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HYDRANT REFUELING SYSTEM AS AN OPTIMISATION OF AIRCRAFT REFUELLING

Summary. At large international airports, aircraft can be refuelled either by fuel trucks or using dedicated underground pipeline systems. The latter, hydrant refuelling, is considered to be an optimal fuelling method as it increases safety, shortens the aircraft turnaround time and cuts the overall costs. However, at smaller airports, implementation of this system can lead to high investment costs. Thus, the paper discusses the airport size from which this system may be efficient to implement. Various definitions of term “airport size” are assessed. Based on data collection, the hydrant system model is created within the paper. As a result, methodology for assessing the suitability of hydrant system implementation is set. This methodology can be used at every airport using three simple inputs.

SISTEMA DE ABASTECIMIENTO DE RIEGO COMO OPTIMIZACIÓN DE LAS GASOLINERAS DE AVIONES

Resumen. En los grandes aeropuertos internacionales, las aeronaves se puede repostar, ya sea por camiones de combustible o el uso de sistemas de tuberías subterráneas dedicadas. Este último, reabastecimiento de combustible boca de riego, se considera que es un método óptimo de abastecimiento de combustible, ya que aumenta la seguridad, acorta el tiempo de respuesta de aeronaves y reduce los costes globales. Sin embargo, en los aeropuertos más pequeños, la implementación de este sistema puede conducir a los altos costos de inversión. Así, el artículo discute el tamaño aeropuerto desde el que este sistema puede ser eficiente de implementar. Varias definiciones del término "tamaño de aeropuerto" son evaluados. Sobre la base de la recopilación de datos, el modelo del sistema hidrante se crea dentro del papel. Como resultado, la metodología para la evaluación de la idoneidad de la implementación del sistema hidrante está establecido. Esta metodología se puede utilizar en todos los aeropuertos utilizando tres entradas simples.

1. 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 Fig. 1. BAFS means Building of Aboveground Fuel Storage, ESD stands for Emergency Shut Down.

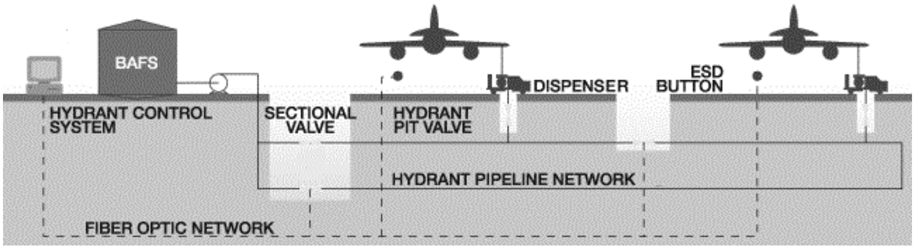

Fig. 1. Airport hydrant system scheme
Img. 1. Aeropuerto esquema de sistema de hidrantes

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 Fig. 2.

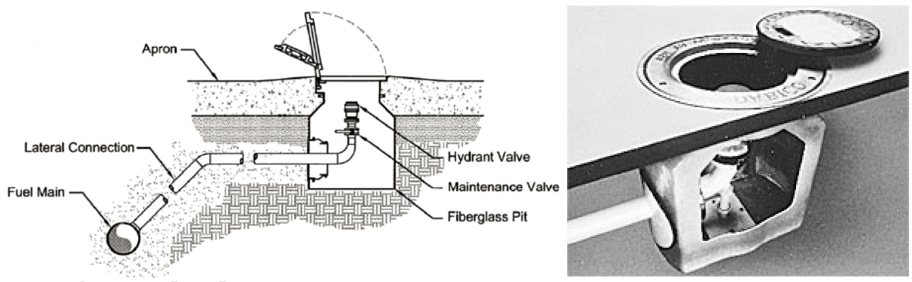

Fig. 2. Hydrant pit [6, 1]
Img. 2. Pit hidrante [6, 1]

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 [5].

2. DEFINITION OF AIRPORT SIZE

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 the 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, [8] 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 [2], 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.

3. CURRENT STATUS AND INITIAL RESEARCH

After defining the airport size, the next step is to examine what the current status is. That means to find out which airports (in terms of their size) uses hydrant systems.

3.1. 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 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 exists at all selected airports with fuel throughput higher than 420 mil. l. On the 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.

3.2. 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 [1]. 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 [6]. 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:

$$q = S \cdot v \tag{1}$$

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

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

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

$$S = \pi \cdot r^2 \tag{2}$$

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:

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

$$q = 0.0328 \quad m^3 / s \tag{3}$$

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:

$$V = q \cdot t \tag{4}$$

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:

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

$$V = 689587.2 \quad m^3 \tag{5}$$

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

4. DATA COLLECTION AND MODEL OF HYDRANT SYSTEM

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.

4.1. 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.

No statistical method can be used to typify these type 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 [7]. 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.

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:

$$C_I = (m \cdot 370 + k \cdot 4344) \cdot 1{,}5 \tag{6}$$

where: C_I - total investment costs [EUR], m - total length of pipeline [m], k - number of hydrant pits.

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**

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**

4.2. Operational Costs

Results of data collection are shown in Table 4. These costs includes 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:

$$C_u = \frac{C_O}{V} \tag{7}$$

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

Values of C_u 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 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 Fig. 3.

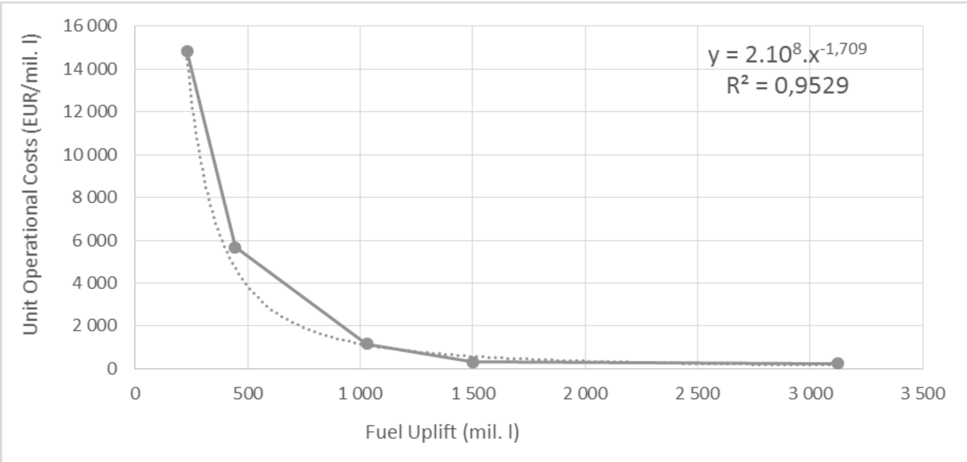

Fig. 3. Unit operational costs as a function of fuel uplift
Img. 3. Los costes operativos de la unidad en función de abastecimiento de combustible

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:

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

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

$$C_O = C_u \cdot V \tag{9}$$

4.3. 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**
Dispener	203 833	15	13 589	5 504	**19 093**

What is important to emphasise is the fact that after constructing and implementing hydrant refuelling, 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 refuelling 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 refuelling 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 defuelling 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, fuelling 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:

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

$$B = n \cdot 44668 - 0{,}8n \cdot 19093 - 44020 \tag{10}$$

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 a 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 fuelling (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 level for trucks, hydrant fuelling, fuel throughput and particular revenues at selected airports

Airport	**Fuel uplift [mil. l]**	**Fee (hydrant) [cent/l]**	**Fee (fuel trucks) [cent/l]**	**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		

4.4. Model Assumption

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 fuelling infrastructure covers operational costs only. This is the very basic assumption. Equation is:

$$C_O = f \cdot V \tag{11}$$

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:

$$C_I = p \cdot B \tag{12}$$

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:

$$C_I + p \cdot C_O = p \cdot B + \sum_{i=1}^{p} f_i \cdot V_i \tag{13}$$

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.

Beside two main assumption there are more of them which complete the 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 fuelling operations. Next, business relation between stakeholders taking part on fuelling 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.

4.5. 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

5. CONCLUSION

Hydrant system model presented in this paper can be used at any airport where the fuel is delivered by fuel trucks only. First off, the airport needs to propose pipeline system tracing. This will provide total length of pipelines as the first input for the model. Next, airport has to consider how many hydrant pits are to be built at each stand which is to be covered by hydrant system. Number of pits is the second model input. The final input is annual fuel throughput. This variable is known by every airport operator. Finally, airport (or investor) has to choose the discount rate for the purposes of cost-benefit analysis. Results of cost-benefit analysis is crucial as it justifies the implementation of hydrant system. However, even if the result are negative, airport can still decide to build this system if it brings advantages which are difficult to be expressed numerically. This may include significant increase in apron safety, lowering the environmental footprint or shortening the aircraft turnaround time.

The bottom line is ownership of the airport. Airports are often owned by private stakeholders who invests their capital and expect the return on their investment. With respect to this, positive output from proposed methodology can justified this kind of investment from the point of view of private stakeholders.

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