for 17 out of 22 instances within five minutes. Lei and Zhao also developed a modelling framework and proposed column generation to deal with it.

5.2.4 Integrated flight, aircraft, crew, and passenger recovery. One can see that in recent years, there have been papers integrating recovery with all the affected parties, including flight, aircraft, crew, and passengers, in order to generate an even better solution, catering for every party's interests. This is called a fully integrated model.

Early in 2006, Bratu and Barnhart (2006) stated that although aircraft swapping can be a less costly and faster recovery option, it may cause seat shortages and crew unavailability due to different fleet types. Therefore, they suggested airlines use common fleet types. In addition, they used an airline operations control simulator to simultaneously consider aircraft, crews and passengers. Castro and Oliveira (2009b, 2010a, b) and Castro *et al.* (2012) proposed a multi-agent approach to model different members in a typical AOCC. They tested their algorithm for the data obtained from the TAP Portuguese airline. Recently, Petersen *et al.* (2012) developed a column generation approach with schedule recovery as the master problem linking with the aircraft recovery, crew recovery, and passenger recovery as the sub-problems. They were the first to propose a computational approach to the fully integrated problem. Their model is capable of handling no more than 65 per cent of flight disruptions with a one day planning horizon for a particular airline.

5.2.5 Integrated cruise speed. Several papers considered cruise speed during the recovery process. Arıkan *et al.* (2013) integrated aircraft and passengers for recovery, minimizing the total cost. In addition, they considered the controllable cruise speed to mitigate delays. Aktürk *et al.* (2014) introduced the cruise speed for aircraft re-scheduling. They considered adjusting the cruise stage speed on a set of affected and unaffected flights with aircraft swapping. They proposed a mathematical formulation considering all the related costs factors, such as costs of the swap, fuel and passenger delay. They analysed a number of disruptions and hubs (Arıkan *et al.*, 2013).

5.3 *Summary of reactive recovery*

Here, we summarize the common techniques that have been used in non-Integrated Recovery or in Integrated Recovery in Table III. For Flight recovery, the techniques are Flight Delays, Flight Cancellations, and Jointing (Combing) Flights. For Aircraft recovery, the related topics are aircraft re-routing, aircraft positioning, and adjusting cruise speed. For Crew recovery, issues such as Deadhead Crew (similar to aircraft positioning), Duty Swapping (similar to aircraft re-Routing), Reserved crew, and Day-off Crew can be addressed. Lastly for Passenger recovery, the techniques are Monetary Compensation, Meals, Water, and Hotel Accommodation, Alternative Transport mode, other airlines or route, and later fights. Table IV summarizes the main focus and the methodology applied in each reviewed paper. One can see from Table IV that nearly all the reactive recovery algorithms are driven by the real-time data collected from a data system, such as the Flight system, Crew System, Weather Forecast System, Airport System, etc. These data include the real-time flight delay and cancellation situation, available crew, cruise speed of individual aircraft, passengers, gateway condition, number of aircraft on ground and on gate, number of aircraft waiting to land, etc.

6. Proactive planning (robust planning)

The most recent research area in air-transportation-related disruption management is the respective Robust Planning. It is a kind of proactive strategy as it is performed in the planning phase, instead of after the occurrence of a disruption. Some researchers noticed that there can be changes in the planning process to cope with the severe impacts of disruptions. The real-time re-scheduling for operations recovery induces further costs which imply that the total operational costs can be considerably greater than the planned costs. Robust planning aims to reduce the sensitivity of the planned schedule to minor or major disruptions, and to incorporate the possibility of disruptions into planning (Burke *et al.*, 2010). The objectives are to construct a flight plan that can remain feasible or can apply simple and less costly recovery measures in the case of disruptions (Dück *et al.*, 2012). It is hoped that the robustness in the schedule can alleviate the propagate effect and the huge impacts of disruptions and flight delays, so that the impact on the express logistics can be minimized. Though both disruptions and flight delays cannot be eliminated, it is still useful to prevent some of them from occurring. To achieve robust planning, the two major concepts are stability and flexibility. Currently, the majority of the reviewed literature applied the strategy in flight, aircraft and crew scheduling. It was also observed that there is no direct model to generate a schedule with robustness at this time. Indicators and simulation models were used to test the robustness of a schedule. Figure 4 summarizes the development of each subcategory throughout the past years in proactive planning.

Flight	Aircraft recovery	Crew recovery	Passenger recovery
Flight delays	Aircraft re-routing	Reserved crew	Monetary compensation
Flight cancellations	Aircraft positioning (ferrying)	Duty swap	Meals, water, and hotel accommodation
Jointing flights	Adjust cruise speed	Day-off crew	Alternative transport mode
		Deadhead crew	Other airlines
			Other route
			Later flights

Table III. Summary of options for operations recovery

Table IV. Summary of main focus and solution method for reactive recovery papers

References	Main focus	Main solution method
Yan and Yang (1996)	Disruption caused by aircraft breakdown	Network simplex method and Lagrangian relaxation
Wei *et al.* (1997)	Crew management	Heuristic search
Argüello *et al.* (1997)	Re-constructing aircraft routing	Greedy randomized adaptive search procedure
Grandeau *et al.* (1998)	Process of airline system operation control	–
Løve *et al.* (2001)	Reassignment of aircraft to flight, flight cancellation, and flight delay	Heuristic
Rosenberger *et al.* (2002)	Stochastic modelling of airline operations	Simulation
Andersson and Värbrand (2004)	Flight cancellations, flight delays, and aircraft swaps	Column generation
Dorneich *et al.* (2004)	Critiques diversion decisions of airline dispatchers	Diversion off-gate management assistant
Yu and Qi (2004)	Formulation of various disruption management	Integer programming
Abdelghany *et al.* (2004)	Crew recovery in large-scale commercial airline	Decision support system
Castro and Oliveira (2005)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent
Guo *et al.* (2005)	Airline crew recovery	Genetic algorithm
Andersson (2006)	Aircraft re-scheduling	Tree search algorithm
Bratu and Barnhart (2006)	Reserved crew	Airline operation control simulator
Liu *et al.* (2006)	Multi-objective decision making	Multi-objective evolutionary algorithm
Malucelli *et al.* (2006)	Cooperation between airlines	Multi-agent
Nissen and Haase (2006)	Duty-period-based formulation	Column generation
Berge *et al.* (2006)	Departure re-routing	Airline operation control simulator
Bierlaire *et al.* (2007)	Airline schedule recovery	Column generation
Castro and Oliveira (2007a)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent
Castro and Oliveira (2007b)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent
Liu *et al.* (2007)	Multi-objective decision making	Evaluated preference genetic algorithm
Yaowiwat *et al.* (2007)	Multi-objective decision making	Multi-objective micro genetic algorithm
Abdi and Sharma (2008)	Flight dispatching, crew rotation, and aircraft control	Management information system
Liu *et al.* (2008)	Flight connections, flight swaps, and flight delay	Inequality-based multi-objective genetic algorithm
Abdelghany *et al.* (2008)	Decision support tool for disruption management	Airline operation control simulator
Acuna-Agost *et al.* (2009)	Re-scheduling aircraft, flights, and passengers simultaneously	Mixed integer programming
Castro and Oliveira (2009a)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent
Janic (2009)	Disruption caused by snow	Deterministic queuing model
Kuster *et al.* (2009)	Aircraft turnaround of airport	Genetic algorithms
Bruce and Newman (2010)	Cumulative process detecting aircraft, crew, and passengers problems	Situational awareness
Castro and Oliveira (2010)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent

(*continued*)

References	Main focus	Main solution method
Darlay *et al.* (2010)	Reassign aircrafts and passenger simultaneously	Mixed integer programming
Eggenberg *et al.* (2010b)	Constraint-specific recovery network	Column generation
Marks and Jenkins (2010)	Estimates flight cancellations impact	Passenger displacement model
Zegordi and Jafari (2010)	Integrating passenger recovery cost into flight and aircraft recovery	Ant Colony algorithm
Cohn and Lapp (2010)	Discussion of passenger issues in disruption	–
Aguiar *et al.* (2011)	Flight and aircraft recovery with crew re-scheduling	Multi-agent
Bisaillon *et al.* (2011)	Minimizing deviation cost and impact on passengers	Large neighborhood search
Ionescu *et al.* (2011)	Evaluate airline schedule robustness	Local rule-based recovery approach
Makhlouf and Waheed (2011)	Flight preparation management	–
Jafari and Zegordi (2011)	Examine various Commonly used recovery techniques	Integer programming
Gao *et al.* (2012)	Flights re-scheduling	Polynomial algorithm
Petersen *et al.* (2012)	A fully integrated recovery model	Column generation
Waheed and Makhlouf (2012)	Flight amalgamation	Multi-objective genetic algorithm
Wu and Le (2012)	Aircraft routing	Iterative tree growing with node combination method
Jeng (2012)	Short haul flights	Inequality-based multi-objective genetic algorithm
Li and Wallace (2012)	Continuous time aircraft routing model	Linear programming with relaxation
Waheed and Makhlouf (2012)	Disruption of flights	Multi-objective genetic algorithm
Castro *et al.* (2012)	Recovery by Airline Operations Control Center (AOCC)	Multi-agent
Arıkan *et al.* (2013)	Recovery by cruise speed	–
Chan *et al.* (2013)	Impact of disruptions to passengers' itineraries	Genetic algorithm
Le *et al.* (2013)	Minimize flight delay cost	Genetic algorithm
Mou and Zhao (2013)	Optimizing total delay minutes of passengers	Hungarian algorithm
Xiong and Hansen (2013)	Flight cancellation	Piecewise linear programming
Kontogiannis and Malakis (2013)	Discussion of lost control situations in air traffic control	Control strategies
Le *et al.* (2013)	Modelling of recovery network	Column generation
Jozefowiez *et al.* (2013)	Passenger reassignment	Heuristic
Aktürk *et al.* (2014)	Recovery by cruise speed	Conic integer programming
Lei and Zhao (2014)	Flight cancellation and delays	Column generation algorithm
Sinclair *et al.* (2014)	Creating new aircraft routes and passenger itineraries	Large neighborhood search Heuristic

Table IV.

6.1 Non-integrated robust planning

6.1.1 Robust flight planning. To capture uncertainties existing in air-transportation operations, Ehrhoff *et al.* (2005) proposed a Game Tree Search modelling approach. Observing that in robust planning, only considering the flight approach, allocation of buffering time between flights is a common technique. Wu (2006) proposed a Sequential Optimization Algorithm to improve reliability of airline schedules by preventing unnecessary slack allocated to flights as the author noticed that aircraft have a much higher opportunity cost than other resources. The author showed that by adding an extra

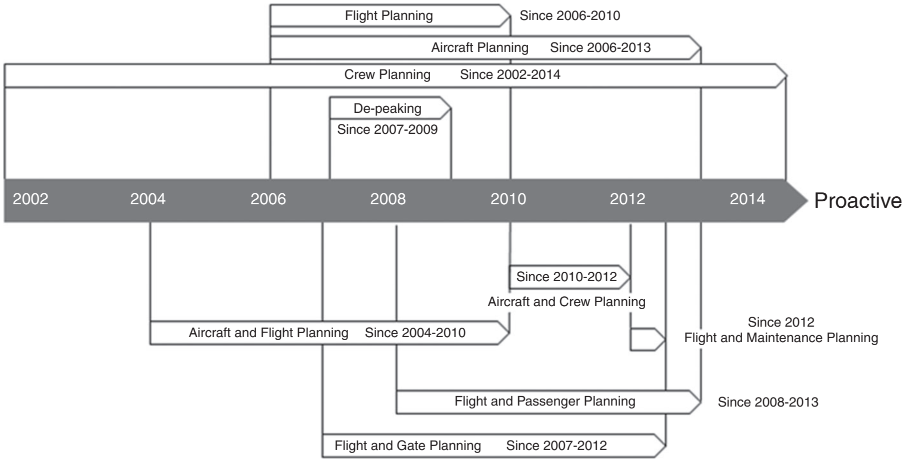


Figure 4.
Timeline of proactive planning papers for each subcategory

260 minutes buffer times in the schedule, departure delays can be reduced by 30 per cent. Similarly, Eggenberg *et al.* (2010a) proposed a methodology to determine an airline schedule that is less sensitive to flight delay by using flight re-timing with the intention of improving the flight schedule properties. The emphasis of other literature is on integrating operational issues and propagating the effect of delays in schedule planning by adding slack to outbound flights that are more prone to delays and disruptions, while reducing slack in inbound flights to reduce the subsequent impacts. Simulation and metrics were used to evaluate the robustness of the plan (Ahmadbeygi *et al.*, 2010).

6.1.2 Robust aircraft planning. To be specific, mainly focusing on optimizing the robustness of the air-transportation schedule with respect to aircraft, Smith and Johnson (2006) studied aircraft fleet types. They proposed a station purity approach, which limited the number of fleet types allowed in an airport for fleet assignment, aiming to maximize the planning flexibility and minimize the cost. They developed the station decomposition approach, which applied column generation to solve the fleet assignment problem. Yang *et al.* (2010) proposed several heuristics focusing on strategically optimizing several areas, including Reserve-fleet heuristic, Dense scheduling heuristics, and Strategic-positioning heuristic. These heuristics enforced idleness of aircraft in creating the original flight schedule and in strategically repositioning aircraft to serve dense scheduling. Landry *et al.* (2012) studied the uncertainty existing in long-distance estimations of arrival times. He proposed a heuristic to schedule aircraft into congested resources.

In robust planning, some may argue that this is a waste of resources that could otherwise generate revenue which would also increase the planned costs. In fact, it is a trade-off between additional costs and robustness. With this idea in mind, Atkinson *et al.* (2013) examined three common robust scheduling techniques aircraft swapping, gate swapping, and schedule downtime to estimate the cost and benefit that robust planning can bring to airlines.

6.1.3 Robust crew planning. Traditionally airlines aim to fully utilize all their crews by planning very tight crew schedules, but it may result in very brittle schedules, which may easily be disrupted by even a minor disruption (Soykan and Erol, 2014). Early work can be found in Ehrgott and Ryan (2002), who studied Robust Crew

Schedules with Bicriteria Optimization, in which the time, cost and robustness were considered. They proposed a non-robustness indicator considering the variance between the expected flight delays and the buffer time of each flight pair. Optimal crew scheduling with costs is created in the first step and then robustness is tested by adding a percentage of crew costs to the optimized plan. Later on, Schaefer *et al.* (2005) studied the scheduling of crew under uncertainties. They compare their model with the one determined by the deterministic approach and demonstrated a better result.

Sohoni *et al.* (2006) mainly focused on Reserve Crews, used to cover those unassigned flights due to disruptions. They also considered paying a premium to regular crew to cover the remaining uncovered flights. Schaefer and Nemhauser (2006) studied the disruption related to departure and arrival times. They characterized different types of disruptions that may affect the crew schedule. Shebalov and Klabjan (2006) studied a Move-up Crew model, in which the possibility of crew duty swaps was the main focus. A crew member from a late-arriving aircraft will fulfil a newly assigned duty of a later flight than the originally assigned one. The originally assigned duty will be performed by a move-up crew which can be crew from earlier flights, reserve or standby crew. The objective of the model is to propose optimized crew pairings and at the same time create a set of swapping opportunities (Shebalov and Klabjan, 2006).

Recently, Muter *et al.* (2013) studied a special flight disruption situation existing in a Turkish airline, in which adding an extra flight in short notice was the challenge. Accordingly, they proposed a robust version of airline crew pairing to support these extra flights. Lu and Gzara (2014) proposed an interesting new robust formulation for crew pairing, in which the flight and connection time are random and vary within a range, without any additional probability assumed. They tested the algorithm on real instances and stated that the algorithm can obtain optimal or near optimal solutions.

6.1.4 De-peak. In non-integrated robust planning, De-peaking is a special stream, emphasizing on Thinning and Shifting (Abdi and Sharma, 2007). Thinning is to cancel the flights to avoid the maximum arrival and departure capacity being reached by reducing to a lower level in peak seasons, where there is no available slot left. It is applied when it is foreseeable to cause lengthy delays. Shifting is to re-time the flights in the peak hours to the "valleys". A "Valley" is the time interval with the arrival or departure rate not reaching the maximum. Other conference papers in this area include those of Castro *et al.* (2009), and Castro and Oliveira (2009a).

6.2 Integrated robust planning

6.2.1 Integrated flight and aircraft. Similar to integrated flight and aircraft recovery, simultaneously optimizing flight and aircraft can benefit the overall planning. Early work can be found in Rosenberger *et al.* (2004), who studied a hub-and-spoke network. They suggested assigning short haul aircraft rotations to aircraft, as a flight cancellation usually causes additional cancellations to the downstream flights. Later on, Burke *et al.* (2010) proposed a memetic approach to improve the robustness of airline schedules by simultaneous flight re-timing and aircraft re-routing. They improved the reliability and flexibility of KLM Royal Dutch Airlines. Similarly, Mohamed *et al.* (2010) proposed an integrated model for robust aircraft routing and flight re-timing and solved by using CPlex. They increased the schedule robustness by optimizing the slack buffering time, which is a common technique in robust flight planning, as discussed in the paper.

6.2.2 Integrated aircraft and crew. Robustness increases from integrated aircraft and crew scheduling were also proposed in prior studies. Flexibility aims to provide a number of options for operations recovery to temper the effects and to have plenty of possibilities for changes to efficiently recover the plan from disruptions. It can be done by adding opportunities for aircraft and crew swaps and the use of reserve crews which are less costly to implement. The airlines may simply apply the existing recovery measures to solve the problems when a disruption occurs. The challenge is to add flexibility to the crew schedule due to the crew licensing restrictions. The cockpit crew is usually trained to fly a particular type of aircraft and the cabin crew can often serve two to three types of aircraft only. Weide *et al.* (2010) studied a model that assigns buffer time to the aircraft change time. Duck *et al.* (2012) studied the crew and aircraft in propagating delays in order to improve the schedule stability. From the simulation results, it was revealed that there are correlations between expected reactionary delays and crew cost, as well as restricted aircraft changes and crew costs. A less than 3 per cent rise in crew costs resulted with a reduction in expected reactionary delays and restricted aircraft changes. However, in the above mentioned papers, reserve crews are assumed to be infinite.

6.2.3 Integrated flight and passenger. Similarly, there are papers focusing on integrated flight and passenger robust planning with the aim of increasing the passenger service level. Sohoni *et al.* (2008) studied two service levels (flight service level and network service level, known as passenger connections) with the uncertainties existing in flight block times, which consist of taxi-out time, enroute time, and taxi-in time. They proposed a Cut Generation Algorithm to deal with the integrated problem separately for comparison with the integrated one. The results indicated that the passenger service level can be increased by trading off with the operating cost. Recently, Aloulou *et al.* (2013) studied increasing the robustness of aircraft and passenger connections by the allocation of slack to those most needed connections in operations by flight re-timing. They used a in network flow-based model and adopted a Branch-and-Price algorithm to solve it. They carried out computational experiments on some real instances with the largest scale of 1,278 flights and 251 aircraft. The results showed that the total delays, number of delayed flights, and missed connections were significantly reduced.

6.2.4 Integrated flight and gate. There has been a stream of papers studying some very interesting topics related to airport gates, known as flight-gate assignment. This topic is getting more and more popular and important due to the boom in air-transportation. The Airport Gate Assignment Problem (AGAP) is the allocation of flights to gates at the airport. Robustness here is to avoid the unavailability of gates for accommodating scheduled flights. It causes propagation problems, such as passenger delays, missed connections due to flight delays, extra fuel, etc.

In the related literature, Dorndorf *et al.* (2007) applied two heuristics to increase the robustness. The first heuristic, known as the Overlap method, is applied to gate assignment by measuring the number of flight gates to determine the number of available gates. This acts as a robust indicator. Then the second heuristic is a fuzzy set approach, which is used to penalize a non-robust plan so that a more robust plan can be obtained. Later on, Dorndorf *et al.* (2012) proposed optional intermediate parking, in which an aircraft can park in other places under the condition that it does not cause blockage to the neighboring gates. The objective is to minimize the number of unassigned flights, number of tows, and deviation from the planned schedule. Şeker and Noyan (2012) proposed a stochastic programming model to capture the uncertainties in the flight arrival and departure times for the AGAP. The proposed large-scale mixed integer programming and used a tabu search algorithm to deal with it. Recently, Castaing *et al.* (2014) proposed some formulation for AGAP by considering the variability in arrival and departure times. They studied Homogenous Gate Assignment and Heterogeneous Gate Assignment.

6.2.5 Integrated flight and maintenance. Feo and Bard (1989) first proposed the idea of integrating the scheduling of aircraft maintenance with the flight schedule. This allows the planner to determine the maintenance stations during the development of the flight schedule to meet the cyclical demand for maintenance. They proposed a two-phase heuristic, which first generates a single tail number schedule without maintenance requirement, and then the best tail schedules determined will further be examined in more detail. They tested the approach in a Boeing 727 fleet and the result showed a substantial cost reduction. However, during that time, uncertainties arose from the maintenance not being considered. Recently, Lapp and Cohn (2012) studied the lines-of-fights (LOFs) to increase the robustness of aircraft maintenance, aiming to increase the recoverability induced by maintenance disruption, without causing costly aircraft swapping.

Table V summarizes the main focus and the methodology applied in each reviewed paper. Similar to reactive recovery planning, nearly all the proactive planning algorithms are also supported by various data systems, such as the Flight system, Crew System, Weather Forecast System, Airport System, etc. However, the data in here are more "historical and expected (planned)" rather than "real-time-based". The purpose is to mitigate uncertainties.

7. Discussion of future directions in enhancing air-transportation express logistics

By analyzing the problem characteristics in the existing literature, this section discusses some potential areas that may further enhance the reliability and efficiency of express logistics in air-transportation.

7.1 Robust aircraft planning with adjustable cruise speed

Adjustable cruise speed has been demonstrated to be a promising approach for aircraft recovery (Arıkan *et al.*, 2013; Aktürk *et al.*, 2014). Here, cruise speed of the aircraft can be increased in order to reduce the flying time, if required. The only drawback will be the extra fuel cost incurred. In the existing literature on robust planning, many studies aimed at increasing the robustness by maximizing the aircraft swapping flexibility, in which the cruise speed is usually assumed to be constant. However, this assumption may limit the flexibility when subject to disruptions, especially in the case of flight delays. Accordingly, in future research, considering adjustable cruise speed as a critical factor during flight and aircraft planning is promising as this measure may further increase the robustness in preventing flight delays. Consequently, the reliability of the express logistics network can be increased.

7.2 Integrated aircraft routing with maintenance

Currently, there has been only one paper considering aircraft maintenance during the LOFs scheduling (Lapp and Cohn, 2012). As discussed in that paper, disruption due to maintenance may occur. Maintenance in aircraft is frequent and inevitable due to aviation regulations, including the A check (every 125 flying hours), B check (every four to six months), C check (every 20-24 months), and D check (every six years).

References	Main focus	Main solution method
Ehrgott and Ryan (2002)	Airline robustness and deviation cost induced	Bicriteria optimization algorithm
Rosenberger *et al.* (2004)	Fleet assignment	String-based fleet-assignment model
Ehrhoff *et al.* (2005)	Stochastic planning task in a "tree-wise" manner	Generic methodology
Schaefer *et al.* (2005)	Crew scheduling under uncertainties	Markov decision process
Shebalov and Klabjan (2006)	Robust crew pairing solutions	Robust optimization
Wu (2006)	Impact of buffering time between flights	Sequential optimization algorithm
Smith and Johnson (2006)	Fleet assignment	Integer programming
Schaefer and Nemhauser (2006)	Scheduling of disruption in flight schedule	Column generation
Sohoni *et al.* (2006)	Reserved Crew	Heuristic
Abdi and Sharma (2007)	Cost minimization and customer satisfaction	Network control centre
Dorndorf *et al.* (2007)	Flight-gate schedules	Overlap method and fuzzy set approach
Sohoni *et al.* (2006)	Operational uncertainty and service level	Stochastic modelling
Castro and Oliveira (2009b)	Solve airline operations recovery problems	Multi-agent
Castro *et al.* (2009)	Relationship between airline schedule and airport peaks	Multi-agent
Ahmadbeygi *et al.* (2010)	Re-timing flight departures to redistribute existing slack	Linear programming
Aloulou *et al.* (2010)	Slack-based robustness measure	Branch-and-price algorithm
Burke *et al.* (2010)	Schedule reliability and flexibility	Multi-meme memetic algorithm
Eggenberg *et al.* (2010a)	Exact unit-specific constraint	Column generation
Weide *et al.* (2010)	Crew pairing and aircraft routing	Iterative algorithm
Yang *et al.* (2010)	Enforce idleness and strategic aircraft repositioning	Dense scheduling
Dück *et al.* (2012)	Aircraft and crew schedules	Column generation
Lapp and Cohn (2012)	Improve maintenance reachability	Relaxation mathematical programming
Landry *et al.* (2012)	Air traffic flow management	Decision support system
Şeker and Noyan (2012)	Flight and gate assignment	Stochastic optimization model
Dorndorf *et al.* (2012)	Flight and gate assignment	Overlap method and the fuzzy set approach
Aloulou *et al.* (2013)	Robust aircraft routes that are less vulnerable to disruptions	Mixed integer programming
Atkinson *et al.* (2013)	Examine efficiency of different robust scheduling practices	–
Muter *et al.* (2013)	Airline crew pairing	Column generation
Castaing *et al.* (2014)	Impact of gate blockage	Network based model
Lu and Gzara (2014)	Crew pairing	Lagrangian relaxation
Soykan and Erol (2014)	Crew pairing	Branch-and-price

Table V.
Summary of main focus and solution method for proactive planning papers

In a situation that an aircraft cannot resume its duty after maintenance, disruption occurs. Accordingly, aircraft swapping may be required for recovery. However, to those express logistics companies, which have their air fleet, the number of owned aircraft is usually relatively smaller than the regular airline companies. In this connection, the flexibility of aircraft swapping is reduced. Thus, the impact of aircraft maintenance delay becomes even more significant. Therefore, uncertainties raised from maintenance should also be studied in the future as a part of robust planning.

7.3 Enhancing efficiency and responsiveness through internet of things (IoT)

Nowadays, the IoT is getting more prevalent and important due to the advances of information and communications technologies (Chan, 2013). The idea of IoT is to connect all the parties/companies into a network through electronics, software, sensors, etc., with the ultimate aim of increasing the responsiveness and service level by a much more efficient and instant way of data exchange. Similar ideas can be found in Malucelli *et al.* (2006) as previously discussed in the recovery section. They proposed the applications of the information obtained from the internet to interact within different airlines, so that the overall efficiency and responsiveness can be increased. In fact, this is especially important to express logistics companies in air-transportation because they are under keen time-based competition. Therefore, studying the applications of IoT in connection between express logistics companies and their customers, as well as the end-users, deserves deeper exploration.

7.4 Big-data in air-transportation express logistics

Data collection and availability are getting easier and cheaper because of the commonly adoption of sensors, software, mobile devices, etc. Intelligently analyzing the massive amount of data collected can benefit companies in enhancing their competitiveness because these "big data" can help them find new correlations, identify future business trends, etc. For example, as previously discussed in the recovery problems, Dorneich *et al.* (2004), Abdi and Sharma (2008), and Abdelghany *et al.* (2008) demonstrated how information can help in the development of recovery plans. In fact, adequate applications of the data collected are known to be beneficial in theory. However, how to efficiently analyse the collected data is the major challenge as the size of the data is growing bigger and bigger. Therefore, more effort should be spent in the future studies on it.

8. Conclusions

Disruption management in air-transportation operations has aroused increasing attention. There is a prevailing trend in conducting research in this field. This paper provides a holistic review and a comprehensive analysis on air-transportation disruption management. We capture and categorize the trends and developments of relevant papers in horizontal and vertical directions to support the future direction. Accordingly, we carried out review work on papers related to airline disruption recovery and robust airline planning by using the keywords "Disruption management", "Air-transportation" and "Airline Operations". After rejecting unrelated articles, a total of 98 papers were left that satisfied the scope of our work.

First of all, we have summarized various reasons for causing disruption in air-transportation. Then, based on the nature and implementation phase involved, we describe the papers into two broad categories: Reactive Recovery, and Proactive

Planning. In addition, based on the problem characteristics and their application scenarios, a total of 11 sub-categories in Reactive Recovery and nine sub-categories in Proactive Planning are further identified. From the analysis, we identify some new categorizes in air-transportation recovery. For Non-integrated Recovery Problems, there are Airport Recovery, Air Traffic Control Recovery, and Recovery by using Information System. In addition, for Integrated Recovery Problems, we identify the categories of Flight and Aircraft Recovery, Flight, Aircraft and Crew Recovery, Flight, Aircraft and Passenger Recovery, and lastly Flight, Aircraft, Crew, and Passengers, and is regarded as a fully integrated model. Moreover, we summarize the common techniques that have been used in various recovery problems. We find that in Flight Recovery, the common techniques are Flight Delays, Flight Cancellations, and Jointing Flights. Aircraft Recovery has Aircraft re-Routing, Aircraft Positioning (Ferrying), and Adjusting Cruise Speed. Crew Recovery has the common techniques of Reserved Crew, Duty Swap, Day-off Crew, and Deadhead Crew. In more recent years, robust planning is a newly emerging research direction, with the aim of returning the air-transportation operations back to the original planning as soon as possible. It stresses the reliability (stability) and flexibility of a schedule plan. Regarding this (Proactive Planning Problems), for non-integrated one, there are Flight Planning, Aircraft Planning, Crew Planning, and De-peaking. For the Integrated case, there are Aircraft and Flight Planning, Aircraft and Crew Planning, Flight and Passengers Planning, Flight and Gate Planning, and Flight and Maintenance Planning.

Lastly, based on our analysis of the papers in robust planning, according to the problem characteristics and the state-of-the-art in recovery problems, we propose four new research directions to enhance the reliability and robustness of air-transportation express logistics: including robust aircraft planning with adjustable cruise speed, integrated aircraft routing with maintenance, enhancing efficiency and responsiveness through IoT and Big-Data in air-transportation express logistics.

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