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Construction of Hydrant Fuelling System in Relation to the Airport Size

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Construction of Hydrant Fuelling System in Relation to the Airport Size

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Abstract

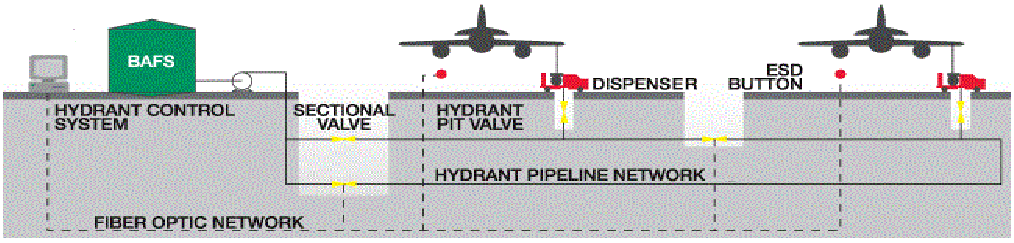
Airport engineering covers wide range of systems as the airport environment provides the platform for a variety of interdisciplinary processes. One of them is aircraft refueling. It is one of the most complex processes of airport's everyday operations. Smaller airports use fuel trucks meanwhile medium-sized and big airports operate dedicated underground fuel hydrant system. Even though there are various studies covering the problem of hydrant systems, nowhere it is said from what airport size it is convenient to build the hydrant system. Especially at airports with density of operation around ten million passengers per annum, it is sometimes difficult to decide between fuel trucks and hydrant system. Thus, this paper draws a recommendation from what airport size the installation of such systems could be efficient. Various meanings of term airport size are assessed, e.g. scale of operations (number of aircraft movements, number of passengers handled), airport design (distances between stands and fuel trucks' filling platform), stands number, fuel throughput, hydrant system building costs, aircraft size, its range and fuel consumption etc. Based on the assessment of all factors, the term "airport size" is defined in relation to the aircraft fuelling operations. In order to draw any recommendation, the sufficient dataset must be gathered. Data was collected through the survey and case studies of airports selected as reference. Some relevant airports were also willing to provide necessary data on hydrant system investment and operational costs. The suitable methodology for assessing all mentioned airport characteristics is set. Finally, the recommendation is drawn to fill up a blank in airport engineering system design issues.

Keywords: Airport engineering, Aircraft Fuelling, Hydrant Systems, Airport Size.

Introduction

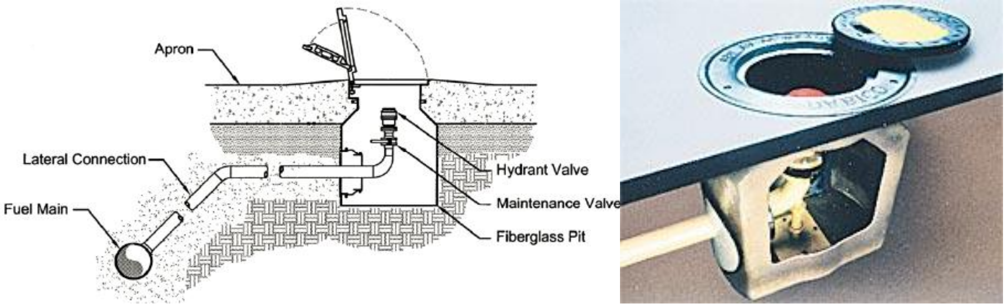
There are basically two ways how to refuel aircraft at airports with significant portion of regular international traffic. First option is usage of fuel trucks which transfer fuel from their own tank into the aircraft which is connected with the fuel truck by the hose. The other option is utilization of dedicated underground piping system which delivers fuel from fuel storage (so called fuel farm) directly to the aircraft. Special vehicle called dispenser is used to connect aircraft tank inlets with underground piping system. One hose connects dispenser and aircraft tanks, the second connects dispenser with hydrant valve. This valve is buried in the apron pavement in special fiberglass pit. Scheme of airport hydrant system is shown at Figure 1. BAFS means Building of Aboveground Fuel Storage, ESD stands for Emergency Shut Down.

Figure 1. *Airport Hydrant System Scheme*



Main pipeline creates closed loop around terminal (or apron). This ensures circulation of the fuel within the system. Moreover, there are many lateral connections linking the main pipeline with hydrant pits. Pit scheme is shown on Figure 2.

Figure 2. *Hydrant pit (Kluttz, 2005), (Austerman, 1997)*



Hydrant systems are considered as an optimal fuelling method since they provide environmentally friendly, fast and reliable refueling method with overall positive impact on safety and efficiency of everyday airport operations (Kazda & Caves, 2007).

Airport Size Definition

First of all, it is necessary to define the term *airport size* which is to be used within this paper from now on. Traditional figures for assessing the airport size are number of passengers handled and number of aircraft movements per year. The former is the most common variable to describe size of any airport with regular traffic however it has no direct relation to extent of fuelling operations at particular airport. On the other hand, the latter is focusing on density of operations at an airport so it is much more viable variable in terms of aircraft refueling problem. More movements means more fuelling operations and vice versa.

The term *airport size* often evokes the physical size of airport site. This has a little to do with fuelling operation even if distance between apron and fuel farms (or fuel truck filling station) has direct impact on operational costs of fuelling system (especially fuel trucks) and safety on airport service roads since traffic increases with the increase in distance between apron and fuel truck filling station. Another variable related to physical airport size is number of aircraft stands. It is generally believed the more stands, the bigger the airport is. This may be true but on the other hand, “smaller” airport can serve more flights a day and handle more passenger than its “bigger” competitor. Moreover, both stands number and station-apron distance directly influences hydrant system investment cost. This cost topic will be covered in one of the next sections.

On contrary, average aircraft size, its fuel consumption and flight structure (meaning average route distance) can have direct impact on the extent of fuelling operation. The bigger the aircraft is, the more fuel it needs. The higher the consumption is, the more fuel is needed. The longer the route distance is, the more fuel must be filled into the aircraft before take-off. However, these three variables has one common denominator which is the fuel throughput at an airport. This value covers average aircraft size, its average consumption and average route distance so it is the most comprehensive variable to describe airport size in terms of fuelling operations along with number of aircraft movements.

As for the relevant sources, (TRB, 2010) recommends that the type of system (hydrant or fuel trucks) used should be determined in relation to the expected rate of aircraft movements at the airport. According to (Boyce, 1999), it depends on the amount of fuel that gets picked up at a particular airport. It is not so much the number of gates but rather the destination of the flights.

Discussion with experts [Křížek, Zoltán, Papapanos, personal communications] within the course of this research confirmed the fact that most important value in terms of decision whether or not to implement hydrant refueling system (HRS) is fuel throughput (or fuel uplift) per year. Thus, referring to airport size from now on is related to volume of fuel uplifted at particular airport per year unless stated otherwise.

Current Status and Initial Research

Fuel Uplift

Thus, initial data collection took place since annual fuel throughput is not a figure which airports reports or has to report e.g. to international organizations, in their annual reports etc. Airports were addressed with short questionnaire in order to provide fuel throughput figures. Results can be found in Table 1.

Table 1. *Fuel Uplift in Relation to the Hydrant System at Selected Airport*

Airport	**Fuel Uplift (mil. l)**	**Aircraft Movements**	**Fuel per Departure (l)**	**Passengers (mil.)**	**Hydrant system**
San Francisco	**3 289,52**	424 566	15 496	44,48	yes
Miami	**3 123,00**	387 581	16 115	40,50	yes
Munich	**2 433,00**	387 983	12 542	38,36	yes
Delhi	**1 500,00**	280 713	10 687	34,37	yes
Madrid	**1 433,78**	373 185	7 684	45,20	yes
Milan Malpensa	**1 029,00**	174 892	11 767	18,54	yes
Oslo	**540,00**	239 357	4 512	22,96	yes
Geneva	**443,52**	192 944	4 597	13,90	yes
Athens	**425,00**	153 295	5 545	12,94	yes
Cape Town	**420,00**	91 486	9 182	8,51	yes
Hamburg	**340,00**	152 890	4 448	13,70	no
Prague	**330,00**	131 564	5 017	10,81	no
Bucharest	**259,24**	98 592	5 259	7,10	no
Stuttgart	**256,00**	131 524	3 893	9,72	no
Larnaka	**230,07**	50 329	9 143	5,17	yes
Porto	**189,00**	59 215	6 384	6,00	yes
Budapest	**179,00**	83 830	4 271	8,52	no
Charleroi	**157,34**	82 322	3 823	6,52	no
Fuerteventura	**144,68**	37 772	7 660	4,40	yes
Göteborg	**133,00**	63 253	4 205	5,00	no
Sofia	**99,00**	43 862	4 514	3,47	no
London City	**76,00**	68 000	2 235	3,39	no
Malmö	**50,19**	28 464	3 527	2,10	no
Gdansk	**42,00**	34 360	2 445	2,91	no

Table shows airports aligned as per fuel uplift. Traditional metrics as aircraft movements and passengers handled are included as well. Data are from 2012 except Munich, Budapest, Goteborg and London City which provided data from 2013. Variable *Fuel per Departure* is fuel uplift divided by half of aircraft movements (movements are sum of both take-offs and landings, but take-offs are refueled only). This value takes into account aircraft size, its consumption and route distance of flights operated from airport. The higher this value is, the longer the refueling takes.

Current status shows that hydrant systems exist at all selected airports with fuel throughput higher than 420 mil. l. On contrary, below 144 mil. l no airport has built hydrant system. In between those values, three of nine airports from selected statistical set uses hydrant system.

Minimum Required Flow

Crucial elements in airport hydrant system design are industry standards and technology requirements. As for the former, standardized diameters of pipeline are used in the engineering industry. This ranges from 6 to 24 inches (Austerman, 1997). As for the latter, the system should be designed to provide extended periods of fuel flow in the 1.8 m/s range in order to provide a sweeping or cleansing action within the piping system. Otherwise, at lower velocities, condensate water may collect in the piping and promote microbial growth (Kluttz, 2005). Knowing the minimum pipeline diameter and minimum required flow velocity, minimum annual volume can be calculated using basic laws of fluid dynamics. Volumetric flow rate is defined as:

$$q = S \cdot v$$

where: q ... volumetric flow rate [m^3/s],
S ... surface of pipeline cross-section [$m^{2]}$,
v ... fuel flow velocity [m/s].

Fuel flow velocity is known; surface of pipeline cross-section is defined as:

$$S = \pi \cdot r^2$$

where: r ... pipeline radius [m].

6 inches is equal to 0.1524 meters so radius is 0.0762 meters. Values are applied into the first equation:

$$q = \pi \cdot 0.0762^2 \cdot 1.8$$

$$q = 0.0328 \quad m^3/s$$

Minimum volumetric flow rate is 32.8 liters per second. Minimum annual volume to be circulated within the hydrant system can be computed from the equation:

$$V = q \cdot t$$

where V ... minimum fuel volume [m^3],
t ... operational period of hydrant system [s].

Operational period is not 24 hours a day since most airports have night curfew of 8 hours:

$$V = 0.0328 \cdot 365 \cdot (24-8) \cdot 60 \cdot 60$$

$$V = 689587.2 \quad m^3$$

From technological point of view, minimum volume to be circulated in the pipeline system per year is almost 690 million of liters.

However, based on the survey from previous subsection, hydrant systems can be operated even if this volume is lower than the one calculated above. The fuel can be circulated inside the pipelines also during the period when the system is not used for refueling. This measure ensures cleansing action within the piping system on one hand, but increase the operational costs on the other since pumping system must be in operation during periods when HRS is not making revenues. The dependence between annual fuel throughput and operational cost will be discussed in the next section.

It may be concluded that minimum technology volume is not a break-even point from which this system could be efficient to build.

Data Collection and Model of Hydrant

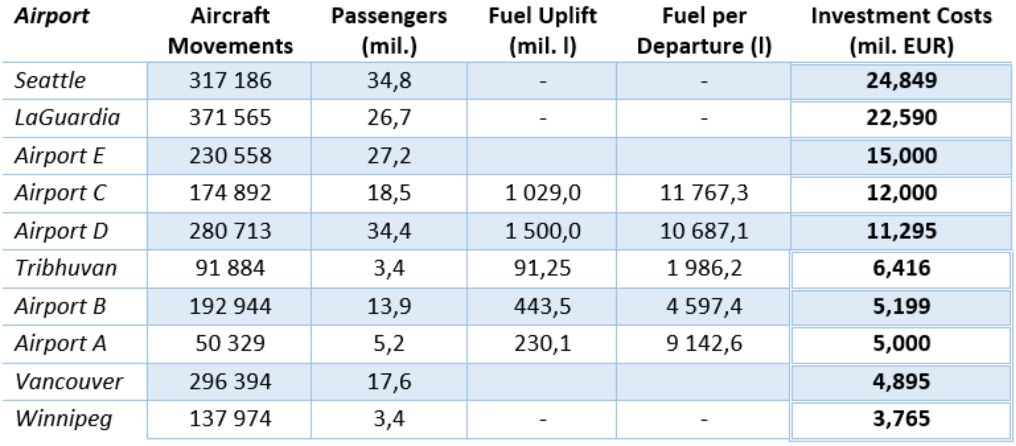
With respect to the previous conclusion, it is necessary to research further in order to find a volume from which it may be efficient to build up hydrant system. Further research requires collection of data associated with hydrant systems already operated at airports. Since these data are sensitive, not many airports are willing to provide datasets for research purposes. Many airports were addressed with data collection form, but only five returned complete dataset. The paper refers to these five airports as Airport A, Airport B, Airport C, Airport D and Airport E due to data sensitivity. Moreover, airports provided data in different currencies so it was necessary to convert them into one common currency. Euro was chosen and average conversion rate for year of 2013 was used.

The model is called *technical and economical hydrant system model* as the inputs are technical data while outputs have economic nature. These outputs will be used for cost-benefit analysis of selected airports which differs in size.

Investment Costs

Results of data collection are show in Table 2. Beside data from Airports A to E, Table 2 includes data available from the internet sources.

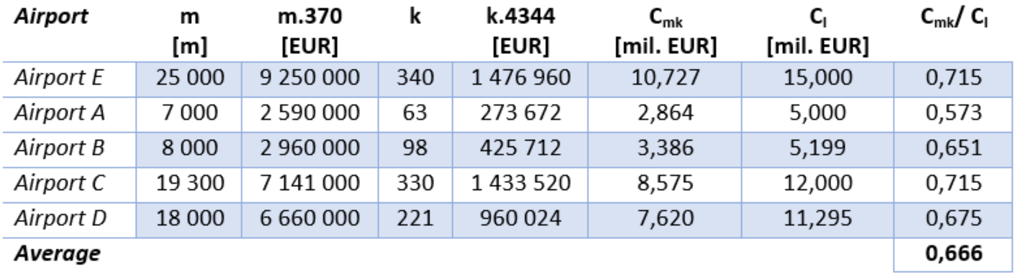
Table 2. *Hydrant System Investment Costs at selected Airports*



Airport	**Aircraft Movements**	**Passengers (mil.)**	**Fuel Uplift (mil. l)**	**Fuel per Departure (l)**	**Investment Costs (mil. EUR)**
Seattle	317 186	34,8	-	-	**24,849**
LaGuardia	371 565	26,7	-	-	**22,590**
Airport E	230 558	27,2			**15,000**
Airport C	174 892	18,5	1 029,0	11 767,3	**12,000**
Airport D	280 713	34,4	1 500,0	10 687,1	**11,295**
Tribhuvan	91 884	3,4	91,25	1 986,2	**6,416**
Airport B	192 944	13,9	443,5	4 597,4	**5,199**
Airport A	50 329	5,2	230,1	9 142,6	**5,000**
Vancouver	296 394	17,6			**4,895**
Winnipeg	137 974	3,4	-	-	**3,765**

No statistical method can be used to typify these types of costs. Hydrant system consists basically of three components; (1) pipelines, (2) hydrant pits and (3) pumping and control system. The costs of the first two components can be standardized and depend on either total length of pipelines *m* or number of pits k. Standardized prices are 370 EUR per meter of pipeline and 4344 EUR per one hydrant pit (SDRCAA, 2006). On the other hand, performance of pumping system and complexity of control system is directly proportional to size and robustness of particular hydrant system. To compare costs for pipelines and hydrant pits C_{mk} and total investment costs C_I, see Table 3.

Table 3. *Hydrant System Investment Costs Calculations*



Airport	m [m]	m.370 [EUR]	k	k.4344 [EUR]	C_{mk} [mil. EUR]	C_I [mil. EUR]	C_{mk}/ C_I
Airport E	25 000	9 250 000	340	1 476 960	10,727	15,000	0,715
Airport A	7 000	2 590 000	63	273 672	2,864	5,000	0,573
Airport B	8 000	2 960 000	98	425 712	3,386	5,199	0,651
Airport C	19 300	7 141 000	330	1 433 520	8,575	12,000	0,715
Airport D	18 000	6 660 000	221	960 024	7,620	11,295	0,675
Average							**0,666**

From the table above it can be concluded that costs of pipelines and hydrant pits represent two thirds of total costs in average, i.e. they must be raised by 50% to reach the level of total investment costs. The formula for investment costs is as follows:

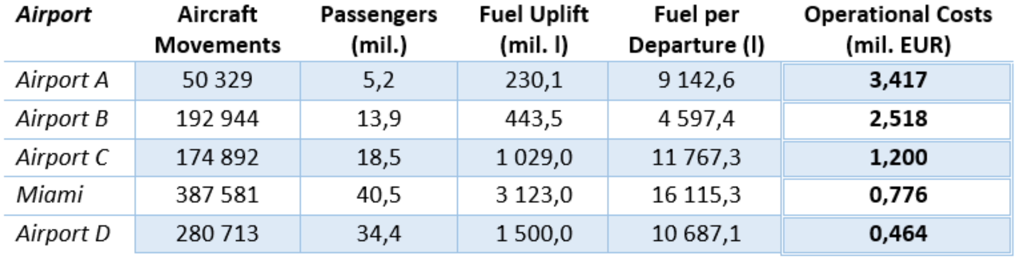
$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$$

where CI … total investment costs [EUR],
m ... total length of pipeline [m],
k … number of hydrant pits.

Operational Costs

Results of data collection are shown in Table 4. These costs include also maintenance costs.

Table 4. *Hydrant System Operational Costs at Selected Airports*



Airport	Aircraft Movements	Passengers (mil.)	Fuel Uplift (mil. l)	Fuel per Departure (l)	Operational Costs (mil. EUR)
Airport A	50 329	5,2	230,1	9 142,6	**3,417**
Airport B	192 944	13,9	443,5	4 597,4	**2,518**
Airport C	174 892	18,5	1 029,0	11 767,3	**1,200**
Miami	387 581	40,5	3 123,0	16 115,3	**0,776**
Airport D	280 713	34,4	1 500,0	10 687,1	**0,464**

Costs differs in relation to the airport size but none of variables (aircraft movements, passengers handled, fuel uplift, fuel per departure) shows functional dependency on operational costs. Thus, it is necessary to create new variable. This variable is unit operational costs and is described as follows:

$$C_u = \frac{C_O}{V}$$

where C_u ... unit operational costs [EUR/mil. l],
C_O ... operational costs [EUR],
V … fuel uplift (volume) [mil. l].

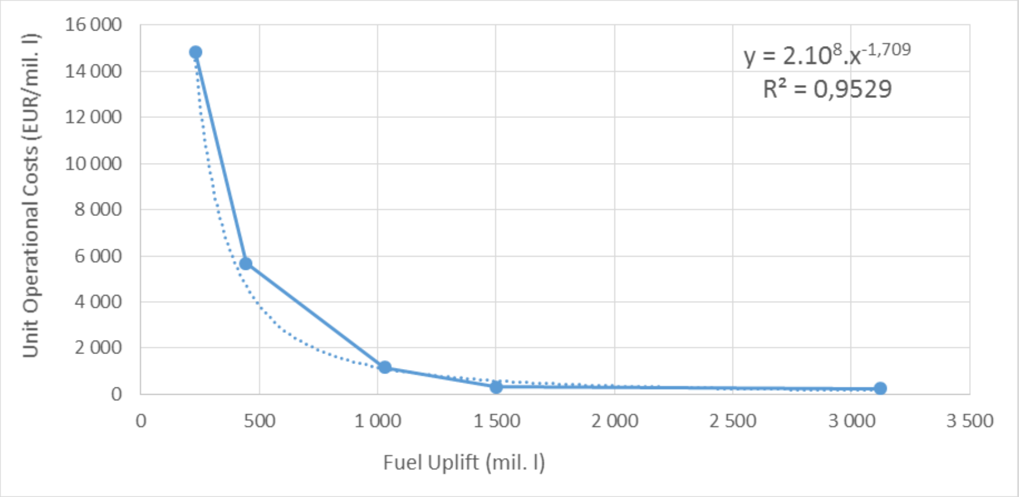
Values of Cu are shown in Table 5.

Table 5. *Hydrant System Unit Operational Costs at Selected Airports*

Airport	**Operational Costs [mil. EUR]**	**Fuel Uplift [mil. l]**	**Unit Operational Costs [EUR/mil. l]**
Airport A	3,417	230,068	**14 853,01**
Airport B	2,518	443,521	**5 677,92**
Airport C	1,200	1 029,000	**1 166,18**
Airport D	0,464	1 500,000	**309,04**
Miami	0,776	3 123,000	**248,50**

Unit operational costs have functional dependency on fuel uplift at particular airport. This dependency is shown at Figure 3.

Figure 3. *Unit Operational Costs as a Function of Fuel Uplift*



MS Excel is able to provide us with equation of trend line and its R^2 value which is 0.9529. That means the trend line copy the input values with accuracy of 95.29%. Knowing the value of annual fuel uplift, unit cost can be calculated:

$$C_u = 2 \cdot 10^8 V^{-1,709}$$

From unit costs, operational costs are calculated using following equation:

$$C_O = C_u \cdot V$$

Benefits

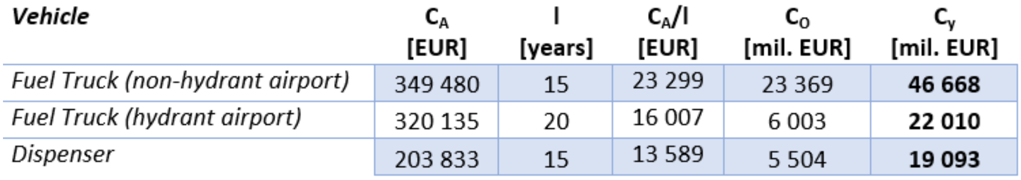
In the previous subsections, costs model related to hydrant systems was set up. For the cost-benefit analysis, benefits must be modeled as well.

There are various types of benefits related to implementation of hydrant system. First off, the total time of refueling is lower. Next, apron safety increases because of utilization of smaller and lighter dispensers which do not carry any flammable fuel. Also, environmental impacts are lower due to lower emissions. All these benefits are hard to quantify financially. Thus, only benefits associated with switching from fuel trucks to dispensers will be taken into account for the purposes of this hydrant model.

In order to do that, additional data must be collected. Beside airports operating hydrant systems, non-hydrant airports and fuelling companies were addressed with data collection questionnaire as well. Dataset includes characteristics of both fuel trucks and dispensers and provides acquisition cost, operational costs (including maintenance) and lifetime of vehicle. Data was acquired from three non-hydrant airport, four hydrant airports and one big international fuelling company operating more than 1 000 vehicles. Afterwards, mean values of all characteristics were calculated as a weighted average. Results are shown in Table 6, where:

C_A … average acquisition costs,
l … average lifetime of vehicle,
C_A/l … acquisition costs per year,
C_O … vehicle operational costs and
C_y … total vehicle costs per year.

Table 6. *Average Vehicle Costs*



Vehicle	**C_A [EUR]**	**l [years]**	**C_A/l [EUR]**	**C_O [mil. EUR]**	**C_y [mil. EUR]**
Fuel Truck (non-hydrant airport)	349 480	15	23 299	23 369	**46 668**
Fuel Truck (hydrant airport)	320 135	20	16 007	6 003	**22 010**
Dispenser	203 833	15	13 589	5 504	**19 093**

What is important to emphasis is the fact that after constructing and implementing hydrant refueling, airport will need less dispensers than fuel truck for the same extent of operation. Unlike fuel trucks, dispensers do not have to ride between truck filling station and the apron. Moreover, dispensers – as a smaller vehicles – can be parked in the vicinity of stands they are serving meanwhile big fuel trucks must be parked in remote areas due to their size. These two factors significantly influence fuel trucks' ridden distances which decreases their usable period of operation. According to discussion with experts, depending on the physical airport size, this can represent half to three quarters of total fuel truck operational period. With respect to that, number of dispensers needed at an airport after implementing the hydrant refueling will be as much as 80% of the total number of fuel trucks operated at an airport before construction of hydrant systems. E.g., if there are ten fuel trucks serving the airport at the moment, eight dispensers will be needed after hydrant system construction. However, implementation of hydrant refueling does not mean that airport can get rid of all fuel trucks. Few of them still must be present if there is a need for aircraft defueling or during the maintenance or failure of part of hydrant system. Thus, two more fuel trucks will be added to sufficient amount of dispensers for the model purposes. At Airport B, Airport C, Airport D and Airport E there are two back-up trucks as well.

As it can be seen from Table 6, fueling vehicles are divided into three categories; (1) fuel trucks serving non-hydrant airports, (2) back-up fuel trucks serving hydrant airport and (3) dispensers. Back-up fuel trucks have longer lifetime and lower operational costs because of their lower utilization.

Benefits are calculated as follows:

$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 2 \cdot 22010$$

$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020$$

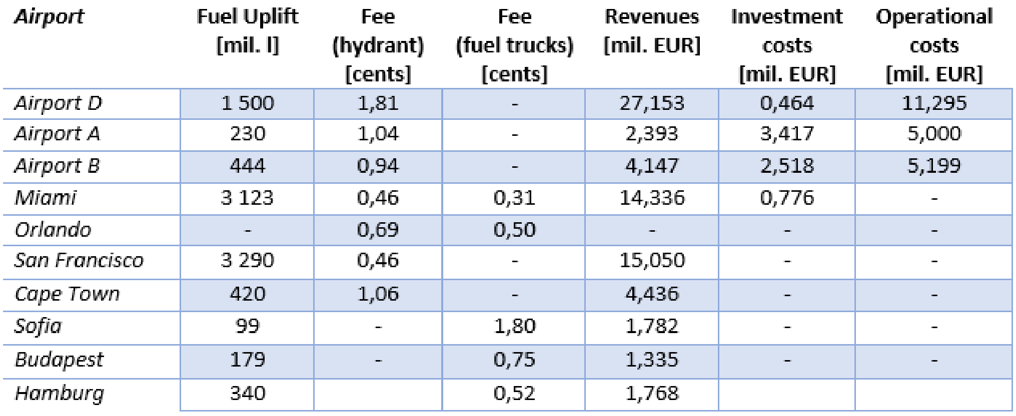
where B …annual benefits of hydrant system implementation [EUR],

n … number of fuel trucks before system implementation,

0,8n … number of dispensers after system implementation (round number).

Another benefits from hydrant system operation which can be expressed financially are revenues from fee for access to fuelling infrastructure. This fee may not be collected directly by an airport operator; airlines (final customers) usually pay to fuelling company (system users) which pay to hydrant operator (airport operator or dedicated company either dependent or independent on airport operator). Business relations can be even more complicated. Fee level for both trucks and hydrant fueling (1 cent = 0.01 EUR), fuel throughput and particular revenues at selected airports are shown in Table 7. Fee ranges from 0.31 to 1.81 cents per liter of aviation fuel.

Table 7. *Fee for Access to the Fueling Infrastructure at Selected Airports*



Airport	Fuel Uplift [mil. l]	Fee (hydrant) [cents]	Fee (fuel trucks) [cents]	Revenues [mil. EUR]	Investment costs [mil. EUR]	Operational costs [mil. EUR]
Airport D	1 500	1,81	-	27,153	0,464	11,295
Airport A	230	1,04	-	2,393	3,417	5,000
Airport B	444	0,94	-	4,147	2,518	5,199
Miami	3 123	0,46	0,31	14,336	0,776	-
Orlando	-	0,69	0,50	-	-	-
San Francisco	3 290	0,46	-	15,050	-	-
Cape Town	420	1,06	-	4,436	-	-
Sofia	99	-	1,80	1,782	-	-
Budapest	179	-	0,75	1,335	-	-
Hamburg	340		0,52	1,768		

Model Assumptions

Every airport is unique so is the design of their hydrant systems. Thus, no model can cover all the operational specifics of all airports. Therefore it is crucial to set a few assumptions which could generalize complexity of this system.

The first one is as follows. Fee for access to fueling infrastructure covers operational costs only. This is the very basic assumption. Equation is:

$$C_O = f \cdot V$$

where C_O ... annual operational costs [EUR],
f ... fee for access to fuelling infrastructure [EUR/l],
V … annual fuel uplift [l].

From the formula above, fee can be calculated as an operational costs divided by fuel throughput. This is the same as formula for unit operational costs, only difference is in units; fee is expressed in *cents per liter* meanwhile unit costs is in EUR *per mil. l*. E.g. if unit costs are as much as 2 000 EUR/mil. l, the fee must be 2 cents/l to cover the operational costs.

Thus, benefits from switching from fuel trucks to dispensers cover the initial investment costs. Assumption is described by equation:

$$C_I = p \cdot B$$

Where C_I ... investment costs [EUR],
p ... payback period [years],
B … benefits [EUR].

Final equation of costs and benefits merges two previous equations and is as follows:

$$C_I + p \cdot C_O = p \cdot B + \sum_{i=1}^{p} f_i \cdot V_i$$

Please note this equation does not take into account time value of the money, i.e. discount rate is as much as 0%. For real investment appraisal, time value of money is always considered. More on this will be discussed in the next section.

Beside two main assumptions there are more of them which complete model background. Model considers constructing hydrant system for all the stands except those for general aviation so hydrant operations could be as close as possible to 100% of total fueling operations. Next, business relations between stakeholders taking part on fueling operations are neglected. Finally, model considers such number of dispensers which is equal to 80% of fuel trucks currently operated at an airport plus two back-up fuel trucks.

Methodology

Finally, the methodology for assessing if building of hydrant system could be efficient or not is set:

Step	Inputs	Formula	Output
1.	Pipeline length m Number of hydrant pits k	$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$	Investment costs C_I
2.	Annual fuel throughput V	$C_u = 2 \cdot 10^8 V^{-1{,}709}$	Unit costs C_u
3.	Unit costs C_u Annual fuel throughput V	$C_O = C_u \cdot V$	Annual operational costs C_O
4.	Number of fuel trucks operated at an airport n	0.8n	Number of dispensers 0.8n (round number)
5.	Number of fuel trucks operated at an airport n Number of dispensers 0.8n	$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020$	Annual benefits B
6.	Annual benefits B Investment costs C_I Discount rate	Cost-benefit analysis	Payback period p
7.	Payback period p System lifetime L	$p < L$ $p \geq L$	Build up hydrant system Do not build up hydrant system

Model Application

Based on previously set methodology, any airport can roughly extrapolate its investment and operational costs and payback period for its hydrant system. However, in order to find out where is the line between efficient implementation of hydrant system in general, it is necessary to apply this model on several airports which differs in size. Selection of these airports is done based on data collection results presented in Table 1. First airport to be selected is biggest airport without hydrant system within the Table 1 – Hamburg Airport with annual fuel uplift of 340 mil. l. If possible, other airport should be separated equally among each other. Table 1 enables to choose airports separated by as much as 80 – 81 mil. l of annual fuel throughput. Thus, other airports selected for model application are Bucharest, Budapest and Sofia with 259, 179 and 99 mil. l of fuel throughput respectively. Under 99 mil. l threshold, no airport has hydrant system implemented within the statistical set.

Methodology

With respect to model application on selected airports, it is necessary to gather required inputs. Annual fuel throughput is known so number of hydrant pits and pipeline length need to be accomplished. In order to do that, proposal of main pipeline loop must be designed as well as proposal of hydrant pits number for particular stands. List of stands and design of airport site can be found in Aeronautical Information Publication (AIP), *Aerodrome Chart* and *Parking and Docking Chart* in particular. Due to requirements for maximum article length, the list of stands with particular number of hydrant pits per each stand and chart of main hydrant pipeline loop tracing are not included.

Pipeline system includes also lateral connections which links the main pipeline with hydrant pit. For this lateral connection, the length of 35 m will be considered for each hydrant pit. It is an average length for the lateral connection based on the average dimensions of aircraft stands which enables hydrant pits to be located at required location within the particular stand so the refueling of all aircraft types using the stand is ensured.

Within the cost benefit analysis (CBA), method of net present value will be used so the next input is discount rate. Selected value of discount rate is 3% according to (Cabinet Office, 2013) which recommends this rate for the investments with lifetime above 30 years.

Final input for the model is lifetime of the system which is to be compared with calculated payback period. Data collection revealed that Airport A and Airport D have systems designed to be operated for 30 years, Airport B and Airport C for 50 years and Airport E for 40 years. Thus, mean value is as much as 40 years.

CBA covers all 40 years of investment. During this period, both benefits and operational costs will be subject to change as air transport grows approximately by 5% per year (Kazda & Caves, 2007). However, fuel consumption grows slower, from 2000 to 2010 at average rate 1.67% (Hromádka, 2014). Thus, according to this rate, the growth of annual fuel uplift will be forecasted at selected airports. With the change in fuel uplift, both unit costs and operational costs will change as well. Also, number of fuelling vehicles must increase with raise in fuel uplift. Two more fuel trucks are considered for each additional 40 mil. l of fuel uplifted (Hromádka, 2014). Again, due to length of this paper, this forecast is not included.

Hamburg Airport

Fuel farm and fuel trucks filling station is located right next to the main apron. Designed length of main fuel pipeline loop is 3 385 m. Number of hydrant pits is considered to be 97 on 39 stands. Thus, sum of lateral connection is 97 multiplied by 35 m which is equal to 3 395 m. Total pipeline length is 6 780 m. Investment costs are as follows:

$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$$
$$C_I = (6780 \cdot 370 + 97 \cdot 4344) \cdot 1{,}5$$
$$C_I = 4{,}394702 mil.EUR$$

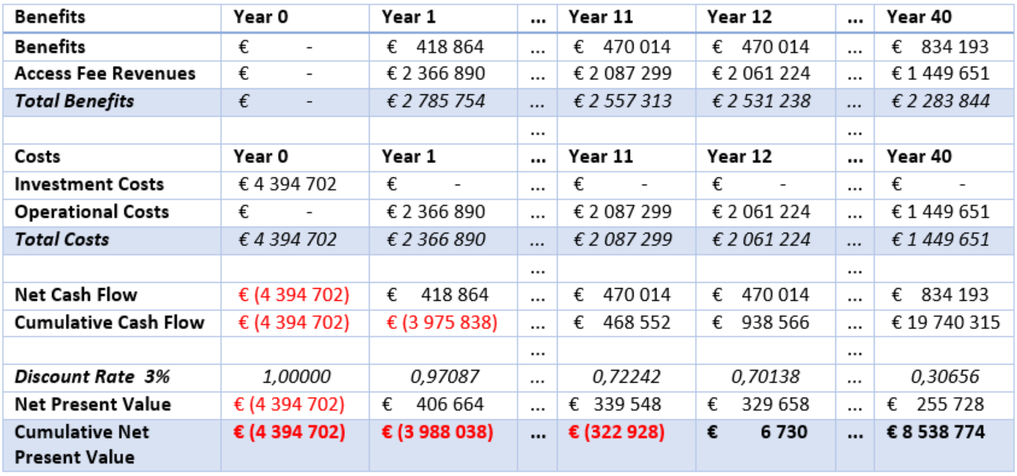
Unit costs for the volume of 340 mil. l are 7 050 mil EUR/l which means fee as high as 0.705 cents/l. Current fee at Hamburg airport is 0,52 cents/l so mild increase would be required. Operational costs are 2.396831 mil EUR per year.

As for benefits, there are 15 fuel trucks operated currently at an airport. That means 12 dispensers plus two back-up fuel trucks. Benefits are as follows:

$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020$$
$$B = 15 \cdot 44668 - 12 \cdot 19093 - 44020$$
$$B = 418864 EUR$$

Table 8 shows results of CBA for selected years. Payback is 11.98 years so CBA results are positive. Red numbers in brackets means negative values.

Table 8. *CBA of Hydrant System at Hamburg Airport*



Benefits	**Year 0**	**Year 1**	**...**	**Year 11**	**Year 12**	**...**	**Year 40**
Benefits	€ -	€ 418 864	...	€ 470 014	€ 470 014	...	€ 834 193
Access Fee Revenues	€ -	€ 2 366 890	...	€ 2 087 299	€ 2 061 224	...	€ 1 449 651
Total Benefits	*€ -*	*€ 2 785 754*	...	*€ 2 557 313*	*€ 2 531 238*	...	*€ 2 283 844*
			...			...	
Costs	**Year 0**	**Year 1**	**...**	**Year 11**	**Year 12**	**...**	**Year 40**
Investment Costs	€ 4 394 702	€ -	...	€ -	€ -	...	€ -
Operational Costs	€ -	€ 2 366 890	...	€ 2 087 299	€ 2 061 224	...	€ 1 449 651
Total Costs	*€ 4 394 702*	*€ 2 366 890*	...	*€ 2 087 299*	*€ 2 061 224*	...	*€ 1 449 651*
			...			...	
Net Cash Flow	€ (4 394 702)	€ 418 864	...	€ 470 014	€ 470 014	...	€ 834 193
Cumulative Cash Flow	€ (4 394 702)	€ (3 975 838)	...	€ 468 552	€ 938 566	...	€ 19 740 315
			...			...	
Discount Rate 3%	*1,00000*	*0,97087*	...	*0,72242*	*0,70138*	...	*0,30656*
Net Present Value	€ (4 394 702)	€ 406 664	...	€ 339 548	€ 329 658	...	€ 255 728
Cumulative Net Present Value	**€ (4 394 702)**	**€ (3 988 038)**	**...**	**€ (322 928)**	**€ 6 730**	**...**	**€ 8 538 774**

Bucharest Airport

In this case, fuel farm and fuel truck filling station is located in the remote area within the airport. Moreover, main fuel pipeline loop has to reach Apron 1 and then Apron 2. This design gives the length of main loop as much as 5 948

m. 105 hydrant pits are considered at 45 stands which means sum of lateral connections of 3 675 m. Total pipeline length is 9 623 m. Investment costs are:

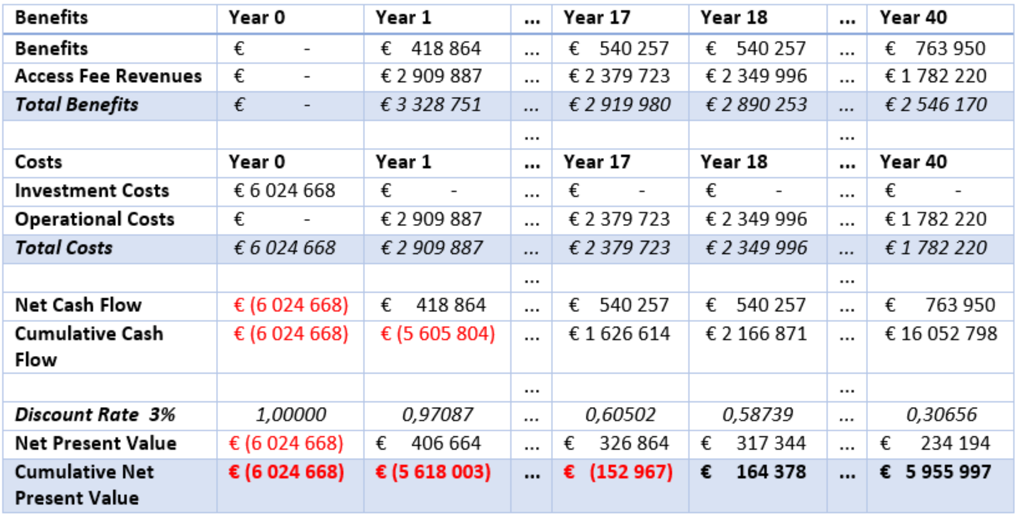
$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$$

$$C_I = (9623 \cdot 370 + 105 \cdot 4344) \cdot 1{,}5$$

$$C_I = 6{,}024668\,mil.EUR$$

Table 9 shows CBA for selected year, the result is again positive with payback period of 17.48 years.

Table 9. *CBA of Hydrant System at Bucharest Airport*



Benefits	**Year 0**	**Year 1**	**...**	**Year 17**	**Year 18**	**...**	**Year 40**
Benefits	€ -	€ 418 864	...	€ 540 257	€ 540 257	...	€ 763 950
Access Fee Revenues	€ -	€ 2 909 887	...	€ 2 379 723	€ 2 349 996	...	€ 1 782 220
Total Benefits	*€ -*	*€ 3 328 751*	...	*€ 2 919 980*	*€ 2 890 253*	...	*€ 2 546 170*
			...			...	
Costs	**Year 0**	**Year 1**	**...**	**Year 17**	**Year 18**	**...**	**Year 40**
Investment Costs	€ 6 024 668	€ -	...	€ -	€ -	...	€ -
Operational Costs	€ -	€ 2 909 887	...	€ 2 379 723	€ 2 349 996	...	€ 1 782 220
Total Costs	*€ 6 024 668*	*€ 2 909 887*	...	*€ 2 379 723*	*€ 2 349 996*	...	*€ 1 782 220*
			...			...	
Net Cash Flow	€ (6 024 668)	€ 418 864	...	€ 540 257	€ 540 257	...	€ 763 950
Cumulative Cash Flow	€ (6 024 668)	€ (5 605 804)	...	€ 1 626 614	€ 2 166 871	...	€ 16 052 798
			...			...	
Discount Rate 3%	*1,00000*	*0,97087*	...	*0,60502*	*0,58739*	...	*0,30656*
Net Present Value	€ (6 024 668)	€ 406 664	...	€ 326 864	€ 317 344	...	€ 234 194
Cumulative Net Present Value	**€ (6 024 668)**	**€ (5 618 003)**	**...**	**€ (152 967)**	**€ 164 378**	**...**	**€ 5 955 997**

As it can be seen from Table 9, operational costs are 2.946697. There are 15 truck at an airport so annual benefits in the first year will be the same as in the previous case (418 864 mil. EUR). Unit costs are 11 400 EUR/mil. l which means fee of 1.14 cents/l. Current value of the fee is not known.

Budapest Airport

Fuel farm and fuel trucks filling point are located further away from apron, in the vicinity of airport perimeter. There are two separated main loops, one connecting the fuel farms with Apron 1, the other with Apron 2, their combined length is 12 292 m. 130 hydrant pits are considered on 54 stands. Sum of lateral connections is 4 550 m which means total length of 16 842. Investment costs are equal:

$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$$

$$C_I = (16842 \cdot 370 + 130 \cdot 4344) \cdot 1{,}5$$

$$C_I = 10{,}194113\,mil.EUR$$

Operational costs are 3.9 mil. EUR per year in Year 1. Current fee is 0.75 while necessary level of fee is 2.18 cents/l which is three times higher. There are 11 fuel trucks which is equal to annual benefits:

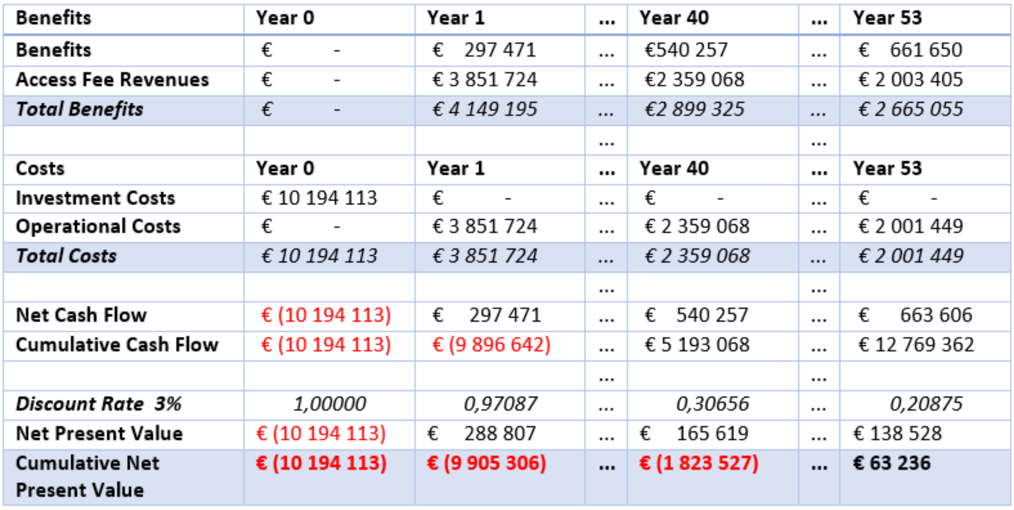
$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020$$

$$B = 11 \cdot 44668 - 9 \cdot 19093 - 44020$$

$$B = 297471 EUR$$

CBA result are negative. Results can be found in Table 10. Last column shows the year when the cumulative net present value is finally positive, this column is not part of CBA as its period is from Year 0 to Year 40. Payback would be eventually 52.54 years.

Table 10. *CBA of Hydrant System at Budapest Airport*



Benefits	**Year 0**	**Year 1**	**...**	**Year 40**	**...**	**Year 53**
Benefits	€ -	€ 297 471	...	€540 257	...	€ 661 650
Access Fee Revenues	€ -	€ 3 851 724	...	€2 359 068	...	€ 2 003 405
Total Benefits	*€ -*	*€ 4 149 195*	...	*€2 899 325*	...	*€ 2 665 055*
			...		...	
Costs	**Year 0**	**Year 1**	**...**	**Year 40**	**...**	**Year 53**
Investment Costs	€ 10 194 113	€ -	...	€ -	...	€ -
Operational Costs	€ -	€ 3 851 724	...	€ 2 359 068	...	€ 2 001 449
Total Costs	*€ 10 194 113*	*€ 3 851 724*	...	*€ 2 359 068*	...	*€ 2 001 449*
			...		...	
Net Cash Flow	€ (10 194 113)	€ 297 471	...	€ 540 257	...	€ 663 606
Cumulative Cash Flow	€ (10 194 113)	€ (9 896 642)	...	€ 5 193 068	...	€ 12 769 362
			...		...	
Discount Rate 3%	*1,00000*	*0,97087*	...	*0,30656*	...	*0,20875*
Net Present Value	€ (10 194 113)	€ 288 807	...	€ 165 619	...	€ 138 528
Cumulative Net Present Value	**€ (10 194 113)**	**€ (9 905 306)**	**...**	**€ (1 823 527)**	**...**	**€ 63 236**

Sofia Airport

This airport has fuel farms and trucks filling point located close to one of the aprons. 93 pits are considered at 41 stands, the length of main loop is 5 084 m, length of lateral connections is 3 255 m, total length is 8 339 m so investment costs are equal:

$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5$$

$$C_I = (8339 \cdot 370 + 93 \cdot 4344) \cdot 1{,}5$$

$$C_I = 5{,}234133 mil.EUR$$

Operational costs are 6.114246 mil. EUR according to this model. Required fee would be 6.18 cents/l while its present value is 1.8 cents/l. Again, the fee would have to be increased eventually by more than three times. Seven trucks means benefits of:

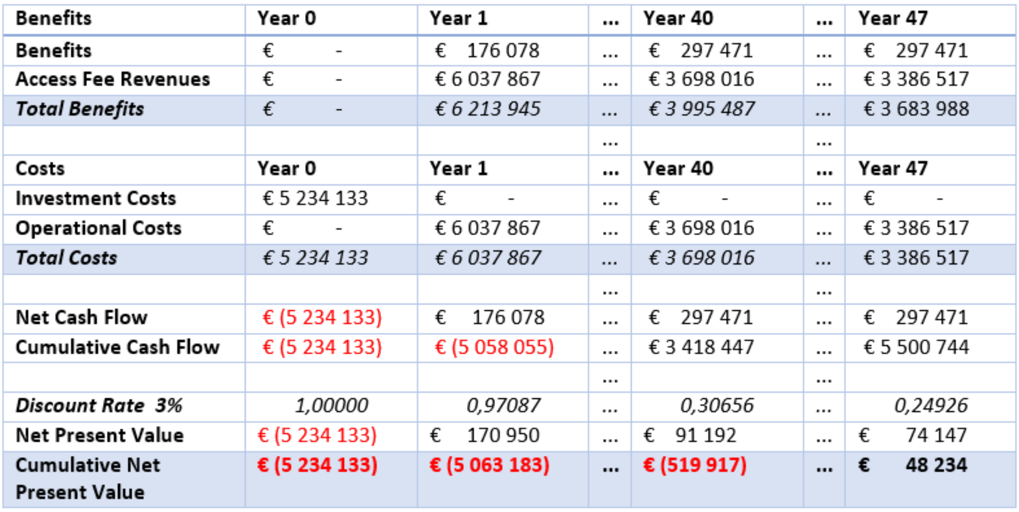
$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020$$

$$B = 7 \cdot 44668 - 6 \cdot 19093 - 44020$$

$$B = 176078 EUR$$

Table 11 shows negative results of CBA. Payback is 46.35 years. Last column is only illustrative and it is not part of CBA.

Table 11. *CBA of Hydrant System at Sofia Airport*



Benefits	**Year 0**	**Year 1**	**...**	**Year 40**	**...**	**Year 47**
Benefits	€ -	€ 176 078	...	€ 297 471	...	€ 297 471
Access Fee Revenues	€ -	€ 6 037 867	...	€ 3 698 016	...	€ 3 386 517
Total Benefits	€ -	*€ 6 213 945*	...	*€ 3 995 487*	...	€ 3 683 988
			...		...	
Costs	**Year 0**	**Year 1**	**...**	**Year 40**	**...**	**Year 47**
Investment Costs	€ 5 234 133	€ -	...	€ -	...	€ -
Operational Costs	€ -	€ 6 037 867	...	€ 3 698 016	...	€ 3 386 517
Total Costs	*€ 5 234 133*	*€ 6 037 867*	...	*€ 3 698 016*	...	€ 3 386 517
			...		...	
Net Cash Flow	€ (5 234 133)	€ 176 078	...	€ 297 471	...	€ 297 471
Cumulative Cash Flow	€ (5 234 133)	€ (5 058 055)	...	€ 3 418 447	...	€ 5 500 744
			...		...	
Discount Rate 3%	*1,00000*	*0,97087*	...	*0,30656*	...	*0,24926*
Net Present Value	€ (5 234 133)	€ 170 950	...	€ 91 192	...	€ 74 147
Cumulative Net Present Value	**€ (5 234 133)**	**€ (5 063 183)**	**...**	**€ (519 917)**	**...**	**€ 48 234**

Conclusions

As for the results of CBAs in previous section, it can be concluded that volume from which it could be efficient to implement hydrant refueling is between 179 and 259 mil. l. However, another factor that must be taken into account is the level of access fee. Its present level is up to 1.81 cents/l which is able to cover operational costs for the fuel uplift of approximately 200 mil. l per year. With decrease in fuel uplift, the fee would raise exponentially, e.g. for uplift of 100 mil. l the required fee level is as much as 6.1 cents/l. High levels of fee may not be acceptable for final customers – airlines.

Based on results of this research, construction of hydrant system may be efficient with annual fuel throughput of 200 mil. l and more.

However, implementation of hydrant fueling is not always about economic benefits. There are many airports which operate hydrant systems even below 200 mil. l threshold. Usually, this system is implemented when the new terminal is build or under reconstruction or when the apron pavement is refurbished. Moreover, many airports are implementing this system even if the CBA is negative, the main reasons are environmental constrains, safety improvements or requirement on aircraft turnaround time. Thus, decision must be made with respect to local conditions as every airport is unique entity.

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