New Approach for Assistance of Airline Operation Controllers Based on Passenger Perception and Stakeholder Business Prioritisation Policy

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A mathematical approach for assisting air transport operation controllers based on the construction of a function evaluating decision options is presented. The function depends on stakeholder prioritization policy referring to passenger priority and ticket revenue per flight, and segmentation of passengers and their distribution according to cabin-class, and passenger perception of service quality considering high-valuable passengers. If dynamic data are available, then the method produces a dynamic recommendation. The proposed method is applied to the decision making process of carrier operator controllers facing flight delays due to waiting for arriving-connecting high-valuable passengers.

Keywords: Decision-making, Decision Support, Situation Awareness, Evaluation of Options, Mathematical Representation of Options

Nomenclature

ATS	Air Transport System
DSS	Decision Support System
PPLoS	Passenger's Perceived Level of Satisfaction
VIP, 1C, BUS	Numbers of VIP, first class passengers, and business passengers and frequent flyers

Subscript

a, c, o	Arriving, connecting, and originating passengers

I. Introduction

Stakeholders involved in the ATS are more and more required to deal with resource and time efficiency. On the other hand, diverse disturbances occurring, for example during all-day airline operations, need to be dealt with sometimes only within few minutes as emphasized in Bruce.[1] Hereby, an amount of flight operational information, such as payment, reservation of air space, and passenger identification and flight-status, has been stored in warehouse to be available throughout the IT-system. By displaying the relevant data as quickly as possible, substantial support can be given to the operation controllers.[2] All resource requirements as well as constraints that can occur within the operating network must also be taken into consideration when making an operational decision. This complexity causes some decisions to be more intuitively (so called, by rule of thumb) than objectively, nor implementing or reflecting the overall decision drivers and constraints. A tool for evaluating the underlying data and displaying a recommendation in a human friendly way would be a benefit.

In this paper a method for combining expected passenger perception of a service quality delivered by the carrier, number of affected passengers, expected costs, and stakeholder prioritization policy is presented. In the case of two

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options, it produces a function for computing a value for a given operational situation. The curve defined by vanishing of the function separates recommending one option from recommending the other option with respect to the specific problem.

The method of constructing this function is robust and flexible enough to cover a wide variety of decision application fields. The approach can be included in a computer program for supporting decision makers while reducing complexity of the decision making process including most of the relevant factors. It can be adjusted by implementing parameters for reflecting the stakeholders prioritization policy.

The method described was applied to the operation situation of an airline in which its operation controller faces making a delay of an outbound flight in order to wait for a delayed inbound-flight. Although detailed data such as passenger cabin-class, flight route with required connections, the whole passenger itinerary, and the ticket price purchased are available in the flight Charta view, the service quality (SQ)-attributes as well as the expected satisfaction level of the passengers involved with the SQ delivered can be difficult for human to incorporate at one glance for implementing into making the decision. The approach has the property: if the value of the function for a specific situation is negative, the method recommends not waiting and vice versa complying with the given carriers prioritization policy.

Unlike the free market of most other businesses and industries, the ATS imposes numerous limitations on airlines strategic planning and daily operations execution, constraining them by the limited capacity of airports and/or Air Traffic Flow Management (ATFM) restrictions and requirements, as well as by the bilateral air transport service agreements between countries.[3]

While by far the most work on operational recovery problems has been reported on the aircraft resource, passengers are generally given a low priority in the disruption management literature. That is because the aircraft has mostly been seen as the easiest resource due to lowest complexity in rules, whereby crews can be repositioned fairly easy often having always available standby crews.[2] Although customer service coordinators are consulted, passenger disruptions rarely drive operational decision-making, while studies show that arriving on-time is the service characteristic most valued by passengers.[4] Therefore, providing it to travelers is important in striving for attracting high-value passengers who are sensitive to on-time reliability, as well increasing passenger loyalty and their retention rate.

Kano's Model of quality (1984) introduced the basis for establishing the importance of product categorization and service quality attributes with respect to the customer's satisfaction. The model employs the extend, to which a service attribute can satisfy the customer's requirements and/or needs. In the original five-level questionnaire categorization, Kano Model distinguishes five types of product/service requirements that differently influence customer satisfaction.[14]

A survey to determine the passengers' perception of low cost carriers and full service carriers was conducted by O'Connell *et al*.[15] Whereas in this study the emphasis was on the service of the carrier, we consider the perception of an all-day situation for any airline, which is not specific to the type of the affected carrier.

DSSs are widely used within the ATS.[5] Even for airline operations there are early examples for employing computer systems to assist operators. Gershkoff describes a DSS for the crew pairing problem of an airline on basis of Pan American.[6,7] Dijkstra *et al*. considers the aircraft maintenance problem from the point of view of personnel planning.[8,9] Flight crew recovery due to unexpected disruptions was dealt with by Yu *et al*. and Abdelghany *et al*.[10,11] A DSS for real-time planning and re-assignment of aircrafts, crew, and passengers was proposed by Mathaisel.[12] More recently, Babić *et al*. considered a heuristic approach to the airline schedule problem in the case of disturbances.[13] The approach employs an objective function for evaluating a list of feasible solutions.

II. Theory

In this section we describe the groundwork for constructing the function. Let $U \subset \mathbb{R}^n$ be an open set and $f : U \to \mathbb{R}$ be a real valued and differentiable function. f is supposed to divide the two options in the following way.

$$x \in \mathbb{R}^n, \quad f(x) \begin{cases} > 0 & \text{recommending option one} \\ < 0 & \text{recommending option two} \end{cases} . \tag{1}$$

The zero set $f^{-1}(0) = \{x \in \mathbb{R}^n | f(x) = 0\}$ of the function f divides the recommendation of the two options. We require the zero set to be a hypersurface in $\mathbb{R}^n$, which leads to the condition of the vector $\left(\partial_j f(x)\right)_{1 \le j \le n}$ of derivatives for all $x \in f^{-1}(0)$ to be non-vanishing.

EXAMPLE (UNIT SPHERE) Suppose $f : \mathbb{R}^3 \to \mathbb{R}$ is defined by

$$f(x_1, x_2, x_3) = x_1^2 + x_2^2 + x_3^2 - 1 , \tag{2}$$

then the zero set is given by the unit sphere in $\mathbb{R}^3$. The derivatives of f are given by $\partial_j f(x) = 2x_j$ which can not be zero for $1 \leq j \leq 3$ if $f(x) = 0$. Thus, the zero set is a smooth hypersurface.

EXAMPLE Suppose we are faced with the decision to buy a TV and we come to a decision between two models. Since we have to act in a cost-based way, we define the function by

$$f_{\text{buy TV}}\big(\text{TV } 1, \text{TV } 2\big) = \text{price of TV } 1 - \text{price of TV } 2\,. \tag{3}$$

If $f_{\text{buy TV}}\big(\text{TV } 1, \text{TV } 2\big) > 0$ for two specific TVs, then buy TV 2 and vice versa. The zero set of this function consists of all TVs having the same price. Of course, this is a rather simple example neglecting features of the TVs considered. The function is defined on a discrete set without having a “natural” extension to the real numbers. Thus, in this case the zero set cannot form a smooth hypersurface.

If there are more criteria for choosing an option, the functions can be combined with prescribed weights. Assume we have two criteria with corresponding functions f and g satisfying (1) for the two criteria. Let $\alpha_1, \alpha_2 > 0$ denote the weights to be used. Since f and g can have different scaling behaviour, it is not sufficient to consider the weighted sum. We have to normalize the functions first and define

$$h(x,y) = \alpha_1 \frac{f(x)}{\max_x |f(x)|} + \alpha_2 \frac{g(y)}{\max_y |g(y)|}\,. \tag{4}$$

This definition is only possible, if the maxima of the functions are both non-vanishing. The function h then divides the two options for the two criteria. The sum and the positivity of the weights provide the vector of derivatives of h to be non-vanishing. The function h has the property, that if $f(x) = 0$ or $g(y) = 0$ then the value of $h(x,y)$ does only depend on the other criteria. If both functions are vanishing, then so does h. Operationally, this behaviour is what we expect. If the first criterion leads to an indifferent result, then the behaviour of the combination should depend solely on the other and vice versa. If both criteria lead to an indifferent result, then so should the combination.

EXAMPLE Let us return to the example of buying a TV. Suppose we are not only interested in the lowest price of a TV, but also in the size. Let f and g be defined by

$$f\big(\text{TV } 1, \text{TV } 2\big) = \text{price of TV } 1 - \text{price of TV } 2 \quad \text{and} \quad g\big(\text{TV } 1, \text{TV } 2\big) = \text{size of TV } 1 - \text{size of TV } 2\,. \tag{5}$$

As in the above example TV 2 is preferred if $f > 0$ and we want to have a big TV, so TV 1 is preferred if $g > 0$. To combine the two functions, we have to consider the right sign for the option preferred. Hence, the function h including weights α_1, α_2 is defined by

$$h\big(\text{TV } 1, \text{TV } 2\big) = \alpha_1 \frac{\text{price of TV } 1 - \text{price of TV } 2}{\max\big(\text{price of TV } 1, \text{price of TV } 2\big)} + \alpha_2 \frac{\text{size of TV } 2 - \text{size of TV } 1}{\max\big(\text{size of TV } 1, \text{size of TV } 2\big)}\,. \tag{6}$$

Here, it is clear that the weighting sum does not suffice, since we would end up with comparing prices and sizes of TVs.

III. Application

In this section the method described in Sec. II is applied to a situation of an airline operator faced within all-day activity. When it is about to make the choice between a monetary benefit and the retention of the reputation of a reliable service provider, the use of the approach aims at affording rather objective instead of still occurring intuitive decision making of operation controllers when dealing with such kind of disruptions.

Particularly the influence of delayed connecting high-valuable passengers (VIPs, first-class, business and frequent flyers) on making decisions on onward delays in the airlines striving to deliver a better service quality (SQ) to these passengers, the passenger segmentation per flight and the associated consequences, in terms of the Level of Service (LOS) performed by the carrier and the one perceived by the passengers, have been taken into account.

In an all-day operations-execution situation, the controllers are required to decide on to wait or not to wait for some times just few of high-valuable passengers who are late on arriving of an in-bound (or in-coming) flight for their following connecting flight to their destination-airport(s). This scenario is illustrated in Fig. 1 showing a simplified network example of two successive flights where the flight F2 shall wait for the flight F1 to arrive, which carries the connecting passengers as well as high-valuable amongst.

Figure 1. Considered network example representing two successive flights: F1 (A to B), F2 (B to C)

The in-coming flight F1 departed from the airport A is late on arriving at the airport B, carrying *arriving* - among them also arriving-*connecting* - passengers. The aircraft of the out-coming flight F2 is waiting for the departure to the destination-airport C, carrying *originating* passengers. In the sequel we use the term *arriving* only for those passengers, who are not arriving-connecting ones.

III.A. Quantifying passenger perception sensitivity

To quantify the passengers perception of the level of SQ delivered by the air carrier, we introduce the Passenger's Perceived Level of Satisfaction (PPLoS) taking values in the interval $[0,1]$. A value of 0 corresponds to the perceived satisfaction level named very dissatisfied and a value of 1 corresponds to the satisfaction level named very satisfied.

Tab. 1 shows the perceived satisfaction levels of the passengers according to their flight-status.

Table 1. Passenger perception sensitivity based on decision options

Passenger flight-status	Waiting	Not waiting
originating	dissatisfied	satisfied
connecting	satisfied	very dissatisfied
arriving	neutral	neutral

On basis of Tab. 1 the overall PPLoS (considered for both flights) can be calculated with respect to both decision options. If the passengers are separated in the following manner

$$\begin{aligned} m_1 &\quad \text{number of arriving passengers,} \\ m_2 &\quad \text{number of connecting passengers,} \\ n &\quad \text{number of originating passengers,} \end{aligned}$$

then we derive the overall PPLoS as

$$\tfrac{1}{m_1+m_2+n}\left(0.5m_1+0.75m_2+0.5n\right)$$

in the case of "waiting" and

$$\tfrac{1}{m_1+m_2+n}\left(0.5m_1+0\cdot m_2+0.75n\right)$$

in the case of "not waiting".

As in the case of the Level of Service with respect to the airline the difference of quantities regarding delaying and departing flight will be considered. In the following we only consider high-valuable passengers (VIP, first class, and business and frequent flyers). The passengers are sorted by a matrix P defined by

$$\mathrm{P} = \begin{pmatrix} \mathrm{VIP_a} & \mathrm{VIP_c} & \mathrm{VIP_o} \\ \mathrm{1C_a} & \mathrm{1C_c} & \mathrm{1C_o} \\ \mathrm{BUS_a} & \mathrm{BUS_c} & \mathrm{BUS_o} \end{pmatrix}.$$

By using the 1-norm we derive that $|P|_1 = m_1 + m_2 + n$. The vector of PPLoS with respect to the different passenger classes can be expressed by

$$\begin{aligned} \text{waiting} &\quad \tfrac{1}{|P|_1} P v_{\text{waiting}} \\ \text{not waiting} &\quad \tfrac{1}{|P|_1} P v_{\text{not waiting}}\,, \end{aligned}$$

where the vectors v_{waiting} and $v_{\text{not waiting}}$ are defined according to Table 1. We consider the difference of the options "waiting" and "not waiting". The vector of PPLoS with respect to VIPs, first class, and business passengers is given by

$$\frac{1}{|P|_1} P\left(v_{\text{waiting}} - v_{\text{not waiting}}\right).$$

The components of this vector attain values in the interval $[-1, 1]$.

IV. Calculation/Results

In this section we describe the settings used for the calculation and the results obtained. We use model data for the ticket prices based on recommendation given by IATA and Doganis.[16]

IATA recommends to take the ratio of fares for first cabin class passengers and business and frequent flyers to be 1.45, whereas Doganis recommends the ratio 1.76. We use for our calculation higher ratios to reflect the effort of the airlines to bind high-valuable passengers. We use the importance ratio 3.5 between VIP and first class passengers, and 2 between first class passengers and business passengers and frequent flyers. Though, neither these values nor ticket prices taken in this paper represent real world data; their aim is to show, how these parameters impact the outcome of the calculations.

In our calculations we consider two airlines with different prioritization policies. One airline puts more emphasis on the PPLoS and the other puts more weight on operating profitability. We use the setting that the first airline emphasize 80% PPLoS and 20% operating profitability and the second airline emphasize 10% PPLoS and 90% operating profitability. In the following simplified examples are shown, where each value in Tabs. 2 and 3 can be changed to encounter another setting and corresponding function value.

We show function values for different cabin classes of arriving-connecting passengers. These passengers are considered, since we obtain from Tab. 1 that these passengers have the highest impact on the PPLoS. Thus, we expect the difference of the function value for the two airlines increases for increasing number of passengers.

IV.A. Scenario I

Table 2. Passenger flight-status and ticket prices

Passenger flight-status	VIP	1C	BUS
originating	2	5	5
connecting	3	2	20
arriving	1	1	5
inbound ticket price	2900	1450	1000
outbound ticket price	8700	4350	3000

For the airline prioritizing the PPLoS the function value is 0.018 and thus, recommending waiting. The function value for the airline emphasizing operating profitability is -0.036 recommending not waiting.

The setting of Tab. 2 is used throughout the calculation and only the cabin class explicitly stated is altered according to the values shown on the axis. The blue graph in each figure shows function values for the first airline emphasizing the PPLoS, and the green graph shows function values for the airline prioritizing operating profitability. The figures show the switching behaviour of the recommendation with increasing number of passengers of the respective cabin class. Since we consider increasing number of passengers on the inbound flight, the recommendation starts with "not waiting" (function value < 0).

Fig. 2 shows the results for VIP passengers who are assumed to be most-valued. The recommendation for the airline emphasizing the PPLoS lies between 2 and 3 VIP passengers and the recommendation for the airline prioritizing operating profitability lies between 7 and 8 VIP passengers.

The switching points for first class passengers are more spread between the two airlines. Whereas the difference for VIP was 5 passengers, the difference for first class passengers as can be seen in Fig. 3 is 10 passengers. The switching for the airline prioritizing the PPLoS between 0 and 1 first class passengers comes from the fact that we used the setting of Tab. 2, where already 3 arriving-connecting VIP passengers are present.

In the case of business passengers and frequent flyers (cf. Fig. 4), more passengers are needed to let the recommendation behaviour switch. The function value for the airline emphasizing the PPLoS changes sign between 17 and

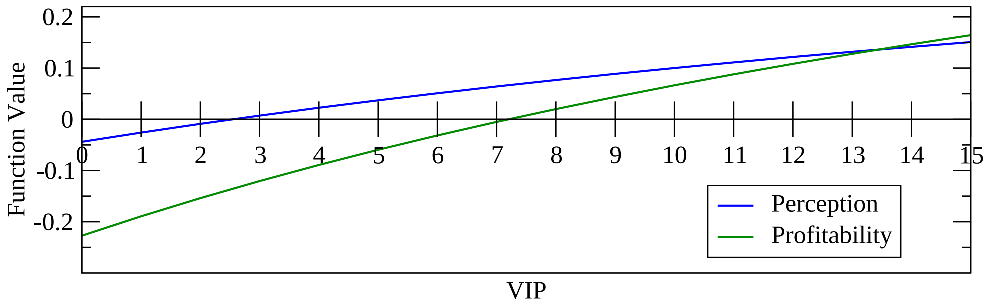

Figure 2. Recommendation function values for VIP passengers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario I

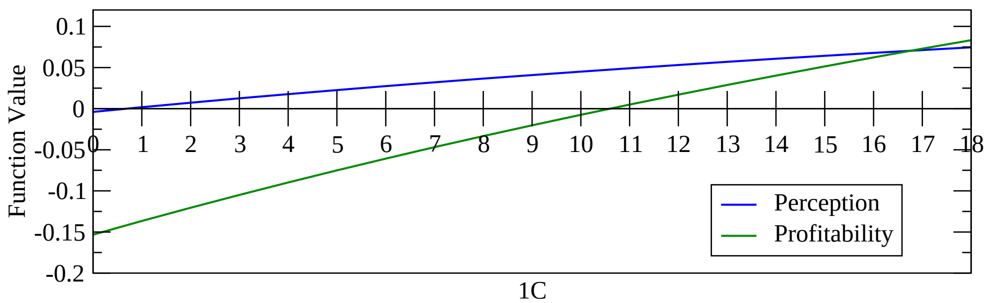

Figure 3. Recommendation function values for first class passengers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario I

18 passengers and it changes sign for the other airline between 32 and 33 passengers. All figures show that for the first airline prioritizing the PPLoS less passengers of the respective cabin class are needed to switch the recommendation. This property reflects the different policies of the airlines. The setting shown in Tab. 2 assumes the tickets of the inbound flight to be one third as high as the ones of the outbound flight. Therefore, more passengers are needed for the airline emphasizing operating profitability to receive the recommendation to wait for the inbound flight.

IV.B. Scenario II

In this scenario we consider a setting comprising of a stand-off situation with respect to ticket prices. The ticket prices of the inbound flight are assumed to be one third of the ticket prices of the outbound flight, and there are 3 times more passengers on the inbound flight. This setting leads to positive function values for both airlines . The function value for the airline prioritizing the PPLoS is slightly greater than the function for the airline emphasizing operating profitability (0.0306 vs. 0.0038). Therefore, in both cases the method recommends “waiting”. This comes from the fact, that from the point of view of operating profitability we have equilibrium and the second airline has a non-zero emphasis on the PPLoS.

In Fig. 5 it can be seen that the difference of the zero-value for both functions is smaller than in Scenario I (1 vs. 5). Ticket price equilibrium is reached, if 2 VIP passengers are present, therefore the switching is slightly before this equilibrium.

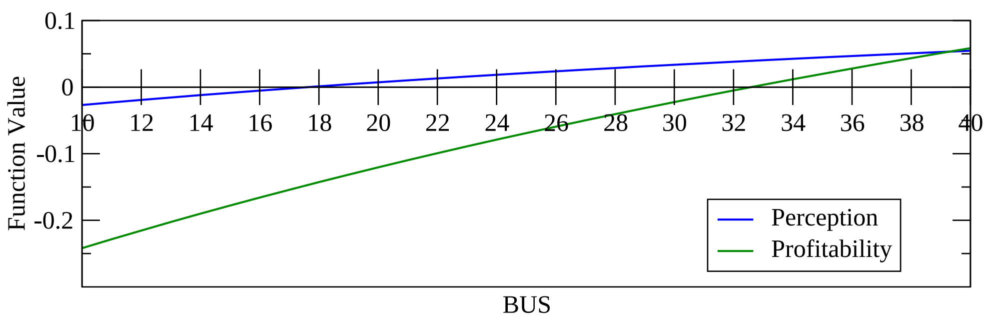

Figure 4. Recommendation function values for business passengers and frequent flyers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario I

Table 3. Passenger flight-status and ticket prices

Passenger flight-status	VIP	1C	BUS
originating	1	2	5
connecting	2	4	5
arriving	1	2	10
inbound ticket price	2900	1450	1000
outbound ticket price	8700	4350	3000

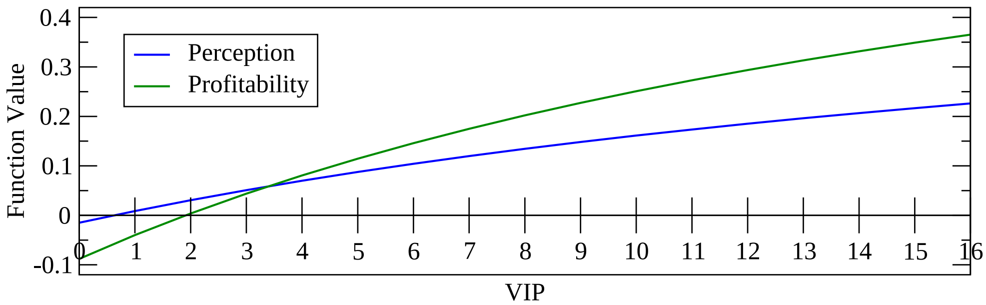

Figure 5. Recommendation function values for VIP passengers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario II

In Fig. 7 the function value for the airline prioritizing the PPLoS is positive for 0 business passengers and frequent flyers. The recommendation is, thus, "waiting" for any number considering the values of Scenario II. However, the recommendation for the airline emphasizing operating profitability switches at a higher number of business passengers and frequent flyers (between 4 and 5 passengers).

V. Conclusions

Decision Support Systems are widely used in the ATS. They assist operators of airports, airlines, etc. throughout all-day operations. We developed a mathematical approach for evaluating decisions with two options. The approach consists of the construction of a real-valued function. If the function attains negative values, one option is recommended, otherwise the other option is recommended. The condition for constructing such a function ensures the divisioning hypersurface $f^{-1}(0)$ to be regular.

We applied the approach to the case of an airline operator faced with the decision, whether to delay the outbound flight in order to wait for delayed inbound high-valuable connecting passengers. The approach incorporates parameters as numbers of VIP, first class passengers, and business passengers and frequent flyers, ticket revenue, the passengers' perception of the service delivered by the carrier on basis of the passenger's flight status, and the importance of operating profitability. We show that different sets of parameters leading to different recommendations by varying the importance of the passenger cabin classes over operating profitability. The passenger satisfaction perception sensitivity is determined by introducing the notion of a Passengers Perceived Level of Satisfaction (PPLoS) enhancing Kano's model of quality. The notion enables us to determine the PPLoS according to both options, which is included in the

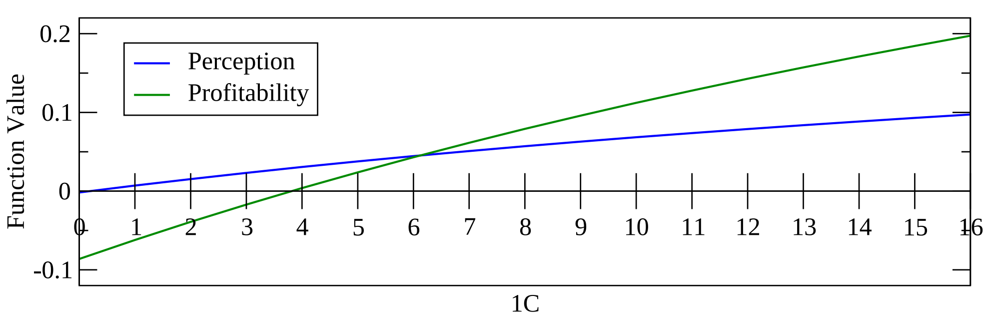

Figure 6. Recommendation function values for first class passengers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario II

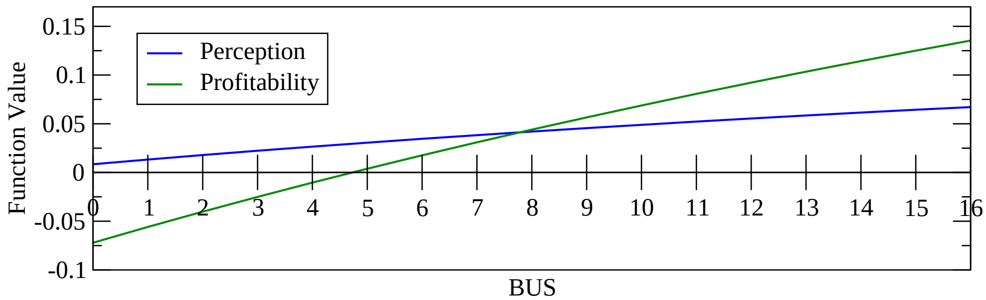

Figure 7. Recommendation function values for business passengers and frequent flyers and airlines prioritizing the PPLoS or operating profitability calculated with the setting of Scenario II

method.

We present graphs of the function applied to a range of passenger numbers for high-valuable arriving-connecting passengers. The graphs show the airline prioritization policy by a shift of the switching of the recommendation from "not waiting" to "waiting". Since business passengers and frequent flyers have the lowest priority for the airlines, more passengers are needed for the recommendation to switch.

The approach is not limited to a fixed point in time. If dynamic data are available, the function and therefore the recommendation becomes dynamic. Hence, a question such as "At which point in time switches the recommendation?" could be answered by using the proposed method. Application of economic optimization-models or purposeful cost-models would enable the proposed method to give more optimal recommendations.

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