Identification of a Consensus in a Multicriteria Decision Process involving several Decision-Makers

Trade-off between global benefits and local consensus for multi-hub airlines operations

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***Abstract*—Despite the continuing Covid crisis, Air Traffic Management (ATM) in Europe faced again during summer 2021 capacity constraints. Multiple airlines are affected by delays and requests for cancellations to help the ATM stakeholders managing together the major disruptions. In such a context, each airline is trying to optimise its own operations to reduce the impact. However, many airlines are belonging to a same group, and putting their resources together to face the disruption with flexibility could greatly improve their operations and propose better travel solutions to the final customers of European ATM: the passengers. In this article, we suppose that a group of airlines optimise together their operations to reduce the disruption impact and we focus on proposing an approach involving each participant in the final decision to identify a compromise among optimal solutions for the group. Based on social vote theories, a two-step approach is suggested to enable the group reaching a consensus among the proposed optimal solutions while ensuring participants acceptance of the chosen solution.**

Keywords-component; multicriteria; multi decision-makers; compromise; social voting theories;

I. INTRODUCTION

Congestion is one of the major bottleneck of the European ATM, and was still observable despite the COVID-19 crisis: summer 2021 was full of challenging operational days due to numerous convective weather events and staff shortages across Europe, resulting in ATFM regulations and delays. Coordination between all ATM stakeholders remains a crucial element to leverage the use of the available capacity, as congested operations is an inherent problem of ATM.

In a group decision, in which several alternatives are considered, multiple elements are necessary to identify the best choice. Whether this is to find the best mitigation measures for a congested airspace or the best flight candidates to be cancelled or delayed due to airport capacity reduction, many aspects and consequences must be assessed prior to the decision. In an operational and dynamic environment, it is mandatory to enable quick and trustable decisions. Multi-criteria Decision Making (MCDM) is a branch of operational research which aims at helping the decision making when several criteria are considered in the choice, either qualitative or quantitative, and possibly conflictual one with another [1]. Thanks to different methods, complex choices can be assessed efficiently. Nowadays, the Air Navigation Service Providers (ANSP) decide with the principal mitigation measure being the delay of flights through departure slots to grant safety level. Coordination is still limited within ATM and within airlines, due to the high complexity and dynamicity of the European air traffic.

In a group decision, not only the multiplicity and complexity of criteria is challenging, but also reaching a compromise, accepted by all decision-makers. In general, some stakeholders will be more affected in some solutions than other ones, and a trade-off as well as an acceptance by all must be reached before implementing the solution. The goal of this paper is to present a new approach to integrate all relevant stakeholders in the decision process and reach a consensus for the group in a short time. This paper is organised as follows: section II explains the context in which we are conducting our research, while section III provides a brief literature review of the MCDM methods. Section IV aims at proposing a two-stage method for identifying a consensus between all solutions in spite of the potential conflicts of interests between some decision-makers, which is illustrated with a simple case study in section V. The last section, VI, will conclude with a discussion about the appropriateness of our approach. Due to confidentiality reason and the need to keep this article easy to read, a full and real operational use-case cannot be developed and discussed.

II. CONTEXT

A. *Multi-Stakeholders Decision within ATM*

Air Traffic management (ATM) is not a standalone environment. All stakeholders must coordinate one with each other to enable safe and smooth flights to the passengers. Airspace Navigation Services Providers (ANSPs) coordinate with Eurocontrol the opening and closing of airspaces as well as the creation of regulations in case of high traffic loads. Eurocontrol coordinates with airports and airlines the departure times according to lots of data and processes. Airlines coordinate with handling agents, crews and local ANSPs to find the most suitable sequence of actions in order to run smooth operations. Coordination is the backbone of an efficient ATM. Airport Collaborative Decision Making (A-CDM) proposes different coordination processes to inform all relevant stakeholders about the status of a flight. Better information quality and real time data allow better situation awareness for all involved stakeholders as well as proactive mitigation measures before a problem arises [2]. Many other initiatives were implemented, from research ideas (AI supported mitigation measures during convective weather such as ISOBAR project [3]) to implementation of projects such as the STAM processes (Short Term ATFCM Measures) or libraries of already discussed and approved measures under certain situations (Network Manager What-if Scenarios). Some projects such as User-Driven Prioritisation Process (UPDD, [4]) or initiatives from the Maastricht Upper Airspace Center offers the airlines to express their priorities within their flights. However, the ANSPs are the one deciding *in fine* for all stakeholders the delay allocated to the flights, in the name of safety, and with the best knowledge of the operational situation of each stakeholders (which is most of the time incomplete).

From an airline perspective, the coordination is necessary between the different teams such as Dispatch, Network Operations Control (NOC), Crew Control and Passengers Care Center to manage any small or big disruption in the planning. However, coordination between the airlines of a same group or alliance is rather poor in Europe. Each airline generally tries to find a solution by itself before coordinating with the others (mainly informatively only). We are willing to change this paradigm.

We aim with this article to integrate the necessary decision-makers and offer them an equal voice to define a consensus with other involved actors. With the dynamic and complex operational situations, urging for a solution in a restricted amount of time, while taking into account the decision-makers preferences, we aim at proposing a new process that could be adapted easily to other problems than the one we present (multi airlines optimisation).

B. Multi-hub Airlines Optimisation and Decision Making

During disruptions affecting several airlines belonging to a same group, we assume that putting the resources of all airlines together (seat capacities and flights operated mainly) offers more flexibility and thus potential optimal solutions, instead of locally managing the disruption with the available resources. [5] defines a virtual hub as an airport to and from which the different airlines of a group are operating more than 25 rotations. In case of an airport capacity reduction, requiring mandatory cancellations from all operating airlines (due to industrial actions or weather phenomena, which happens quite often per month in Europe [6, p. 4,5]), the cancellations could be wisely split among the different airlines of the same group to reduce the operational impacts. Thanks to this resource sharing allowing more flexibility, the disruption will less affect the passengers and the operations. This passenger centric approach is far easier to reach with greater means, hence an airlines group collaboration.

We focus in this article on the decision process, which allow the group of participants, with potential conflictive point of views, to reach a consensus on the solution to implement. We consider that a solver proposes a set of optimal solutions for the group, among which a consensus must be identified. Although the flexibility of a group offers better global solutions, it could hamper the operations of an airline more than the others [5]. Thus, imbalances or negative impacts must be communicated, assessed, and a trade-off must take place between the stakeholders to find the most suitable solution for all airlines, according to their preferences and specificities. Decision-making is a key aspect of a global optimisation of multi-hub airlines operations, and all stakeholders must be involved to grant an acceptance of the consensus. . Figure 1 is illustrating the business model process proposing global optimised solutions and incorporating a consensus methodology.

It is well known that airlines operations is a complex environment, in which numerous criteria are influencing a decision [4]. In this regard, advantages and drawbacks of all proposed solutions must be precisely identified according to the local vision of each participant on its own operations. The available data is not sufficient to model accurately the internal decision process of each representative, as each airlines has its own business specificities. It neither catches the sensitivity of the current operational situation at each airline operations center, nor takes into account the forecasts and extensive experience of the operational experts of each airline representative. Thus, the process must take into account the necessary representatives inputs to propose a real consensus.

Therefore, we must establish a process, which allows the identification of an acceptable compromise among the optimal solutions for the group proposed by the solver. This process must take into account and respect the sensitivity and sovereignty of each airline, in order to ensure the adherence of each decision-maker to the solution to implement for the best benefits of the group. In this article, we concentrate our research on the following aspect: how to propose a multi-criteria and multi-stakeholders decision process, which ensures efficient and optimal consensus identification, accepted by all involved decision-makers within the allocated time. Many methods are suited to propose an approach allowing a group of decision-makers, in a potential conflictive situation, to reach a consensus. A short literature review with an explanation of our method statement is presented in the following section

III. Multi-Stakeholders MCDM Methods for Consensus Identification, a brief Litterature Review

Within airlines operations, with or without disruption, several criteria have conflictive positions. To illustrate with one example out of many, accepting delays on given flights would allow more passengers to catch their connecting inbound flights, but would cause crews and aircraft rotations problems, that could then create critical reactionary delays on the entire operations. Therefore, multi-criteria decision-making is relevant for the current studied problem, in which importance is defined by the decider sensitivity and local approach.

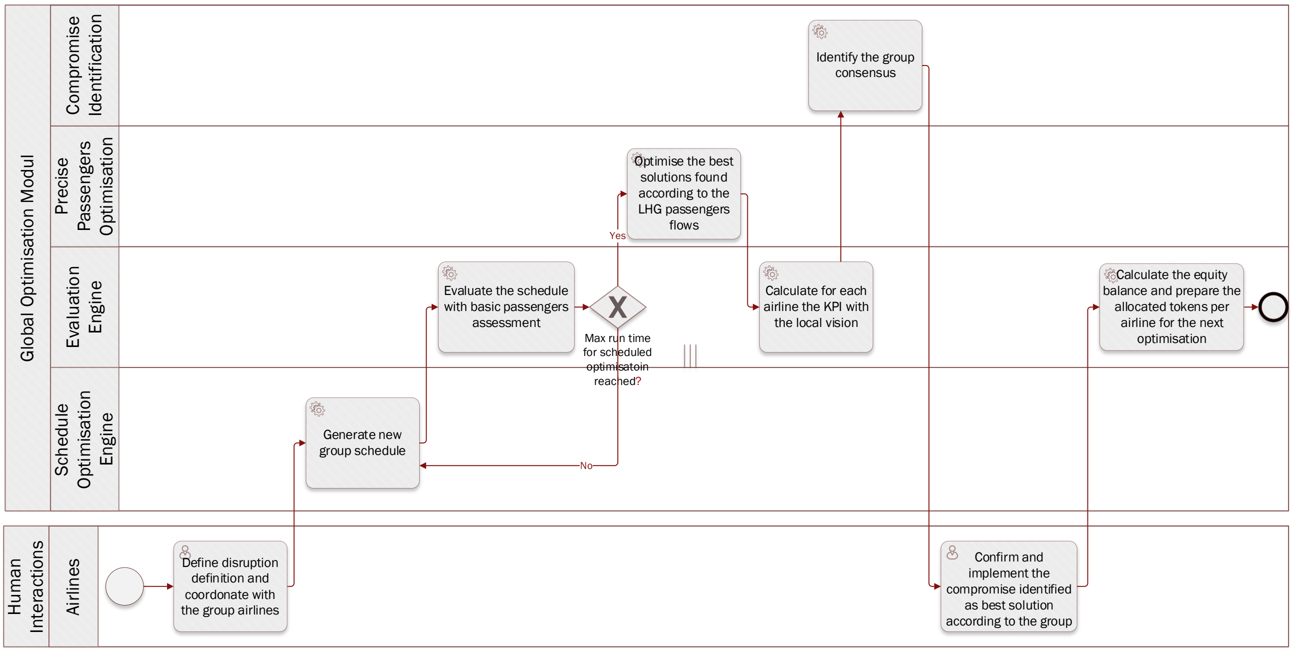

Figure 1: Business process model for the global opitmisation within a group of airlines

A. Current Multi-Criteria Decision Making Methods

Transportation literature appears to be an stimulating area for MCDM problematics [1]. To allow a trade-off between possible conflictive criteria and thus identify the best suitable alternatives, several approaches were developed. MCDM methods with uncertain preferences (such as Choquet integral [7] or Sugeno interval-valued integral [8]) are not relevant in our case as the user requires understandable and intuitive methods. Numerous MCDM approaches exists based on user-defined preferences and are commonly gathered into two mains groups:

- The additive aggregation of criteria, such as weighted sum found in Multiple Attribute Utility Theory (MAUT), the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS), the Analytical Hierarchy Process (AHP) or its generalization called Analytical Network Process (ANP). This consists in aggregating the performances of the criteria – each independent one with each other – according to weights, that are obtained through different methods;
- The outranking methods, based on a relational system of preferences, which is assessing each action with the others as ordered pair comparison (*a* preferred to *b* can be different from *b* preferred to *a*). Two famous outranking methods are Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE), recent enhancement applied by [9], and Elimination and Choice Expressing Reality (ELECTRE).

It is, in our case, mandatory to translate the most accurately possible the deciders' thinking and preferences, which is enabled by the methods mentioned above. As the decision-makers have a limited time to dedicate to the group optimisation, and due to the operational complexity that they have to deal with, an aggregative method could be adapted to their workload. However, most of the methods named above are requesting extensive inputs from the decision-makers, by comparing each alternative toward two criteria, pairwise. In an operational situation, in which the solver has a limited time to propose optimal solutions, among which the compromise must be efficiently identified, these methods would not fit in the allotted time. Thus, one must consider other methods allowing fast ranking, but still ensuring a quite high quality of each decision-maker sensitivity.

B. Social Vote Methods to support Expert Ranking of Solutions

As stated before, we need a method which is able, from the different decision-markers' rankings, to identify the consensus with no further parameters. Social voting theories have the advantage that they identify quickly and without additional inputs than the rankings, a consensus between the deciders.

A typical case of multi-deciders is the election of representatives, for example a president. Several methods were proposed and are still currently used, such as the majority (the candidate who received the most votes), two-rounds electoral system (first round selecting the two candidates with the most votes, and the second one selecting the candidate with more than 50% of votes), Condorcet method or Borda method [10].

Condorcet method (proposed in the XVIII century) proposes to count the times where the candidate A is preferred to candidate B. The candidate gathering the highest preferences amount is elected. For example, if:

- B is preferred 10 times over 19 to A;
- A is preferred 16times over 19 to C;
- B is preferred 12 times over 19 to C;

Then B is elected. However, several situations lead to a “no decision status”.

For example, there is no clear preferred choice, if:

- A is preferred 5 times over 7 to B;
- B is preferred 5 times over 7 to C;
- C is preferred 4 times over 7 to A;

A famous method – especially in sports competitions – is based on scores. For each round, the candidates are attributed given number of points, as a function of their rank and performances. When the points are linearly attributed according to their rank, the first one getting *N-1* points, the second one *N-2* points, etc, this is called the Borda method. By summing the Borda points gathered for each round and ordering it decreasingly, one can obtain easily the corresponding ranking. This can be mathematically formalized as follows: let us note $r_{i,k}$ the rank of alternative *i* given by the k^{th} voter. Borda Points for alternative *i* is noted b_i and calculated as in Eq. 1.

$$b_i = \sum_k (N - r_{i,k}) \qquad \text{Eq. 1}$$

One of the advantages of Borda counts is that two solutions can have the same rank, if the sensitivity of the decider considers them equivalent. Moreover, Borda method has a great advantage on Condorcet: it is electing a winner whatever the situation is, in the contrary to Condorcet, which drawback is not always able to design a winner. As Borda method is based on ranking points, it will always be able to provide a winner [11]. Some authors also propose to combine both methods [12].

As pointed out, one elector could rank two solutions as equivalent with the users’ inputs. For two equivalent solutions, the same number of points should be attributed. As the two solutions are using the ranks k and k+1, we apply the average score proposed by [13] in the context of partial voting. Thus, each solution will receive $\frac{(n-k)+(n-(k+1))}{2}$ points. The solution ranked next the two equivalent solutions will get the standard Borda point attributed to its rank, (n-(k+2)). This enables to consider two solutions as equivalent – which respects the decision-maker’s sensitivity –, ensure the respect of the total amount of Borda points distributed among the solutions by one elector as well as preserve the points allocated to any solution ranked after the equivalent solutions. In the final ranking, if ever two solutions are ranked equivalent on the first position, Condorcet method could be used to distinguish the solution representing the best consensus for the group.

Decision-maker knowledge and sensitivity are primordial in the evaluation of several complex solutions, in order to reach a group consensus. Indeed, in our multi-hub airlines operations optimisation, which is run on big volume of data, these data cannot translate the full reality and subtleties of an operational situation. Therefore, it is crucial to support the decision-maker in the solutions ranking thanks to semi-automated process due to the complexity of the data, but they must have a control on the final ranking to influence it with their own operational sensitivity. This will reduce the complexity for the decision-maker while ensuring a ranking capturing the subtleties of the local operations.

IV. A Two-Stage Method for Compromise Identification

Multi-hub airlines compromise identification aims at finding optimal solutions for the group while respecting the local constraints and preferences. Therefore, the system proposes a two-steps approach, once the set of optimal solutions identified. First, the group optimal solutions are assessed with a local vision for each decision-makers and a ranking is proposed, representing the votes of the airlines. The second step aims to elect the solution offering a consensus acceptable to the stakeholders. Therefore, solution assessment requires a coordination among all decision-makers to determine the preferred one (or less disliked one).

We consider in this problem that the decision-makers are having a rational behavior, which means that they are ranking the solutions according to their own benefits and drawback assessment but not trying to influence the vote results by voting in a manner that would favor their preferred solution. This is a very strong hypothesis, which is justified by the several facts. First, all airlines representatives are aiming at the group benefits and the reduction of the disruption on their own operations, as long as equity is ensured. This can be guaranteed thanks to the introduction of a new indicator, measuring the long-term equity. If imbalances are spotted after several rounds of common optimisation, one should introduce compensation mechanisms for the disadvantaged stakeholders (such as tokens for flight priority), thus restoring equity balance (refer to [5] for the concept introduction, first steps and discussions). Therefore, one stakeholder trying to gain more than the others would be twice penalized: by not reaching the best results of the group and by the compensation mechanism. This should incentive all stakeholders to aim for the group benefits. Secondly, joining the optimisation is no obligation but rather an opportunity. Third, a transparent monitoring of these collaboration rounds must be available to all stakeholders and objectively assess the respect of long-term equity as well as the global and local benefits in comparison to acting alone (baseline). Based on these three assumptions and propositions, one can reasonably expect a rational behavior from stakeholders for a local assessment of the global optimal solutions, and this especially within a group of airlines, that are not competitors one towards the other.

A decision-support method is proposed to enable a quick and efficient ranking for the user. Once all participants submitted their rankings, the system proposes the solution which reaching a group consensus.

1) Needed Inputs from each Decision-Maker

In this first round of Borda, each criterion is considered as a voter. Based on the operational data only, the system is not able to know all the specificities of the current operations. To remediate to this situation, the expert is proposed to provide for each criterion two types of information to define a ranking of all solutions. Let *S* be the set of solutions to rank indexed by *s*; let *I* be the set of criteria considered indexed by i. We note $g_i(s)$ the performance and $r_i(s)$ the rank of solution *s* for criterion *i*.

a) Indifference threshold: Defined by *[14]*, for each criterion, an indifference threshold allows the system to model the human behavior considering that two solutions with very similar performances for a criterion are equivalent in the ranking for this criterion

$\forall i \in I, q_i$ is the indifference threshold for the criterion *i*.

b) Acceptable interval of performances criterion per criterion: the decision-maker can indicate its preferred value of performance for the given criterion. This can be either an interval, a specific value (lower bound=upper bound) or minimum/maximum threshold value (one of the lower or upper bound is the minimum or maximum of the performance for the given criterion). This enables to rank several solutions, which performances are contained in the acceptable interval, to be ranked all first and equivalent for the given criterion. The major reason for this interval per criterion is the following situation: the disruption to optimise might take place in parallel to another local disruption for a participating airline. For example, if a capacity constraint takes place at the airline hub, this airline might be happy if a major part of its flights towards the disrupted virtual hub are cancelled and that its passengers are taken over by the over airlines. Therefore, the acceptable interval of performances for some criterion might be different from the expected one (maximum of benefits).

$\forall i \in I, O_i = [O_i^-; O_i^+]$ is the acceptable performances interval for the criterion *i*.

We note $dist(g_i(s) - O_i) = \min_i(|g_i(s) - O_i^+|, |g_i(s) - O_i^+|, |g_i(s) - O_i^-|, |g_i(s) - O_i^-|)$ the distance between the performance of solution *s* for criterion *i* towards O_i.

The system works as follows: for each criteria, a ranking is defined as of the following rules:

1. All solutions with performances belonging to O_i get the first rank:
   $$\forall s \in S, such\ as\ g_i(s) \in O_i, r_i(s) = 1 \qquad \text{Eq. 2}$$
2. For all other solutions:
   - If two solutions have equivalent performances according to the decision-maker, then they receive the same rank:
     $$\forall s, s' \in S, g_i(s) \notin O_i\ and\ g_i(s') \notin O_i,$$
     $$if\ |g_i(s) - g_i(s')| \leq q_i\ then\ r_i(s) = r_i(s') \qquad \text{Eq. 3}$$
   - If three solutions *s, s'* and *s''* exist such as *s* is equivalent with *s', s'* is equivalent with *s''* but *s* is not equivalent with *s''*, then *s'* is equivalent to the solution having the nearest performance*:*

$$\forall s, s', s'' \in S, g_i(s) \notin O_i, g_i(s') \notin O_i, g_i(s'') \notin O_i$$
$$such\ as$$
$$dist(g_i(s) - O_i) \leq dist(g_i(s') - O_i) \leq dist(g_i(s'') - O_i)$$
$$and$$
$$|g_i(s) - g_i(s')| \leq q_i\ and\ |g_i(s') - g_i(s'')| \leq q_i\ and\ |g_i(s) - g_i(s'')| > q_i$$
$$Then:$$
$$If\ |g_i(s) - g_i(s')| \leq |g_i(s') - g_i(s'')|\ then\ r_i(s) \geq 1\ and\ r_i(s) = r_i(s') = r_i(s'') - 1$$
$$Else\ r_i(s) \geq 1\ and\ r_i(s) + 1 = r_i(s') = r_i(s'') \qquad \text{Eq. 4}$$

These two inputs are likely to consider several solutions as equivalent. Part III.B presented a possible approach to deal with these equivalently ranked solutions.

In order to provide a user friendly and interactive interface for the experts to enter their inputs, all solutions will be represented in a spider graph, in which each axe represents a criterion of the AHP tree for compromise. Each solution will be represented as a point, with – in a first step – no possibility for the user to identify the relation between the points and the solutions. This is a deliberated choice in order to avoid biasing the user judgment by already choosing a solution as favorite one. It is nevertheless a useful information for the users to know on which range the solutions are spread, to assess accordingly if some performances would be acceptable. The user is able to select on the graph the value or interval of acceptable performances and just need to adapt the indifference threshold if necessary (already populated with standard values).

All these inputs are useful to model efficiently the decisions-maker operational expert sensitivity, as the data available in the solver will never be enough to represent fully the operational situation with all its subtleties and nuances.

B. Social Vote Methods to Support the Identification of the Group Compromise

The system is supporting each airline representative to rank the solutions with their local view. Thanks to the users' inputs (indifference threshold and acceptable performances interval), the solutions performances for each given criterion are ranked automatically. According to its ranks for each criterion (criterion=voter here), a solution gets a number of points based on the Borda method. The solution with the maximum amount of points gets the first rank for the local ranking, etc. If two solutions have the same amount of Borda points, placing both on rank *m*, we consider them as equivalent and the rank *m+1* is then empty. This can be further generalized: if *n* solutions are allocated the same amount of points and therefore are ranked equivalent by the user, then the *m+1* to *m+n-1* ranks are empty.

Once all representatives have adapted or/and validated their proposed rankings by the system, another Borda round is launched, this time considering each airline as a voter, and counting the Borda points attributed by the local rankings previously done. With this method, a consensus solution according to all decision-makers inputs is identfied and can be implemented. We differ here from a standard Borda method as the user expert sensitivity is modelled thanks to pseudo-criteria (through indifference threshold and acceptable interval of performances) and integrated in the proposed ranking, which can be adapated by the user before getting in the global ranking. A standard application of the Borda method would not allow to take into account this human sensitivity and knowledge. This is a key element in airlines operations and ATM as the complexity can not be fully caught by data, and that the human has a broader situation awarness and operations knowledge.

V. ILLUSATRION AND DISCUSSION ON A BASIC USE-CASE

A. *Local Ranking*

For a given airline *A*, participating to a group optimisation, let us suppose that the optimizer proposes eight different solutions, optimal for the group of airlines. Each performance of each criterion is presented to the airline *A* representative, who provides for each criterion an indifference threshold and the acceptable performances interval (see *TABLE I*).

In *TABLE II*, each solution is affected a number of points according to the amount of time they are chosen to a specific rank by criterion, and how many solutions are ranked equivalent by the same criterion. For instance, S4 is ranked first by:

- the criterion on operational impact (equivalent with S, S2 and S3, therefore earning 5.5 points),
- the criterion "invalid crew" (equivalent with S1, S2, S3, S6 and S7, thus earning 4.5 points),
- the criteria on dead head crew impacted, on crew impacted on the next operational days and on passengers with costly solutions (equivalent with all other solutions, thus earning three time 3.5 points),
- the criterion on passengers without satisfying solutions (equivalent with all other solutions, except S6, and thus earning 4 points).

S4 gets then 24.5 points from being ranked first by four criteria, with the influence of the equivalent ranked solutions. Once the points attributed by all criteria, the system sorts the sum of attributed weights from the largest to the smallest, which proposes the ranking for airline *A*. Its representative can then check the ranking and adapt it if necessary. All other users are proceeding similarly to generate and adapt their local rankings.

TABLE I TABLE OF SOLUTION FOR THE AIRLINE A

Solution ID	***Cancellation ratio***	***%OPS Impact***	***Aircraft Complexity***	***% invalid Crew***	***% crew impacted next day***	***% Dead Head Crew impacted***	***% Passengers with costly solution***	***% Passengers without solution***
S1	10%	30%	17%	25%	0%	0%	0%	1%
S2	17%	19%	30%	40%	0%	2%	13%	2%
S3	33%	30%	20%	14%	0%	0%	12%	5%
S4	50%	20%	10%	38%	3%	1%	1%	2%
S5	43%	90%	45%	71%	0%	0%	0%	0%
S6	21%	90%	20%	36%	2%	0%	4%	18%
S7	17%	40%	20%	14%	0%	0%	5%	3%
S8	0%	90%	40%	66%	0%	0%	0%	0%
Acceptable Performance Upper Bound	40%	30%	40%	40%	10%	20%	60%	10%
Acceptable Performance Lower Bound	0%	20%	30%	0%	0%	0%	0%	0%
Indifference Threshold	1%	5%	2%	5%	1%	5%	5%	5%

TABLE II TABLE OF BORDA POINT ATTRIBUTED TO THE SOLUTIONS

ranks	***S1***	***S2***	***S3***	***S4***	***S5***	***S6***	***S7***	***S8***
rank1	29	35.5	29	24.5	14.5	19.5	23.5	25.5
rank2	0	0	0	0	0	0	0	0
rank3	0	0	0	0	5	0	0	0
rank4	0	0	3	0	0	3	3	0
rank5	0	0	0	0	0	0	3	0
rank6	0	0	0	0	1	1	0	1
rank7	1	0	0	0	1	0	0	1
rank8	0	0	0	0	0	0	0	0
SUM	30	35.5	32	24.5	21.5	23.5	29.5	27.5

TABLE III RANKING FOR AIRLINE A BASED ON BORDA COUNTS

Ranking for Airline A	***Solution ID***	***Borda Points***
1	S2	36
2	S3	34.5
3	S1	30.5
4	S7	28
5	S8	25.5
6	S4	24
7	S5	23
8	S6	22.5

B. *Compromise Identification and Discussion*

The goal of this section is to highlight the particular behavior and possible outputs of the Borda method for a group consensus. We first illustrate on a simple and clear use-case the Borda calculations before deep diving into the particular cases. In our simple use-case, we suppose that three airlines *A*, *B* and *C* are participating to the group compromise identification. The respective rankings are presented in *TABLE IV*.

TABLE IV RANKINGS FOR THE THREE PARTICIPATING AIRLINES

Rank	***Ranking for Airline A***	***Ranking for Airline B***	***Ranking for Airline C***
1	S2	S2	S1
2	S3	S1_S3_S7	S2
3	S1	-	S7
4	S7	-	S3
5	S8	S8	S5
6	S4	S4	S8
7	S5	S5	S4
8	S6	S6	S6

As for the first round of Borda points allocation in part V.A, the solutions ranked first are getting 7 points, the solutions ranked second are getting 6 points, etc. Thus, we get the following group ranking in *TABLE V*. Solution1 gathers 5 points, as ranked third by airline *A*, 7 points as ranked first by airline *C* and 5 points as ranked second by airline *B* but equivalent to S3 and S7 (average of the points allocated to the three first ranks). Therefore, Solution 1 gets 17 points while solution 2 gets the maximum of Borda points (20 points) in comparison with the other solutions.

TABLE V RANKING OF THE GROUP VISION WITH ALL AIRLINES VOTES

Global Ranking	*Solution ID*	*Borda Points*
1	S2	20
2	S1	17
3	S3	15
4	S7	14
5	S8	8
6	S4_S5	5
7	-	-
8	S6	0

Let us now assume that the three participating airlines have very different rankings, as see in *TABLE VI*.

TABLE VI: ILLUSTRATION OF VERY DIFFERENT RANKING

Rank	*Ranking for Airline A*	*Ranking for Airline B*	*Ranking for Airline C*
1	S1	S6	S8
2	S4	S7	S5
3	S6	S2	S3
4	S3	S3	S2
5	S2	S4	S7
6	S8	S1	S1
7	S5	S8	S4
8	S7	S5	S6

By following the Borda method and attribution of the points, the *TABLE VII* provides the group ranking, eliciting S3 as the group consensus. One can observe that S3 is no favorite solution ranked first or second by any airline. Actually, it is a rather averaged ranked solution at the positions 3 and 4. None of the top ranked solutions by the participating airlines is gathering as many points as S3 because of low ranks given by the other airlines (See S1, S6 and S8). Even if S6 is well ranked by A and B, the fact that C ranked it at the worse position by one airline disqualifies it from the best-scored solutions. This outlines the Borda behavior aiming at finding a consensus rather that following the majority of voters' rankings. This is important in our proposed method, as the goal is to reach the best compromise for the whole group.

TABLE VII RANKING FOR THE GROUP VISION WITH ALL AIRLINES VOTES

Global Ranking	*Solution ID*	*Borda Points*
1	S3	13
2	S2_S6	12
3	-	12
4	S1	11
5	S4_S8	10
6	-	10
7	S7	9
8	S5	7

Let us use another example, in which the chosen solution is ranked at the worse position by an airline:

TABLE VIII: ILLUSTRATION OF A VERY IMBALANCED SITUATION

Rank	*Ranking for Airline A*	*Ranking for Airline B*	*Ranking for Airline C*
1	S1	S6	S8
2	S3	S7	S1
3	S5	S2	S7
4	S4	S8	S5
5	S2	S3	S2
6	S6	S4	S3
7	S8	S5	S4
8	S7	S1	S6

TABLE IX RANKING OF THE GROUP VISION WITH ALL AIRLINES VOTES

Global Ranking	*Solution ID*	*Attributed Borda Points*
1	S1	13
2	S8	12
3	S2	11
s4	S3	11
5	S7	11
6	S5	10
7	S6	9
8	S4	7

The solution gathering the maximum of Borda points is S1. However, this solution is ranked first by A, last by B and second by C. This is a very imbalanced situation, in which the Borda process is identifying a controversial solution. By having a look to the other solutions, such as S8, which is ranked second in the global ranking, one can remark that S8 is ranked 6th, 4th and 1st by the participating airlines. Even if this solution would balance the "fairness" of the consensus, S8 is still less preferred by the third airline, as the 4th rank has less influence on a group level than the 2nd one. Borda can lead to controversial consensus, but the goal of our method is to identify the best compromise. In future research, we aim at enabling an inequity calculation to compensate the disfavored airlines during the next run of optimisation and thus target a long-term equity.

One path of research would be to use further the Borda method with weights, as it is already done during elections when groups of voters voted the same way. Let us illustrate the principle based on the former votes presented in *TABLE VIII*. We assume that airline A was slightly advantaged during the last rounds of optimisation and therefore get a weight of 0.9, while airline B, being slightly disadvantaged, get a weight of 1.1. To illustrate the three cases, we suppose that airline C was reaching the perfect equilibrium with equity towards the other airlines and therefore gets a weight of 1. The global ranking is then:

TABLE X RANKING OF THE GROUP VISION WITH ALL AIRLINES VOTES

Global Ranking	*Solution ID*	*Borda Points*
1	S8	12.3
2	S1	12.3
3	S7	11.6
4	S2	11.2
5	S3	10.7
6	S5	9.6
7	S6	9.5
8	S4	6.8

Here the weights slightly disregard that S8 is ranked 6th by A and give more importance to the ranked 4th S8 and ranked last S1 from airline B. This leads to a situation in which two solutions are equivalent for the first rank in the global ranking. The assignment of weights should be linked to the long-term equity balance, our target of future research activities.

In many situations, Borda method can lead to *ex-aequo* solutions being ranked first in the global ranking. Thus, a process must be proposed to insure that a solution will be picked as the best compromise for the group. Because as few inputs from the user may be asked, we propose to use the Condorcet method to identify a consensus among the ranked first solutions. The reason why Condorcet is used as the identification of the best solution only on the equally ranked first solution is that – as pointed out in III.B – Condorcet method is often unable to identify the best compromise, while Borda always identify at least one best-ranked solution. In our example, S1 is preferred once to S8 (by A) while S8 is preferred twice to S1 (by B and C). Therefore, S8 should be the solution to implement.

A possible extension of this research could be to assess evaluate and analyze two aspects of the process and propose machine-learning methods to pre-fill the users inputs required: the operational assessment made in the first step, and the ranking proposal calculated per airline. This would lead to even less time required by the user as well as better quality of local ranking, thus reducing through the utilizations.

VI. CONCLUSION

In this paper, we present a two-step approach to identify a consensus among optimal solutions for a group of airlines facing together an operational disruption in a virtual hub. As each airline is impacted differently in its local operations by the solutions proposed by the group solver, all airlines' decision-makers must reach a consensus to pick the best (or less bad) solution towards airlines local operational impacts. To reach this consensus, a semi-automatic system is proposed. As the amount and complexity of data does not enable a human brain to assess quickly and efficiently all proposed solutions, the user gets an overview of the performances of the different solutions. He then provides two types of inputs per criterion: indifference threshold, modeling the human sensitivity, which perceives two similar performances levels as equivalent, and the acceptable performance interval, to indicate to the system the preferred output. Based on these user inputs, the system proposes a ranking to the user based on Borda method. The user can either adapt the ranking, if he does not totally agree, and validate it. Once all decision-makers confirm their rankings, the system proceeds to the election of the consensus based on the Borda method. As this method can lead to several solutions ranked first in the global ranking, we propose then to distinguish the solution to implement thanks to the Condorcet method.

This two-steps approach enables quick and efficient group consensus identification. Involving all relevant stakeholders enable an adherence to the decision. Within group decision, a major hurdle is to reach a consensus in conflictive situations, for which several solutions could favor or disfavor some actors or some operational fields more than others. The trade-off reached between efficient automation and human decision behavior modelization thanks to users' inputs, allows the stakeholders to accept a group solution, disfavoring some participants or local performances. Therefore, this approach must be complemented with a transparent and reliable long-term monitoring of the imbalances between the stakeholders, to enable long-term equity guarantee as well as develop the users' trust in the system. The first thoughts were published [5] and further research will aim at linking the two aspects to propose a scientific endeavor on long-term equity in the context of group decision during disruption.

This paper does not aim only at proposing a method for airlines of a same group facing a disruption together, but also at proposing a new kind of approach applicable and adaptable on an ATM level (such as capacity reduction at airports or en-route weather restrictions requiring rerouting). Ensuring quick and efficient decision-making based on the preferences of relevant stakeholders could only have positive effect on the overall European ATM, as the preferences are reflecting the needs of the stakeholders to reduce operational impact. Considering the priorities of the airlines and reaching a consensus involving all stakeholders would result in an enhanced travel experience for the European passengers, a decrease of the environmental impact of aviation as well as an increase of Safety (less high speed flights and reduction of unnecessary movements in TMA -Terminal Navigation Area-) without forgetting a reduction of noise disturbance for the inhabitants of airport's vicinities.

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