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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References

[1] G. Yannis, A. Kopsacheili, A. Dragomanovits, and V. Petraki, "State-of-the-art review on multi-criteria decision-making in the transport sector," *J. Traffic Transp. Eng. Engl. Ed.*, vol. 7, no. 4, pp. 413–431, Aug. 2020, doi: 10.1016/j.jtte.2020.05.005.

[2] EUROCONTROL Airport CDM Team, "Airport CDM Implementation Manual," EUROCONTROL, Mar. 2017.

[3] A. Jardines, M. Soler, A. Cervantes, J. García-Heras, and J. Simarro, "Convection indicator for pre-tactical air traffic flow management using neural networks," *Mach. Learn. Appl.*, vol. 5, Sep. 2021, doi: 10.1016/j.mlwa.2021.100053.

[4] N. Pilon, L. Guichard, Z. Bazso, G. Murgese, and M. Carré, "User-Driven Prioritisation Process (UDPP) from advanced experimental to pre-operational validation environment," *J. Air Transp. Manag.*, vol. 97, Oct. 2021, doi: 10.1016/j.jairtraman.2021.102124.

[5] M. Carré, E. Nantier, S. Durieux, and L. Piétrac, "Equity within Air Transportation Management – an Analysis of Inequity Index for Multi-Stakeholders Optimisation," in *ATM Seminar 2021*, Sep. 2021, p. 10.

[6] EUROCONTROL, "CODA Digest All-causes delay and cancellations to air transport in Europe," Annual report for 2019, Apr. 2020.

[7] G. D. Pelegrina, L. T. Duarte, M. Grabisch, and J. M. T. Romano, "The multilinear model in multicriteria decision making: The case of 2-additive capacities and contributions to parameter identification," *Eur. J. Oper. Res.*, vol. 282, no. 3, pp. 945–956, May 2020, doi: 10.1016/j.ejor.2019.10.005.

[8] M. Grabisch and C. Labreuche, "A decade of application of the Choquet and Sugeno integrals in multi-criteria decision aid," *Ann. Oper. Res.*, vol. 175, no. 1, pp. 247–286, Mar. 2010, doi: 10.1007/s10479-009-0655-8.

[9] S. Greco, A. Ishizaka, M. Tasiou, and G. Torrisi, "The ordinal input for cardinal output approach of non-compensatory composite indicators: the PROMETHEE scoring method," *Eur. J. Oper. Res.*, vol. 288, no. 1, pp. 225–246, Jan. 2021, doi: 10.1016/j.ejor.2020.05.036.

[10] L. B. Anderson, "Chapter 16 Voting theory," in *Handbooks in Operations Research and Management Science*, vol. 6, Elsevier, 1994, pp. 561–584. doi: 10.1016/S0927-0507(05)80097-0.

[11] H. P. Young, "An axiomatization of Borda's rule," *J. Econ. Theory*, vol. 9, no. 1, pp. 43–52, 1974, doi: https://doi.org/10.1016/0022-0531(74)90073-8.

[12] C. Herrero and A. Villar, "Group decisions from individual rankings: The Borda–Condorcet rule," *Eur. J. Oper. Res.*, vol. 291, no. 2, pp. 757–765, Jun. 2021, doi: 10.1016/j.ejor.2020.09.043.

[13] N. Narodytska and T. Walsh, "The Computational Impact of Partial Votes on Strategic Voting," Prague, May 2014.

[14] B. Roy, "The outranking approach and the foundations of electre methods," *Theory Decis.*, vol. 31, no. 1, pp. 49–73, Jul. 1991, doi: https://doi.org/10.1007/BF00134132.