Airport planning using fuzzy dual dynamic programming

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ABSTRACT

Airports are asset-intensive businesses that require a large amount of time to recover the significant financial investments in specific infrastructure such as runways and terminals. Then airports investors must perform strategic moves based on calculated risks before taking investment decisions. This communication puts forward a new approach for airport investment risk assessment. The approach takes explicitly into account the degree of uncertainty in activity levels prediction and proposes milestones for the different stages of the project for minimizing risk. Uncertainty is represented through fuzzy dual theory and risk management is performed using dynamic programming.

Keywords: airports, financial risk assessment, uncertainty, fuzzy dual, dynamic programming

1 INTRODUCTION

Airports are a paramount piece of the economic puzzle with a multiplier economic, social and environmental impact at national, regional and international level. In a highly volatile and uncertain economic environment, airports must be capable to attract sufficient revenues to finance their operations and investments while maintaining a satisfactory quality of service for both their primary clients: airlines and passengers, and also maintaining its role of economic driver supporting in a sustainable manner its local community.

Airports are asset-intensive businesses that require extensive amount of time to recover the significant financial investments in the specific infrastructure, like runways, terminals. This aspect forces airports investors to make strategic moves and to carefully calculate the risks before taking investment decisions. The highly deregulated and liberalized air transportation market determined airports to adopt a more business like operational approach, focusing on non-aeronautical activities as a strategy to achieve self-reliance and financial independence which will allow them to develop in accordance with the market needs. This process of airport commercialization transformed the passenger as the ultimate beneficiary of airport infrastructure.

In the last decades, airports evolved from being simply infrastructure elements to business oriented service providers, pressured to operate in an optimal manner. They proved to be flexible in turbulent economic times proving they had the capability to meet the needs of the air transportation industry, sector that has known a sustained high rate of growth of approximately 5% annually in the last decades even through global economic disturbances, with more than 3 billion passengers transported in 2013 (IATA, 2014).

The structure of the article is as follows: Section 2 provides a general background for long term airport planning, section 3 introduces a concise mathematical formulation of the long term airport planning problem with emphasis on the financial aspects and uncertainty degree. In Section 4 mathematical model is proposed to address airport investment risk assessment. In Section 5 a fuzzy dual dynamic programming approach is discussed to tackle an airport case study. Final conclusions are presented in Section 6.

2 THE AIRPORT PLANNING PROBLEM

As the world economy is going through successive economic downturns, the air transport industry is expected to continue to grow steadily on the long run, then airports should be expanded accordingly. Airport planning is in general a long term planning issue which has at its core the following objectives: optimized infrastructure development costs and functionality, optimized economic and operational performance and a high degree of flexibility in order to integrate all the shifts in demand and potential disturbances according to the airport future needs and level of growth. The new business culture concepts that airports need to embrace includes strong air service competitor advantages, capability of taking long term risks, adopting the stakeholder collaborative decision making culture, diversifying the revenues sources and most of all putting the passenger at the core of the business. The construction of a new airport or the extension of an existing one requires significant investments and many times public-private partnerships has been considered in order to make feasible such projects. One characteristic of these projects is uncertainty with respect to financial and environmental impacts on the medium to long term. Another one is the multistage nature of these types of projects. While many airport development projects have been a success like Munich Airport or Palma de Mallorca Airport, some others have turned into a nightmare for their promoters.

Airports were traditionally seen as the responsibility of governments to manage and operate, typically in line with strategic economic and defense policies (IATA, 2014). In the more recent economic environment, a paradigm shift occurred were private stakeholders emerged as investors evolving from decision makers in airport planning and development to full owners and operators. Privatization of airports emerged as the tool “to go to” for governments looking for strategies to make the local aviation market more dynamic and to achieve their long term planning goals when the costs of funding new infrastructure or maintaining the existing one exceeds their resources. The privatization of airports makes for a governance space where different governance modes intersect and overlap as noted by Donnet and Keast (2011).

The long term airport planning process is a complex endeavor due to the intricacies of the airport system, stakeholders involved and the significant degree of uncertainty. In a highly volatile economic context the planning process needs to be constantly adjusted to the realities of the market

the airport will serve. Quantities such as "demand" and "capacity" need to be re-thought in a dynamic context to compute the operational parameters of the future airport. The fact that long term airport planning is a multibillion business investment requiring a systemic and flexible approach must be acknowledged.
The demand for air transport services has risen much faster than demand for most other goods and services in the world economy. Since 1970 air travel demand, measured by Revenue Passenger Kilometers flown (RPKs) has increased ten times compared to a three-four expansion of the world economy. Along the same period, international passenger and cargo demand, both reflecting and facilitating the globalization of business supply chains and economies generally, was multiplied forty times (IATA, 2013).
Major associated risks that need to be assessed and mitigated during the implementation of the master plan include possible deficit in airport capacity leading to unsustainable levels of traffic and airport economic performance over long term, generation of unacceptable environmental impacts, failing to achieve transport integration with the surrounding multimodal ground transportation system, lack of quantifiable economic benefits for the region the airport serves.
In order to sustain all the forecasted traffic, targeted investment should focus on projects such as: expending existing runways and the construction new ones, increasing airfield capacity, increasing passenger terminals capacity and construction of new ones, construction of dedicated cargo terminals, adding new airside facilities for ground handling operations support, adding landside facilities for airport related activities support, improving surface access to the airport by all modes of transportation.

3 GENERAL FORMULATION OF THE AIRPORT PLANNING PROBLEM

3.1 The planning context

The starting point of any airport planning project and its financing are its current state and the potential demand evolution forecast. The forecast generally covers the time horizon of the project and includes potential demands for the annual volumes of international and domestic scheduled and nonscheduled passengers, freight and aircraft movements. Also, daily and monthly traffic distributions are required in order to identify traffic trends and peaking patterns along with the fleet mix. Of paramount importance is the integration of uncertainty in demand forecasting since the decisions taken at a specific step of the development plan can have a long term impact over the general outcome of the project.
Long term airport planning can expand up to 20 years as a time horizon with a proposed six months incremental milestone in order to accurately monitor the progress of the development project. In this way, an important degree of adaptability will allow airport planers to take better informed decisions over a more controllable time frame.

3.2 Adopted assumptions

Different traffic types leading to costs and revenues can be considered in airports, they cover passengers and freight flows as well as aircraft traffic which is related with the level of these flows. Let the level of predicted potential demand for traffic type *i* along the planning horizon *K* be given by $D_k^i,\ i \in I, k \in \{1, 2, \cdots, K\}$, where *I* is the set of traffic activities.
The necessary aircraft traffic T_k^i to cope with a predicted passenger demand level D_k^i can be approximated by:

$$T_k^i = D_k^i / (S_k^i \alpha_k^i) \tag{1}$$

where S_k^i is the mean capacity of aircraft type *i* at time *k* corrected by the expected mean load factor α_k^i. The rate of return, r_k^i, associated with the traffic of type *i* at time *k*, depends on the investments made until that period. Let the potential airport passenger processing capacity be $C_k^{P_i}$ and the potential aircraft movements processing capacity be C_k^{Ti}, then the estimated level of demand of type *i* at period *k*, $\overline{D}_k^i$, is such as:

$$\overline{D}_k^i = \min\{D_k^i, C_k^{Pi}, S_k^i C_k^{T_i}\} \tag{2}$$

Let L_i be the number of candidate upgrades which can be performed for traffic type *i* at the considered
airport. Let θ_l^i be the period (an integer) at which upgrade *l* for traffic type *i* is planned to be done. When a project is retained, the corresponding value of θ_l^i is within the set $\{1,2,...,K\}$ and when it is not retained $\theta_l^i = K+1$, $l \in \{1,2,...,L_i\}$.
Different types of constraints may be found between interrelated projects:

- Sequential constraints: Technical considerations impose in general sequential constraints, so it is supposed that for given a type of traffic *i* and a pair of projects (*l* , *l'*), there may be constraints such as :

$$\exists l, l' \in \{1,\cdots,L_i - 1\}, i \in I : \theta_l^i \leq \theta_{l'}^i \tag{3.a}$$

- Exclusion constraints such as if project *l* for traffic type *i* is retained, a set of concurrent or contradictory projects will be dismissed:

$$\theta_l^i \in \{1,2,...,K\} \Rightarrow \theta_{l'}^i = K+1, l' \in \Lambda_l^i \subset \{1,\cdots,L_i\} \tag{3.b}$$

- Inclusion constraints such as if project *l* for traffic type *i* is retained, a set of complementary projects related with other traffic should be performed altogether:

$$\theta_l^i \in \{1,2,...,K\} \Rightarrow \theta_{l'}^j = \theta_l^i \text{ , } l' \in M_l^i \subset \{1,\cdots,L_j\} \tag{3.c}$$

Since the different types of traffic may use common resources in the airport, global capacity constraints must be satisfied. Let Δ_k be the set of projects which have been retained until period *k*, then the corresponding capacities with respect to passengers and flights are $C_k^{Pi}(\Delta_k)$ and $C_k^{T_i}(\Delta_k)$.
Let $c_l^{ik}(\Delta_k)$ be the cost of upgrade *l* with respect to traffic type *i* when performed at period *k*. Revenues R_k^i from traffic type *i* at period *k* will be supposed to be given by:

$$R_k^i = r_k^i \cdot \overline{D}_k^i(\Delta_k) \tag{4}$$

where r_k^i is the corresponding service rates.

3.3 Deterministic problem formulation

The adopted strategy develops at first a deterministic approach which leads to the formulation of an optimization problem. Then the parameters and variables subject to significant uncertainty are pointed out and a fuzzy-dual based model of their uncertainty is established. Finally a fuzzy dual formulation of the airport planning problem is proposed.

The deterministic formulation of the optimal programming problem associated to airport planning can be such as:

$$\max_{\theta_l^i} \quad \pi([\theta_l^i], l \in \{1, \cdots, L_i\}, i \in I \tag{5}$$

under constraints (3.a), (3.b) and (3.c).

Here the expected net present value of whole project is given by:

$$\pi([\theta_l^i], l \in \{1, \cdots, L_i\}, i \in I) = \sum_{i \in I} \left(\sum_{k=1}^{K} \left(\frac{r_k}{(1+\rho)^k} \overline{D}_k^{iL}(\Delta_k) \right) - \sum_{\substack{l=1 \\ \theta_l^i \le K}}^{L_i} \left(\frac{c_l^{ik}(\Delta_k)}{(1+\rho)^{\theta_\rho^i}} \right) \right) + \frac{R_V(\Delta_K)}{(1+\rho)^K} \tag{6}$$

where ρ is the rate of actualization and where $R_V(\Delta_K)/(1+\rho)^K$ is the current fuzzy dual residual value of airport equipment.

Observe that, according to expression (2) the estimation of demand levels at period k will depend of previous planning decisions.

4 AIRPORT PLANNING WITH EXPLICIT UNCERTAINTY

Here it is considered that uncertainty regarding the effective levels of demand, the rates of return and the upgrade costs can be represented by fuzzy dual numbers (Cosenza et al, 2011).

4.1 Fuzzy dual numbers

A set of fuzzy dual numbers is defined as the set $\tilde{\Delta}$ of numbers of the form $a+\varepsilon.b$, where a is the primal part and b is the dual part of the fuzzy dual number, $\forall a \in \Re, \forall b \in \Re^+$. Here ε represents the unity pure dual number. A fuzzy dual number loses both its dual and fuzzy attributes if b equals zero. The lower and upper bounds of $a+\varepsilon b$ are given respectively by $B^{low}(a+\varepsilon \cdot b) = a-b$ and $B^{high}(a+\varepsilon \cdot b) = a+b$ while the pseudo norm of a fuzzy dual number is given by:

$$\| a+\varepsilon.b \| = | a | +\rho.b \in \Re^+ \tag{7}$$

Here ρ is a real positively valued shape parameter given by:

$$\rho = (1/b) \int_{a-b}^{a+b} \mu(u) \cdot du \tag{8}$$

where μ is the membership function in the sense of Zadeh (1965). The following properties of the pseudo norm are met no matter the values the shape parameters take:

$$\forall\ a+\varepsilon \cdot b \in \tilde{\Delta} : \|a+\varepsilon \cdot b\| \ge 0 \tag{9}$$

$$\forall a \in \Re, \forall b \in \Re^+, \|a+\varepsilon \cdot b\| = 0 \Rightarrow a = b = 0 \tag{10}$$

$$\|(a+\varepsilon \cdot b)+(\alpha+\varepsilon \cdot \beta)\| \le \|a+\varepsilon \cdot b\| + \|\alpha+\varepsilon \cdot \beta\| \quad \forall a, \alpha, b, \beta \in \Re^+ \tag{11}$$

$$\|\lambda \cdot (a+\varepsilon \cdot b)\| = \lambda \cdot \|a+\varepsilon \cdot b\| \qquad \forall a \in \Re, \forall b, \lambda \in \Re^+ \tag{12}$$

Total orders between fuzzy dual numbers can be introduced using the above pseudo norm. The strong partial written $\breve{\ge}$ can be defined over $\tilde{\Delta}$ by:

$$\forall a_1+\varepsilon b_1, a_2+\varepsilon b_2 \in \tilde{\Delta} : a_1+\varepsilon b_1 \,\breve{\succ}\, a_2+\varepsilon b_2 \Leftrightarrow a_1-\rho b_1 \succ a_2+\rho b_2 \tag{13}$$

The *mean* partial order of *case b*, written $\hat{\geq}$, is defined over $\tilde{\Delta}$ by:

$$\forall a_1+\varepsilon b_1, a_2+\varepsilon b_2 \in \tilde{\Delta} : a_1+\varepsilon b_1 \,\hat{\succ}\, a_é+\varepsilon b_2 \quad \Leftrightarrow a_1+\rho b_1 \succ a_2+\rho b_2 \succ a_1-\rho b_1 \tag{14}$$

The *weak* partial order of *case c*, written $\tilde{\succ}$, is such as:

$$a_1 > a_2,\;\; a_1-\rho b_1 \succ a_2-\rho b_2,\;\; a_1+\rho b_1 \prec a_2-\rho b_2 \tag{15}$$

The *fuzzy equality* between two fuzzy dual numbers, corresponding to case *d*, is symbolized by $\cong$ and is characterized by:

$$a_1 = a_2 \tag{16}$$

Then, it appears that it is *always possible* to rank two fuzzy dual numbers and to assign a qualitative evaluation to this comparison (strong, mean or weak). When either (13), (14) or (15) is satisfied, it will be said that *fuzzy dual number* $a_1+\varepsilon b_1$ *is greater than fuzzy dual number* $a_2+\varepsilon b_2$ and we will write:

$$a_1+\varepsilon b_1 \succ a_2+\varepsilon b_2 \tag{17}$$

A degree of certainty *c* can be attached to assertion (17). A candidate expression for this degree of certainty is given by:

$$c = 1-\frac{1}{2}\min\left\{\frac{\alpha}{b_1},\frac{\alpha}{b_2}\right\} \text{ if } a_1 \geq a_2 \quad \text{and} \quad c = \frac{1}{2}\min\left\{\frac{\alpha}{b_1},\frac{\alpha}{b_2}\right\} \text{ if } a_1 < a_2 \tag{18}$$

where α is the area of the intersection between fuzzy dual numbers $a_1+\varepsilon b_1$ and $a_2+\varepsilon b_2$.

Since two fuzzy dual numbers can now be always compared, even introducing a degree of certainty, this opens the way to the application of the dynamic programming paradign to sequential decision problems where performance is assessed using fuzzy dual numbers: fuzzy dual dynamic programming.

4.2 Fuzzy dual representation of uncertainty for airport planning

Let the fuzzy dual representations of the effective levels of demand, the rates of net return and the upgrade costs be given by:

$$r_k^i = r_k^{iL} + \varepsilon\, r_k^{iD} \tag{19}$$

$$\overline{D}_k^i(\Delta_k) = \overline{D}_k^{iL}(\Delta_k) + \varepsilon\, \overline{D}_k^{iD}(\Delta_k) \tag{20}$$

$$c_l^{ik}(\Delta_k) = c_l^{ikL}(\Delta_k) + \varepsilon\, c_l^{ikD}(\Delta_k) \tag{21}$$

where the likely components are indexed by *L* and the dual components are indexed by *D*. In many situations, the likely components can be associated with mean estimated values while the dual components can be associated with their corresponding standard deviations. The expression of the fuzzy dual net present value is given by:

$$\pi([\theta_l^i], l \in \{1,\cdots,L_i\}, i \in I) = \pi^L([\theta_l^i], l \in \{1,\cdots,L_i\}, i \in I) + \varepsilon\, \pi^D([\theta_l^i], l \in \{1,\cdots,L_i\}, i \in I) \tag{22}$$

where

$$\pi^{L}([\theta_l^i], l \in \{1,\cdots,L_i\}, i \in I) = \sum_{i\in I}\left(\sum_{k=1}^{K}\left(\frac{r_k^L}{(1+\rho)^k}\overline{D}_k^{iL}(\Delta_k)\right) - \sum_{\substack{l=1 \\ \theta_l^i \le K}}^{L_i}\left(\frac{c_l^{ikL}(\Delta_k)}{(1+\rho)^{\theta_\rho^i}}\right)\right) + \frac{R_V^L(\Delta_K)}{(1+\rho)^K} \tag{23}$$

and

$$\pi^{D}([\theta_l^i], l \in \{1,\cdots,L_i\}, i \in I) = \sum_{i\in I}\left(\sum_{k=1}^{K}\left(\frac{r_k^D}{(1+\rho)^k}\overline{D}_k^{iD}(\Delta_k)\right) - \sum_{\substack{l=1 \\ \theta_l^i \le K}}^{L_i}\left(\frac{c_l^{ikD}(\Delta_k)}{(1+\rho)^{\theta_\rho^i}}\right)\right) + \frac{R_V^D(\Delta_K)}{(1+\rho)^K} \tag{24}$$

where $\dfrac{R_V^L(\Delta_K)}{(1+\rho)^K} + \varepsilon\dfrac{R_V^D(\Delta_K)}{(1+\rho)^K}$ is the current fuzzy dual residual value of airport equipment**.**

5 CASE STUDY

In this section, the overall assumptions allowing to characterize the airport planning case study are established.

5.1 The considered background

For the numerical illustration the case of a national airport expected to gain an international position has been considered. The airport is expected to be managed under a BOT agreement (Build – Operate – Transfer) over a period of thirty years. In this situation, the BOT project financing involves a private entity which has received a concession from the public sector to finance, design, construct, and operate the complex of airport infrastructure facilities, according to the concession contract. The financial risk of the concessionaire is to be unable to recover its investment, operating and maintenance expenses in the project. In this type of situation, the project proponent is facing a significant amount of risk that needs to be assessed and mitigated.

The considered case consists in constructing a Master Plan which must incorporate the main elements encountered in airport projects, focusing on infrastructure needs. It sets the problem of the timing of the construction of facilities in order to meet future traffic demand, covering a 25 years time span. The Master Plan is built on a flexible framework by no committing in advance to any particular project, but following a comprehensive decision-making process that will avoid situations in which short-term initiatives could preclude long-term opportunities.

The major constraint the airport development project is facing is the fact that the airport operational area is restricted by the land the airport owns. For the initial stages of the development project additional land has already been acquired to facilitate infrastructure expansion. Further land will be acquired to allow or safeguard the potential airport expansion as long as it remains a commercially viable option. A factor to be noted is the location of the airport in an urban area, which imposes aerodrome and navigational constraints beyond the boundary of the airport operational area. Also, the operational area is currently constrained by the adjoined land use, including rail network and highway. Completing the 25-year Master Plan based on the potential traffic will definitely require acquisition of land to the south and safeguarding also land to the east as a way of not risking future airport and airport-related development projects.

As seen, the traffic mix is generating specific costs and revenues, with primary focus on passengers and freight flows as well as aircraft traffic that is related with the level of these flows.

5.2 The airport planning scenario

The region the airport is serving is expected to become increasingly important at regional and national level with a catchment area of 8 million people living within one-hour travel time of the airport, and 40 million living within two-hours travel time. Currently, less than 40% of the region's demand for air travel is served by the local airport. A significant air travel demand is therefore underserved in the region, contributing to an overgrowing number of unnecessary surface trips and congestion. An overall unsustainable situation is expected within a decade. In this context, guaranteed access to markets are more and more relevant for economic development both from a business and commercial perspective but also for boosting tourism and creating a more efficient transportation system.

The airport is strategically located, which generates the potential of becoming the principal international gateway for the region it is serving. The need for access to sustainable air travel is expected to continue its positive trend, the airport becoming a basic driver for economic growth in the region. The airport is already providing access to air travel in an integrated way, acting as a regional transport hub with interchange facilities across all modes.

The airport has a mixed ownership with the majority share belonging to private investors.

A Master Plan covering a 25 years time-span details future airside and landside infrastructure requirements and flexible and sustainable expansion strategies necessary to implement in order to accommodate the forecasted traffic growth while mitigating potential risks that may jeopardize irreversibly the chances of success of the entire development project. The main objective of the airport is to claw back traffic, which currently travels to other regions for access to air travel with the benefit of decongesting the over capacitated airports and creating the premises for a sustainable regional economic development and increased environment awareness and mitigation.

Current passenger throughput is 9 million, expected to reach the 35 million passengers level in 25 years. This will suggest the addition of a new runway and the possibility of adding a new terminal building to the current airport configuration. The airport has experienced strong growth of passenger traffic, over the last two decades averaging at 8% per year, with the national market share increasing from 3% to 4%.

Currently, the air traffic breakdown by market sector at this airport is: low cost: 45%, short haul: 35%, long haul :10% and charter: 10%. Long-haul is expected to be the most potent sector of growth. This sector is currently limited by the lack of proper airside infrastructure – the existing length of the runway is precluding operation of commercial flights both east and west and severely limits access to emerging markets. Short haul traffic historically has been the fastest growing market sector for the airport and going forward the assumption that the sector will continue its steady growth will stand. A similar trend can be identified for the low cost sector who is looking to further expand its network. The only sector who is predicted to contract will be the charter flights due to continuous consolidation and expansion of low-cost carriers. Overall, the focus and opportunities for growth are identified solely in the international sector, while domestic traffic is forecasted to have the slowest growth, reaching complete maturity. The forecasted growth of long-haul flights will also trigger an increase of future freight activity. This is also supported by the progressive addition of new routes, giving the airport access to new markets and positioning it as a regional cargo hub.

5.3 Traffic forecast

The traffic forecast provides estimates every five years. This forecast is one of the key indicators that will deem which phase of the master plan is the best trade-off between commercial viability and associated risks.

Table 1: Forecast of nominal passenger, ATM and freight activity levels

	Pax	*ATM*	*Freight*
Current	9 million	100,000	15,000 t
5 year mark	12 million	130,000	30,000 t
10 year mark	15 million	160,000	55,000 t
15 year mark	20 million	180,000	80,000 t
20 year mark	25 million	200,000	100,000 t
25 year mark	35 million	220,000	125,000 t

Table 2: Uncertainty for passenger, ATM and freight activity levels

	δPax/Pax	*δATM/ATM*	*δFreight/Freight*
Current	0%	0%	0%
5 year mark	10%	9%	6%
10 year mark	15%	12%	10%
15 year mark	20%	18%	15%
20 year mark	25%	20%	16%
25 year mark	30%	28%	20%

Fuzzy dual demand levels will be directly associated with these uncertainty levels. For instance in the case of passenger demand we have:

$$\overline{D}_k^{Pax} = \overline{D}_k^{Pax} + \varepsilon \left(\delta Pax / Pax\right) \cdot \overline{D}_k^{Pax} \tag{25}$$

6 SOLUTION PROCESS AND NUMERICAL APPLICATION

Fuzzy dual dynamic programming has been used to solve the proposed airport planning problem.

6.1 The sequential decision problem

Figure 1 displays the dynamic programming decision graph associated to the airport plan development including two new runways, two terminal buildings (one passengers, one cargo) control buildings, fire and rescue facilities, multi-store car parks, taxiways, hangars, rail access over a period of 25 years divided in five stages of five years duration and corresponding to five different operational configurations for the airport. Here 31 different paths lead to the states of the final stage while 20 different states at equal or different stages must be evaluated following relations (22), (23) and (24). To each state is associated the corresponding passengers and cargo capacity.

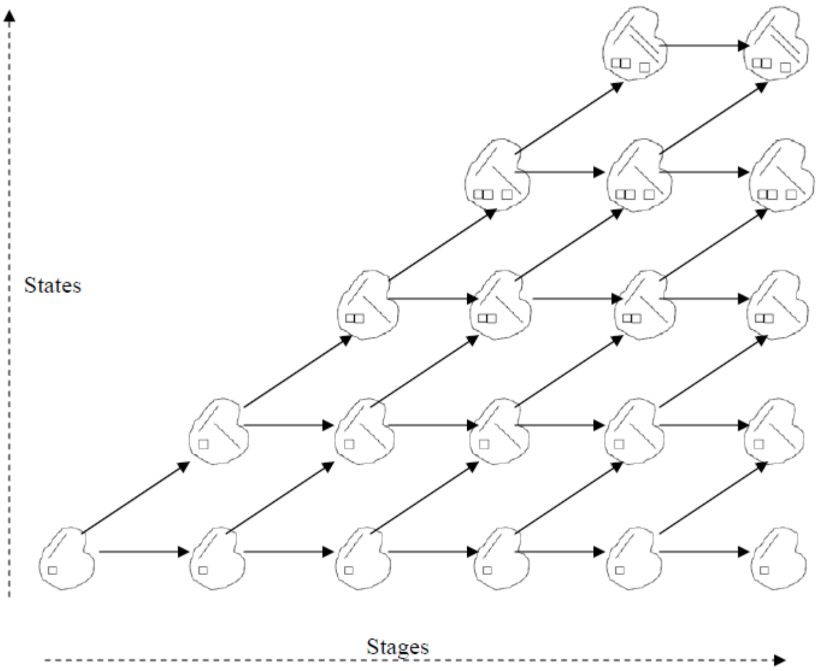

Figure 1: Dynamic Programming Decision Graph

The expected passengers and cargo capacities associated to each of these states are the following:

states (i, 1) :Passenger capacity = 10 million, Cargo capacity = 30, 000 t.
states (i+1, 2) : Passenger capacity = 15 million, Cargo capacity = 45, 000 t.
states (i+2, 3) : Passenger capacity = 25 million, Cargo capacity = 65, 000 t.
states (i+3, 4) : Passenger capacity = 25 million, Cargo capacity = 125, 000 t.
states (i+4, 5) : Passenger capacity = 35 million, Cargo capacity =135, 000 t.

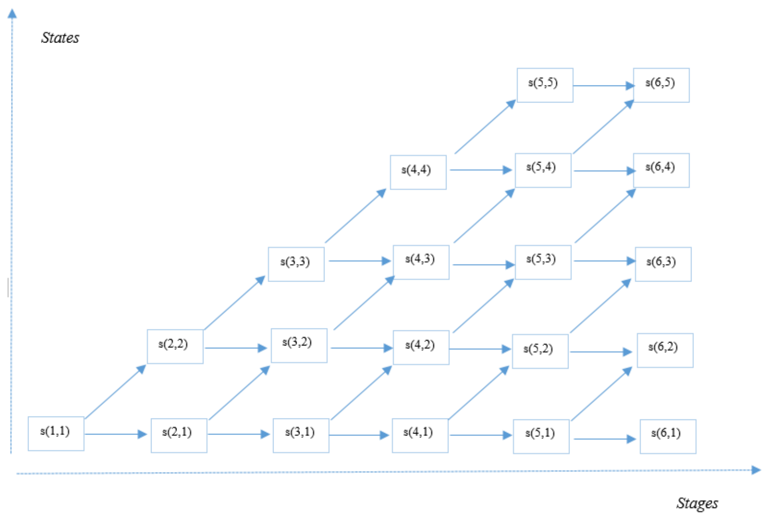

Figure 2: Identification of potential options (stages and states) for the airport infrastructure development plan

6.2 The solution through fuzzy dual dynamic programming

The application of the proposed fuzzy dual dynamic programming approach leads to the following optimal decision tree represented in Fig. 3 where each potential state corresponding to every stage has associated a fuzzy dual performance, a degree of certainty and a fuzzy dual net present value.

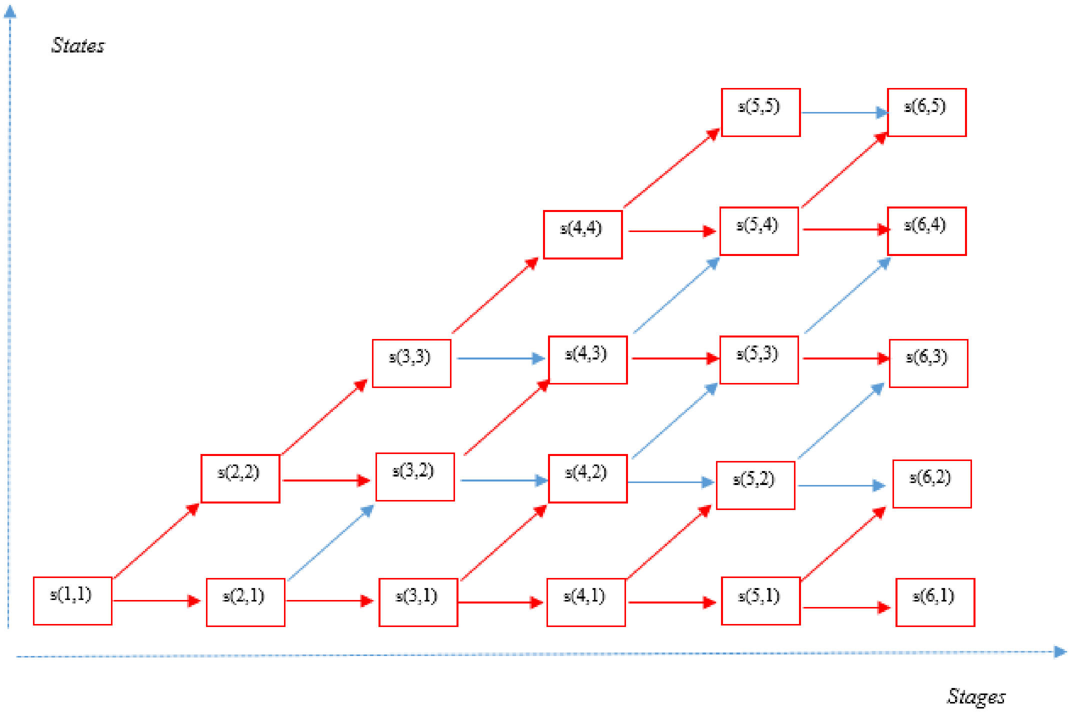

Figure 3: Fuzzy dual dynamic programming solutions tree

The breakdown for every stage and states in the optimal decision tree is detailed bellow:

Stage 1: present state
state (1,1) – represents current airport situation, with the following associated parameters:
Fuzzy dual performance: 0 + ε 0 , degree of certainty =1, fuzzy dual NPV: 1000 + 0 ε .

Stage 2: five-year milestone

state (2,1) – no facilities added
Fuzzy dual performance: 150 + ε 20, degree of certainty = 1, fuzzy dual NPV: 970 + ε 150.

state (2,2) - addition of the second runway
Fuzzy dual performance: -250 + ε 30, degree of certainty=1, fuzzy dual NPV: 1280 + ε 140.

Stage 3: ten-year milestone
state (3,1) – no facilities added
Fuzzy dual performance: 135 + ε 32, degree of certainty=1, fuzzy dual NPV: 950 + ε 310.

state (3,2) – addition of the second runway
Fuzzy dual performance: 125 + ε 34, degree of certainty= 0.90, fuzzy dual NPV: 1210 + ε 275.

state (3,3) – addition of the second passenger terminal
Fuzzy dual performance: -230 + ε 35, degree of certainty= 1, fuzzy dual NPV: 1450 + ε 190.

Stage 4 – fifteen-year milestone
state (4,1) – no facilities added
Fuzzy dual performance: 128 + ε 56, degree of certainty=1, fuzzy dual NPV: 925 + ε 525.

state (4,2) – addition of the second runway
Fuzzy dual performance: -235 + ε 48, degree of certainty=0.84, fuzzy dual NPV: 1210 + ε 490.

state (4,3) – addition of the second passenger terminal
Fuzzy dual performance: -25 +ε 41, degree of certainty= 0.83, fuzzy dual NPV:1400 + ε 320.

state (4,4) - addition of the cargo terminal
Fuzzy dual performance: -220 + ε 35, degree of certainty = 1, fuzzy dual NPV: 1750 + ε 260.

Stage 5 – twenty-year milestone
state (5,1) – no facilities added
Fuzzy dual performance: 123 + ε 97, degree of certainty =1, fuzzy dual NPV: 905 + ε 840.

state *(5,2)* – addition of the second runway
Fuzzy dual performance: -227+ ε 84, degree of certainty = 0.75, fuzzy dual NPV: 1195 + ε 766.

state (5,3) – addition of the second passenger terminal
Fuzzy dual performance: 115 + ε 73, degree of certainty= 0.75, fuzzy dual NPV: 1380 + ε 470.

state (5,4) - addition of the cargo terminal
Fuzzy dual performance: 110 + ε 42, degree of certainty= 0.77, fuzzy dual NPV: 1675 + ε 365.

state (5,5) – addition of the third runway
Fuzzy dual performance: -210 + ε 55, degree of certainty= 1, fuzzy dual NPV: 1800 + ε 466.
Stage 6: - twenty-five-year milestone
state (6,1) – no facilities added
Fuzzy dual performance: 120 + ε 129, degree of certainty between=1, fuzzy dual NPV: 894+ ε 962.

state (6,2) – addition of the second runway
Fuzzy dual performance: 115 + ε 105degree of certainty = 0.66, fuzzy dual NPV: 1185 + ε 971.

state (6,3) – addition of the second passenger terminal
Fuzzy dual performance: 110 + ε 92, degree of certainty= 0.59, fuzzy dual NPV: 1370 + ε 750.

state (6,4) - addition of the cargo terminal
Fuzzy dual performance: 108 + ε 65, degree of certainty= 0.68, fuzzy dual NPV: 1650 + ε 582.

state (6,5) – addition of the third runway
Fuzzy dual performance: -200 + ε 75, degree of certainty = 0.67, fuzzy dual NPV: 1810 + ε 684.

Then it appears that (degree of certainty 0.67) to get at the horizon of 25 years with the project entirely complete (i.e. airport with three runways, two passenger terminals and a cargo terminal) the best solution is to start immediately the construction process by adding each five years a new element (second runway, second passenger terminal, cargo terminal in this particular order), then wait for five years before constructing the third runway. There is no financial risk in this case. In the case in which it is considered that the third runway will not be taken into consideration (traffic deficit, environmental considerations, lack of quantifiable economic benefits, difficulties in funding, etc.), then the best solution appears to be (degree of certainty 0.59) starting as soon as possible the second runway (+5), the second passenger terminal (+10) and the cargo terminal (+15). Here also, there is no financial risk attached. However, the do nothing solution (state (6,1)) has a financial risk attached. In this particular case, airport congestion will generate increasing operating costs.

7 CONCLUSIONS

This communication after performing an analysis of the long term airport planning problem, proposes a new approach for long term airport investment planning. This approach takes explicitly into account the degree of uncertainty in the prediction of activity levels while proposing milestones for the different stages of the airport project in view of maximizing profit over the planning horizon while assessing the resulting financial risk. Uncertainty is represented through fuzzy dual numbers which allows limiting the problem complexity and the computational burden to get a solution. Here the sequential decision process is performed using a fuzzy dual extension of dynamic programming and the applicability of the proposed approach is discussed through a case study.

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