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An AHP analysis of air traffic management with target windows

Lorenzo Castelli [a], Paola Pellegrini [b,*]

[a] DEEI, University of Trieste, Via A. Valerio 10, 31427 Trieste, Italy
[b] Department of Applied Mathematics, University Ca' Foscari, Dorsoduro 3825/E, 30123 Venice, Italy

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A B S T R A C T

The main operational concept of Single European Sky ATM Research Programme is the notion of business trajectory. One possible implementation is based on the notion of a contract of objectives; an agreement among the main air traffic management actors on spatial and temporal intervals called target windows. These 4D windows are defined prior to flight departure by the airlines, airports and air navigation service providers to increase punctuality. We use an analytic hierarchy process to assess the opportunity of implementing this concept by considering the views of experts. The findings indicate that there are net benefits for airlines and air navigation service providers but not for airports

1. Introduction

The Single European Sky ATM Research Programme (SESAR) aims at modernizing air traffic management (ATM) infrastructure by identifying the technological steps and priorities for implementing a new target concept (SESAR Consortium, 2007a). This concept is centered around the notion of business trajectories that consider airspace users' intention with respect to any given flight. The ATM services are organized to guarantee that this trajectory is carried out safely and cost efficiently within infrastructure and environmental constraints. Business trajectories are expressed in four dimensions (latitude, longitude, flight-level and time) and evolve out of a collaborative decision making (CDM) process developed in two phases: flight planning and execution. The former starts several months before the day of operation: the flight is defined according to the airline schedule and specific resources are assigned to it (aircraft type, crew, network resources, etc.). On the day of the operation, the flight is made as closely as possible to the plan and deviations are managed to minimize their impact on the larger schedule.

One mechanism to formalize the business trajectory is through contracts of objectives (CoO), as developed by the Contract-based Air Transportation System (CATS) research project (www.cats-fp6.aero). The CoO is a formal commitment among airlines, airports and air navigation service providers (ANSP) for the completion of each flight. It consists of a sequence of spatial and temporal constraints that constitute milestones to be met during a flight's execution. These 4D intervals are the target windows (TW). They are defined at each area where responsibility between actors is transferred (e.g., between different area control centers). The determination of the TW in each CoO is by negotiations that take into account constraints such as runway capacities and en route congestion. Any divergence in the flight from the planned CoO, for example due to unforeseen weather conditions, triggers a re-negotiation.

Under the current system, flight plans filed by airspace users constitute an intention to fly and there is no formal commitment to adhere to these. Moreover the various actors interacting during the execution of a flight are not fully aware of their differing objectives and priorities, and this can lead to a sub-optimal management of operations (Eurocontrol Experimental Centre, 2005). The CoO provides a formal description of each ATM actor's objectives and requirements, as well as a mutual commitment to respect them, thus leading to improvements in planning and earlier detection of unplanned disruptions.

This paper looks at the opportunity for implementing the CoO/TW concept, and weighs the benefits and drawbacks with respect to the current system. The assessment is made with the support of a group of experts from the CATS consortium. Subject matter experts belong to air traffic stakeholders: Air France Consulting (airline view), ENAV, the Italian Air Navigation Service Provider (ANSP view), and Flughafen Zürich AG, the company managing the Zurich airport (airport view). They are fully aware of the details of the CoO/TW concept having all been involved in the CATS project from the beginning. The assessment uses an analytic hierarchy

* Corresponding author.
E-mail address: paolap@unive.it (P. Pellegrini).

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process (AHP) methodology, which allows incorporation of qualitative and quantitative considerations (Saaty, 1977, 2000).

2. The AHP methodology

The goal of the analysis is to compare the benefits and drawbacks linked to the implementation of the business trajectory through the "CoO/TW concept of operations" (CoO/TW) *vs.* the "Business-as-Usual" (BaU) scenario. In accordance with the AHP methodology, we decompose this decision problem into a hierarchy of criteria (or elements) which are likely to have an impact on it.

We consider six independent hierarchies: flight-planning and execution phases for each of the three actors. Each hierarchy allows the actor to choose the alternative that maximizes its utility, defined as the difference between benefits and drawbacks associated with implementation. The net utilities are not expressed in monetary terms because some elements of the hierarchies are hard to evaluate in monetary terms.

The different hierarchies are depicted in Figs. 1–3. Lower nodes represent the criteria and the arrows show the relationships among them. Evaluation of the criteria is by pair-wise comparisons between all elements at the same level of the hierarchy (i.e., sharing the same parent node). After the validation of the hierarchies, experts assess the comparisons: for each pair of criteria, they identify the one more important and decide on the magnitude of the difference relying on a Saaty's (2000) scale where the relative importance of two nodes may be equal, or moderately, strongly, very strongly, and extremely different. These judgments are translated into a numerical scale, and a local priority number in the interval [0,1] is associated with each criterion. Then we derive a global priority value for each criterion by multiplying its local priority with the global priority of its parent node. Following the same rationale, the experts compared the two alternatives (CoO/TW and BaU) with respect to each node at the lowest level of the hierarchy, and a priority value was computed in the range [0,1] with the sum over the alternatives adding to one. As we are comparing just two scenarios, the alternative whose priority value is higher than 0.5 is the preferred option. Using the global priorities and the alternative priorities of the nodes at the lowest level, we calculate an alternative priority value for each node up to the root node. The best alternative for each criterion, and eventually for the actor's final decision, is thus found.

In Figs. 1–3 the global priority values are seen in parentheses next to each node. The best alternative for each criterion is also highlighted: the solid line is thick when CoO/TW is the preferred option, dashed when BaU wins, and thinner when the alternatives are equivalent (Castelli and Pellegrini, 2010).

3. The airline perspective

In the flight-planning phase an airline utilizes human resources and equipment to prepare its operations, with the main tasks of the staff being split into training and performing their main activities, which requires time and may produce stress (Fig. 1(a)). On the benefit side, the implementation of the business trajectory may foster a common responsibility in the management of the whole system. In fact, the clear definition of actors' specific duties for each flight may allow, in case of a disruption, to quickly identify the causes of the problem, and who must act to solve it. Furthermore, the agreement and compliance with everyone else's requirements may enhance the traffic predictability. This may lead to an increase of the quality of service, a reduction of the scheduling buffers that airlines introduce to account for the possible delays, and an increase (or better use) of the capacity. In turn, a scheduling buffer reduction may allow decrease of aircraft maintenance costs, crew costs, airport charges, and aircraft ownership costs (i.e., depreciation, rentals and leases of flight equipment) as a better exploitation of the fleet is possible through, e.g., an optimized aircraft rotation (Cook et al., 2004).

An airline executes the business trajectory relying largely on human resources because operating costs of equipment are, in the execution phase, of marginal importance (Fig. 1(b)). Similarly to the planning phase the main benefit drivers are the common responsibility and the increase of predictability. Greater predictability may

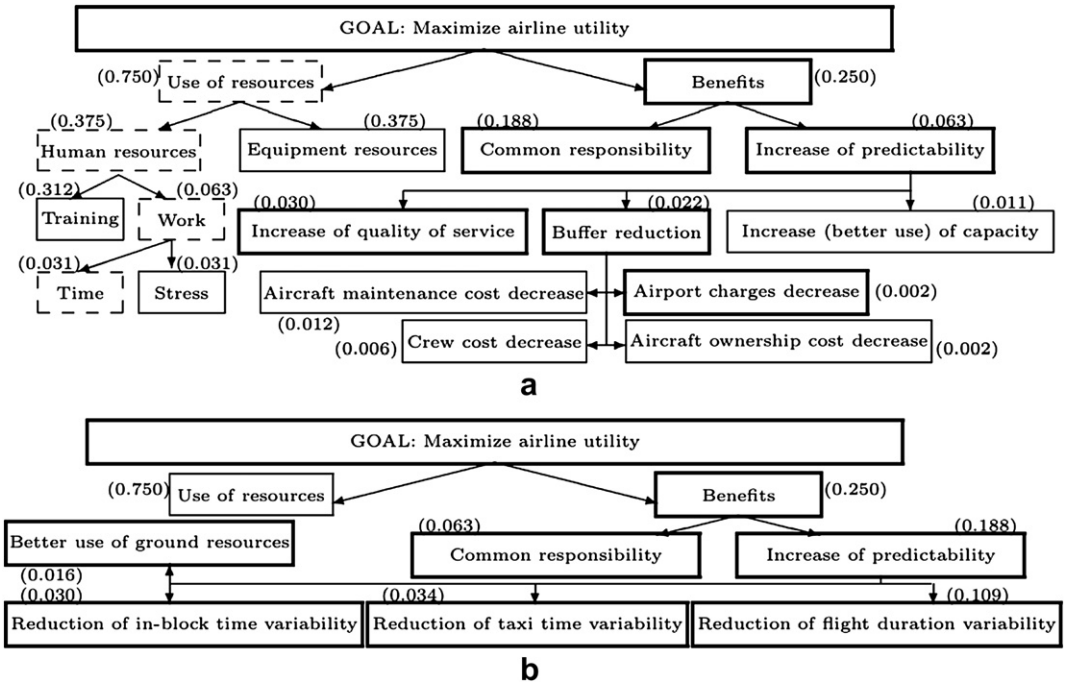

Fig. 1. AHP model: airline perspective (a) planning phase and (b) execution phase.

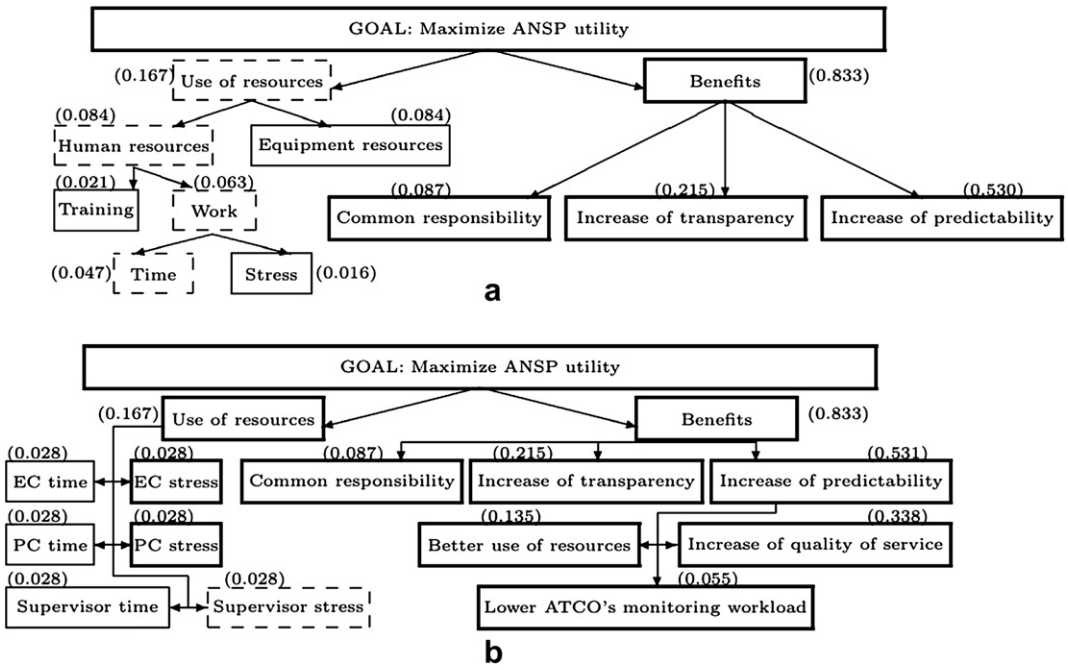

Fig. 2. AHP model: ANSP perspective (a) planning phase and (b) execution phase.

provide a better use of ground resources in terms, for example, of luggage handling and personnel. Improvement can propagate to all facilities and services associated with ground operations on air passengers, from curb to the airplane and vice versa. Terminal curb usage and parking are also considered (Brunetta et al., 1999). Moreover, an increase of predictability may imply a reduction of variability of the in-block time, taxi time, and flight duration.

From the experts point of view, an airline optimized resource utilization is moderately more important than the maximization of benefits in both the planning and execution phases. Such a relationship is certainly due to the economic situation: when demand grows, the maximization of benefits may be favored through the introduction of additional flights. The opposite is true in recession phases: it may well be the case that even the existing offer is excessive, and then, saving on resources may be crucial.

The analysis shows that in the planning phase the implementation of CoO/TW would not impact much the use of resources. There would be a slight cost increase of the working time because some effort would be requested for defining TW through the negotiation process. However, the impact of the new operational concept would be clearly visible on the benefit side: the common responsibility in the management of the whole ATM system is expected to increase significantly. Further advantages could follow the increase of predictability: higher quality of the service offered to passengers and lower airport charges due to reduced scheduling buffers.

In the execution phase the experts feel that the use of resources is not influenced by the implementation of CoO/TW. Instead, benefits increase: as in the planning phase a strong gain in terms of common responsibility is foreseen thanks to the relevance that airline decisions and priorities may have on airport and ANSP behavior. The increase of predictability is considered moderately more relevant than the common responsibility. Thus its consequent benefits are much more significant here than during the planning phase. This result likely derives from an easier quantification in monetary terms of some elements such as the reduction of fuel consumption or crew costs, and this influences positively the judgments.

From the criterion and alternative priority values, it follows that for an airline the implementation of CoO/TW has priority equal to 0.565 in the planning and to 0.567 in the execution phase, and thus it is the preferred alternative in both cases. This preference relationship appears very robust. In fact, only the priority of the use of resources *vs.* benefits has a significant impact on the final value. Fig. 4 describes the results of the sensitivity analysis with respect to these elements, in the planning and execution phases, respectively.

On the horizontal axis, the priority values of the criteria are reported. The vertical dotted line shows the value derived from our analysis (0.750 for both phases as displayed in Fig. 1(a) and (b)). On the vertical axis, the priority values of CoO/TW *vs.* BaU are represented. As it can be observed, BaU never becomes the selected option.

4. The ANSP perspective

Like the airline, the introduction of the business trajectory may require the ANSP to make use of some human resources and equipment to plan its operations (Fig. 2(a)). It may also provide benefits such as a common responsibility and an increased predictability. In addition, the pool of experts points out that such a new operational concept may overcome the (partial) absence of transparency of the system, mainly in terms of information sharing drawbacks currently experienced by the ANSP. In fact, the anticipated knowledge of the agreed business trajectories and the participation in negotiation process may give the ANSP the opportunity to identify demand/capacity imbalances much earlier than today.

The execution of the business trajectory may affect the work performed by the different operational roles: the planning controller, the executive controller, and the supervisor (Fig. 2(b)). The activity of each of them implies the use of time and some level of stress. On the benefit side, we identify the same drivers as in the planning phase with some additional details following the increased predictability. In particular, the enhanced coordination through the use of shared trajectories may be considered as means

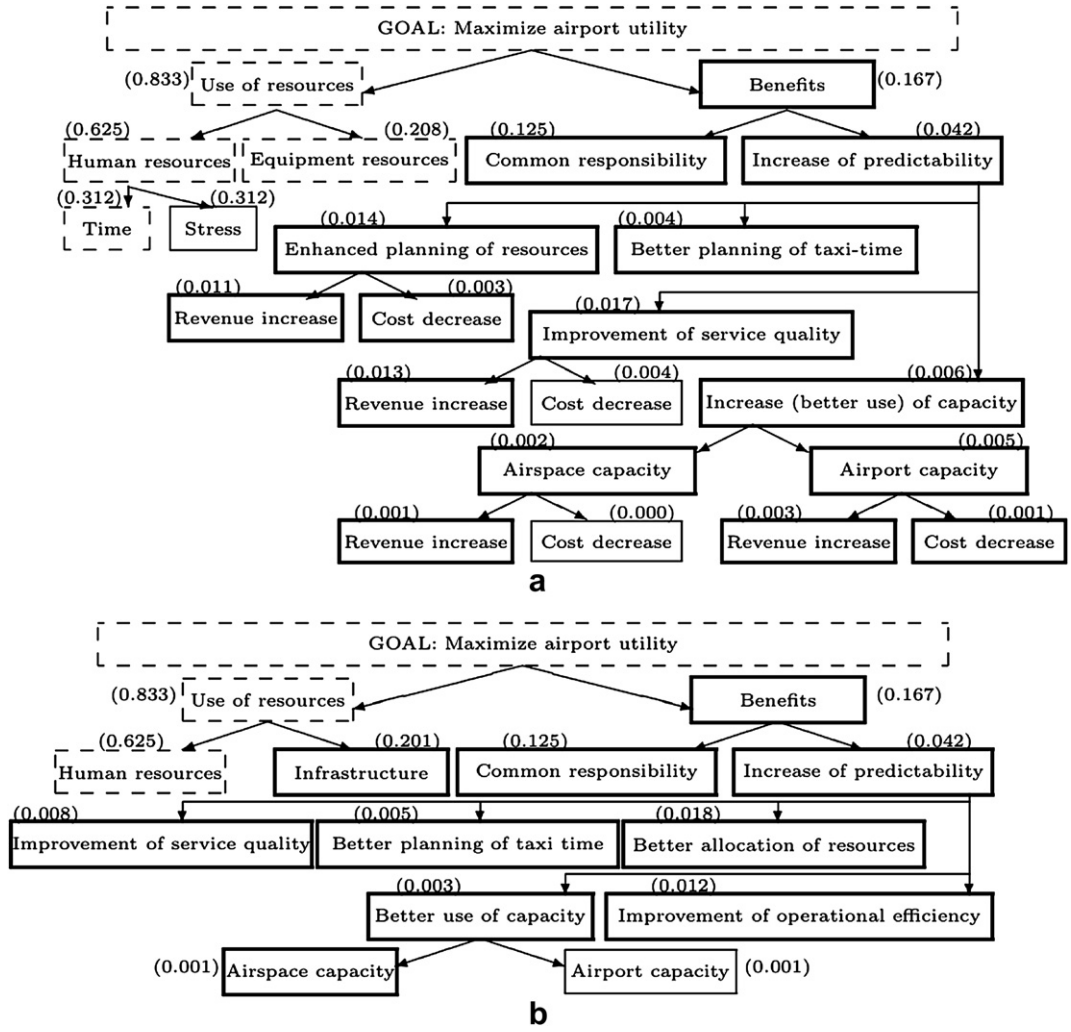

Fig. 3. AHP model: airport perspective (a) planning phase and (b) execution phase.

to detect and reduce potential conflicts (SESAR Consortium, 2007b). This may lead to a better use of resources (e.g., in terms of personnel), to improve the quality of service, and to lower the air traffic controller's (ATCO's) workload.

All European ANSPs, with the exception of the UK's NATS, operate under the full cost recovery regime, i.e., they completely recover the costs they incur to provide their services through the air navigation service charges (European Commission, 2006). Thus in experts opinion naturally follows that the ANSP mainly focus on potential benefits rather than on the possible additional costs when some innovation in the ATM system is proposed. In particular, in our case benefits are strongly preferred with respect to an optimized use of resources in both flight phases. Among benefits the increase of the predictability is always the most important option. And among the subsequent features identified in the execution phase, the improvement of quality of service is valued more than the better use of resources and the lower ATCO's monitoring workload. As a matter of fact, once safety is ensured, a high quality of service provided to airspace users is the ultimate goal of the ANSP.

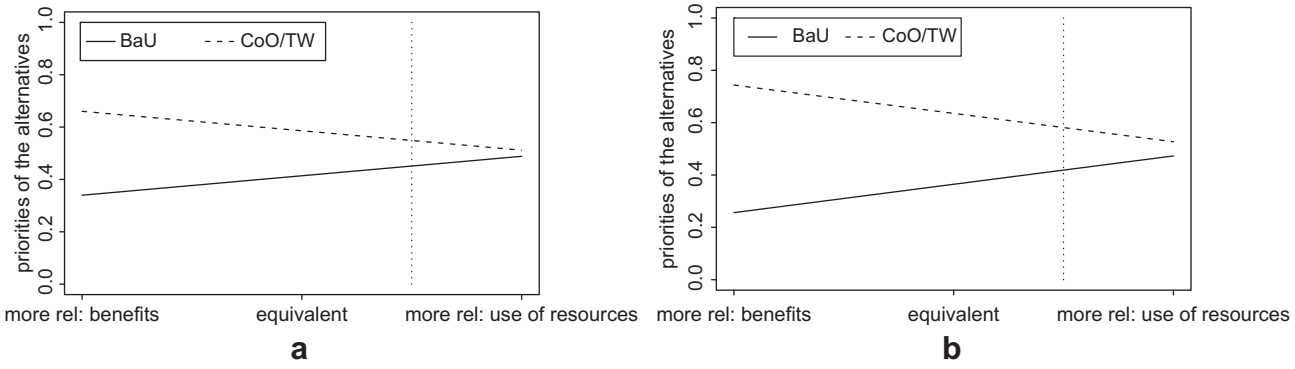

Fig. 4. Sensitivity analysis of the priorities for use of resources *vs.* benefits for airline (a) planning phase and (b) execution phase.

In the planning phase the effects of the implementation of CoO/TW on the ANSP and on the airline are very similar: it does not have a relevant impact on the use of resources (the only cost slightly increased is the working time) and it provides the ANSP with a strong enhancement in terms of common responsibility and transparency of the system.

In the execution phase, CoO/TW is foreseen to slightly decrease the stress of all the ANSP actors but the supervisor, who is in charge of the re-negotiation process. We observe that both stress and working time of the planning controller, the executive controller, and the supervisor are considered equally relevant. The new operational concept is expected to strongly improve all benefits but the monitoring workload. In fact, the additional complexity required to comply with TW will likely even-out the positive effects on ATCOs' workload due to the introduction of the business trajectory, as described by the SESAR Consortium (2007b).

From the criterion and alternative priority values, it follows that for an ANSP the implementation of CoO/TW has priority equal to 0.726 in the planning phase, and 0.781 in the execution phase, and thus it is the preferred alternative in both cases. This preference relation appears very robust.

Fig. 5 describes the results of the sensitivity analysis for the priorities of benefits *vs.* use of resources in the two phases. The vertical dotted line shows the priority relationship between these criteria that is considered in the model (0.167 for both phases as seen in Fig. 2(a) and (b)). In the execution phase the trend of preferences is similar to the airline's situation: BaU never becomes the selected option. The two alternatives are almost equivalent when the use of resources is considered much more important than benefits (Fig. 5(b)). In the planning phase (Fig. 4(a)), BaU is preferred only in cases where the use of resources becomes extremely important. Even in this case, nonetheless, the two alternatives are almost equivalent.

5. The airport perspective

The analysis of the business trajectory shows that the resources that an airport may need to employ in the planning phase mimic those required by an airline or an ANSP (Fig. 3(a)). The main difference as seen by the experts is that no additional staff training is considered as a recurrent cost. The reason is that all major European airports take part in the process of assigning airport slots to airlines (Czerny et al., 2008). Thus they are already performing some negotiation activities as advocated by SESAR in the definition of the business trajectory (SESAR Consortium, 2007a). It follows that there is no need for specific additional expertise. As far as benefits are concerned, the common responsibility and the increase of predictability are singled out. The latter may provide an enhanced planning of resources such as an improved stand and gate planning and management, an efficient use of runway capacity, and airport slot adherence with consequent avoidance of capacity loss. Furthermore, the increase of predictability may lead to a better planning of taxi times, an improvement of service quality, and an increase (or better use) of airport and airspace capacities. Most of these activities may permit increased airport revenues and lower costs.

In the execution phase, airports need to explicitly consider the use of their infrastructure, in addition to human resources (Fig. 3 (b)). In fact, airports must provide aircraft and passengers with a non-negligible set of facilities in case disruptions occur within the system. The main benefits are again the common responsibility and the increase of predictability. As in the planning phase, we may have an improvement of the service quality, a better planning of taxi times, and a better use of airport and airspace capacities. Moreover, we may have a better allocation of resources due to their enhanced planning identified in the previous phase. Finally, the operational efficiency may be improved because the predictability allows to achieve a better use of airport resources (manpower and equipment). Resulting benefits can be expressed in terms of savings on operational costs (e.g., operational cost increases at a lower rate than it does currently) and of reduction of inefficiencies (Eurocontrol Experimental Centre, 2008).

Similarly to the airline case, the economic situation as seen by the experts plays a central role for the airport in the priority of use of resources *vs.* benefits: the optimization of resources is considered strongly more relevant than the benefit enhancement. Nonetheless, a sort of optimistic point of view emerges: the experts from Flughafen Zürich AG underline that the same analysis carried out in a different moment might suggest a diverse preference relation between benefits and use of resources, with significant effects on the final results (Fig. 6). Further relationships exist between benefits in the execution phase. In particular, many important criteria are easily expressed in monetary terms and thus allow direct consideration of resource allocation and operational efficiency. The criterion that comes next is the improvement of service quality: two elements that are recognized to be very important as the better planning of taxi times and the better use of capacity, are not as relevant as the improvement of service quality. In this sense the passengers' feeling about the airport is highly valued.

Differently from the other two stakeholders, in the planning phase the CoO/TW is seen by the experts to require a slightly lower amount of resources with respect to the BaU scenario. This is true for both the equipment maintenance and the working time. In fact, the main difference between the current procedures in the planning phase and the process for defining CoOs consists in the level of formalization. The clear definition of roles and tasks in CoO/TW will help in reducing inefficiencies. Alternatively, most benefits are

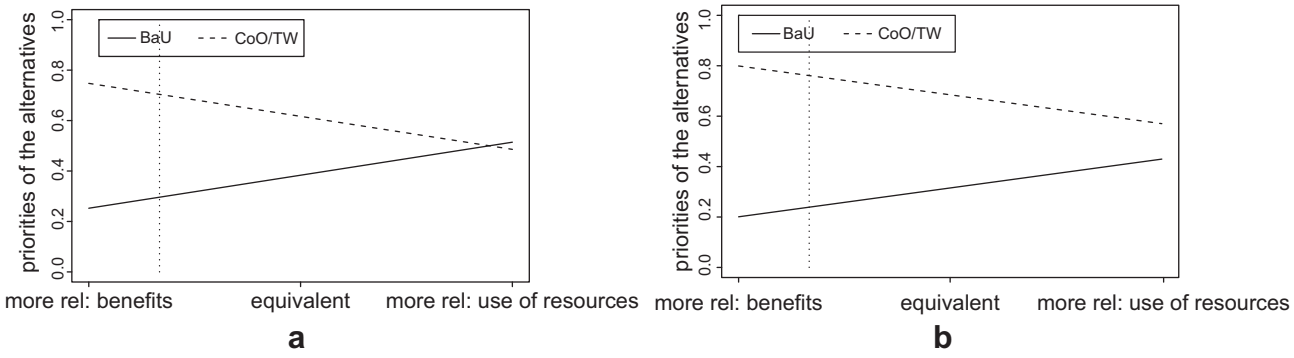

Fig. 5. Sensitivity analysis of the priorities for use of resources *vs.* benefits for ANSP (a) planning phase (b) and execution phase.

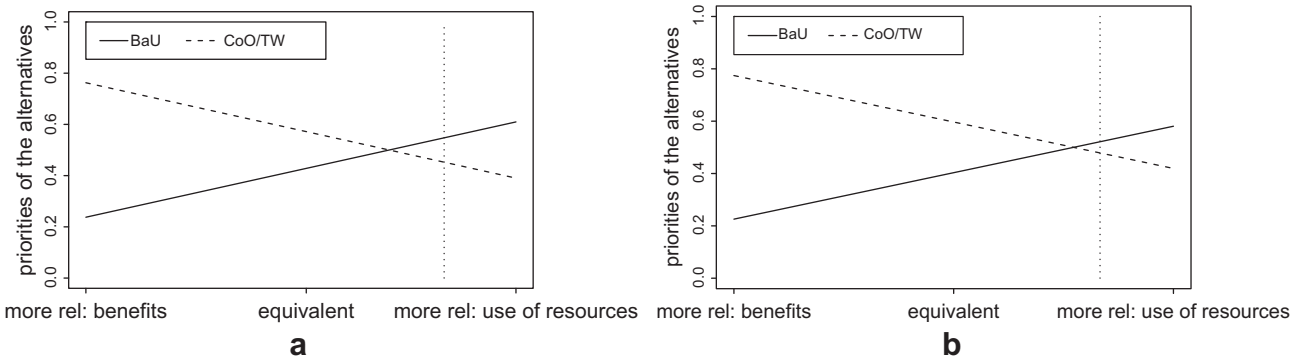

Fig. 6. Sensitivity analysis for the priorities of use of resources *vs.* benefits for airport (a) planning phase and (b) execution phase.

expected to be affected positively with respect to BaU, with more emphasis on common responsibility.

Also in the execution phase the introduction of CoO/TW may significantly increase all benefits; the better use of resources will lower the cost of infrastructure use thanks to the greater predictability in the system, but it slightly increases the cost of human resources when dealing with re-negotiations.

From the criterion and alternative priority values, the implementation of CoO/TW is not the preferred option. In the planning phase its priority value is equal to 0.421 and in the execution phase it is 0.449. This seems mainly due to the strong higher importance assigned to the use of resources over benefits. Moreover, the experts interviewed are from an airport where some CDM mechanisms have already been implemented (Eurocontrol Experimental Centre, 2008). Thus, the introduction of the CoO/TW is not foreseen to change the current situation as much as it would for other airports.

Fig. 6 describes the results of the sensitivity analysis for the priorities of benefits *vs.* use of resources in the two phases. The vertical dotted line shows the priority relationship that is considered in the model (0.833 for both phases – Fig. 6(a) and (b), respectively). The priority of the alternatives shows an inversion when the use of resources becomes moderately more important than benefits. When the latter are favored, the attractiveness of CoO/TW is greater than BaU. The difference is even larger than for airlines.

6. Concluding remarks

This paper analyzes the potential benefits and limitations of implementing a specific CDM process among airlines, airports and ANSPs in the framework of the European ATM system. The target of the proposed concept is to identify a set of 4D intervals (latitude, longitude, flight-level and time) called target windows which are defined at specific transfer of responsibility areas. These intervals are to be met by each flight during its execution to guarantee punctuality at destination. Target Windows are agreed prior to flight departure by means of a negotiation mechanism among all actors. They constitute the so-called Contract of Objectives for the flight. For three main stakeholders, we present two distinct Analytic Hierarchy Process models to evaluate the effect of the introduction of these agreed target windows in the planning and execution phases of a flight. A group of experts from Air France Consulting, ENAV SpA and Flughafen Zürich AG validated the layout of the six hierarchies and assigned priority values among the various criteria and alternatives.

Our analysis shows that the implementation of the new protocol appears to be the preferable choice for the airline and the ANSP. The opposite holds for the airport. This result is quite robust in the first two cases. In the third, a clear inversion of attractiveness exists with optimization in the use of resources becoming less relevant. However, the economic situation from 2007 has forced the airline and the airport to limit investment. Some experts explicitly underlined that the same comparison made some time ago, and possibly some time in the future, would give an opposite result. For the ANSP, instead, the practice of full cost recovery allows to favor the increase of benefits. The lower performance of CoO/TW in the airport case may also depend on the fact that at the airport of Zurich some CDM mechanisms among airlines and the airport authority have already been established.

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