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The futures of the air transportation system : automated foresight scenarios generation and analysis

Camille Blanchard*

ONERA, Toulouse, France

*Corresponding author: camille.blanchard@onera.fr

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Abstract

The aviation sector needs to face multiple challenges whether it is to mitigate its environmental impact, to recover from the sanitary crisis or to satisfy its customers. This paper presents a foresight tool to help to make decisions considering possible futures. It is designed to automatically and exhaustively generate all the possible futures of a system of agents, based on a formal model to define the system and its components along with the interactions between them. It is applied to the air transport system and the questions an airline company could ask itself. It aims at limiting the impacts of past data and cognitive biases of participants with classic scenario production methods while using qualitative data. As moral principles of the agents of the system are considered, it adds a new perspective to make decisions and enables us to consider a notion of moral conflict. In fact, the analysis of generated scenarios shows that, to reach a goal may require to make a compromise between moral principles or to define priorities. It shows also that an agent, whatever decisions it can make, may face conflict situations because of other agents. The representations of the results allow a better understanding of the situation and analyses of the initial knowledge. The exhaustive scenario generation however may be questioned to minimize the computational resources currently needed.

Keywords: aviation future; foresight scenarios; decision-making; knowledge and reasoning formal modelling; moral principles

1. Introduction

For the past few years, the air transport sector has been facing challenges with the Covid-19 crisis, the rise of global warming concerns [1] (e.g., the *flygskam* movement) combined with the war in Ukraine and the energy crisis while keeping the customers satisfied. In this context, the stakeholders have to make decisions while dealing with uncertainty. A possible and natural stance is therefore to consider the possible futures of aviation. This means taking into account the various stakeholders interacting in the sector, from governments and international organizations to airline companies, fuel suppliers and populations. They all make decisions on their own, controlling various variables to achieve their own objectives. This may result in internal or external conflicts within a stakeholder or between them.

Designing foresight scenarios is one way to contemplate the future, as it helps stakeholders to make decisions. Moreover, the building process enhances the stakeholders' comprehension of the system of agents they belong to. The scenarios built at the end of the process help to define consistent goals

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and being prepared to possible breakthroughs. They can highlight the importance of a decision and its possible consequences and they offer a new perspective on the relationships between stakeholders. Numerous methods have been proposed to generate scenarios, each with different objectives, relying on qualitative or quantitative data, and based on workshops or on formal models. In the air transport sector, they have helped to produce a high number of reports including scenarios, either global or on specific issues, considering uncertainties or staying in the trend.

This paper focuses on generating scenarios about the future of the aviation sector and analysing them. It offers a methodology and formal tools to automatically build a high number of foresight scenarios. Indeed, automated calculus is likely to help to generate the scenarios faster than participatory approaches. Moreover,it aims at helping a stakeholder to make decisions by systematizing the reflection process and considering a high number of scenarios, which is not done today. It is also expected that cognitive biases that may distort manually-built scenarios will be mitigated.

In this paper, we first focus on the various scenarios about the future of the air transport system (section 2). Many of them have been published, which highlights the concerns of the sector. This also gives a first outlook of the existing types of scenarios. The approaches and methods to build and generate scenarios are presented in further details in section 3 along with the different definitions given to the term "scenario". We then present (section 4) the detailed objectives of our work. Section 5 describes the initial knowledge used to generate our own scenarios on the future of aviation, which is followed (section 6) by the description of the formal approach to model a system of agents and generate scenarios. Section 7 focuses on the generation process and the resulting scenarios. The last section (8) focuses on the analysis of the generated scenarios and their representation according to different criteria. We conclude (section 10) with a discussion on usual biases in current methods and how we can reduce some of them, and on the further possible developments of our work.

2. Scenarios for aviation future planning

Many organisations, both from the inside and the outside of the aviation sector, have built foresight scenarios about the future of aviation; see Table 1 for some of these studies.

Table 1. Some scenarios about the future of aviation

Title	Date	Agencies	Number of scenarios	Method	Previous Version	Aim
EREA Vision Study - The Future of Aviation in 2050 [2]	2021	EREA	4	Workshops with experts (spring 2020), analysis tools	2010 [3]	Decision making inside EREA
Global Market Forecast 2022-2041 [4]	2022	Airbus	1	Airbus model, quantitative forecasting	2019 [5]	Decision making inside Airbus, inform stakeholders
Environmental trends in aviation to 2050 [6]	2022	ICAO	1 to 4	Quantitative models	2019 [7]	Guide the aviation sector and all its stakeholders
Élaboration de scénarios de transition écologique du secteur aérien [1]	2022	Ademe	3	Workshops on socio-economic issues and use of a quantitative model	No	Analyse ecological transition paths for aviation on the french national scale
Waypoint 2050 [8]	2021	ATAG	3 + 1 "scenario 0"	Airbus model, forecasting	No	Strategic perspectives for decision makers

Narrative scenarios are produced through participating methods with workshops animated by facilitators and surveys filled out by experts. For example, the EREA (Association of European Research Establishments in Aeronautics) has produced four narrative scenarios including variations among possible future technologies, states of the world or ways to achieve sustainability. They result from workshops that took place during several months, attended by EREA R&D experts after having evaluated the scenarios they had made in 2010. Similarly, the French public agency ADEME (French Agency for Ecological Transition) has produced three narrative scenarios. Thanks to a literature review they have based their work and assumptions on four relevant scenarios studies ([9],[10],[11],[12]). They have also conducted a two-month consultation including three workshops involving stakeholders to enrich the work. However, the questions and answers of the consultation are not provided in the final report. Then, another set of workshops (attended only by the three scenarios builders : ADEME, DGAC (French Civil Aviation Authority), DGEC (French Energy and Climate Authority)) took place to produce the scenarios. Assumptions were made here on the economical context, aviation decarbonation and customers uses. For both studies, even though the methods are precisely described, little information is given concerning the actual use of these scenarios. They are however claimed to be used for decision making inside the organisations that built them.

On the other hand, formal quantitative models are used especially in the context of forecasting with trend scenarios based on past data. ICAO (International Civil Aviation Organization), and especially the Committee on Aviation Environmental Protection, published a report about trend scenarios on environmental issues including Greenhouse Gas emissions, noise and Local Air Quality. Many different computational models were used to build the scenarios that are based on quantitative data on a wide range of factors (Covid-19 impact, fuel prices, global economic conditions, etc.). Scenarios are represented as quantitative curves including the representation of the uncertainties. There are no concrete applications for these scenarios claimed in this work; they are however included in a larger report that is intended to guide international aviation. Likewise, Airbus publishes a trend scenario every three years. It is composed of trend curves computed by quantitative models, mostly Airbus own models. This type of scenario is claimed to be exploratory, starting from the current state of the world and using past data. It includes projections on the possible evolution of the fuel price, air traffic and demand, and the customers uses. It is said to be used as a reference for all the aviation sectors (airlines, airports, investors, governments, etc.). In the same way, Boeing has its trend scenario [13] so as Comac [14]. Finally the scenarios from the Waypoint 2050 report published by ATAG (Air Transport Action Group) aim at presenting the different paths to decarbonize the air transport and thus focus on CO_2 emissions. They present a baseline (scenario 0) and three backcasting scenarios (starting from a defined target in the future). The latter are built on assumptions about the use of new technologies like blended wing bodies, sustainable fuels and electric aircraft. They are composed of trend curves with a large place given to uncertainties, with attached texts highlighting changes, making a link between forecast and foresight (see section 3). They are generated using various sources of traffic forecasting models like the ones cited above (Airbus, Boeing, ICAO, etc.). Cost of travel, changes in demand, acceptability or policies are considered among other variables. To our best knowledge, the use of these different scenarios inside aviation companies is not documented in the literature.

From this small but representative spectrum, we can first say that scenarios building is highly topical. This is surely related with the many issues that the air transport sector is facing today and its objective to mitigate its environmental impact [15]. In fact many organisations focus their scenarios on CO_2 emissions. However non-CO_2 effects must not be forgotten [16]. Moreover, even if aviation has almost fully recovered from the Covid-19 crisis, practices have changed e.g., the way customers buy their tickets [17], teleworking or flightshaming [18]. The sector has to balance this with keeping air transport affordable, safe and efficient [19]. Scenarios help to prepare these disruptions allowing companies, organisations and governments to anticipate. However, as far as we know, there is no narrative scenario about the future of aviation from other parts of the world or from independent agencies.

It is worth noticing that both groups mentioned above have their own biases, whether caused by participants' backgrounds and opinions or by past data that may blind models to breakthrough scenarios. Moreover, little information is available on the funders of these studies. Some of the organisations are both judge and jury, making scenarios for their own benefit. As far as methods used to generate those scenarios are concerned, they are part of an abundance of methods for planning the future. They are presented in the next section.

3. Future planning: a focus on scenario generation

The future of a system of agents can be considered in many different ways. K. Muiderman [20] suggests four categories to classify the different approaches for considering the future and anticipating [1]: strategic planning – also called forecasting – to identify likely futures, possible futures building – also presented as foresight –, co-creation of futures and finally critical approaches.

Co-creation of futures, also called *experimental* approaches, is based on experimentation and collective creation and imagination of new, mostly radical, futures, with a complete disconnection from the present. For example, the Red Team is a French team of science-fiction writers and researchers who imagine and produce scenarios on possible future threats [22]. [23] also presents "*Techniques of Futuring*" to imagine fictional futures in working groups of actors and produce discussions on what strategies to adopt considering these imagined futures. These approaches do not involve any formal methods.
Critical approaches include various thinking processes on how anticipation and studies of possible futures impact current government policies and choices; for example, how the expectation of seeing certain technological innovations in the future leads to taking them for granted in the present [24]. These approaches do not actually relate to scenario generation, therefore they will not be developed further in this paper.

Forecasting and *foresight* consider the future in a very different way. They usually rely on the use of scenarios. However, defining the term "scenario" is not easy as many methods exist. The multiple attempts to define it are the origin of the term "methodological chaos" used in the literature of this field [25]. As there is a radical difference in its use in forecasting methods and foresight methods, we will give a proper definition in each part (see 3.1 and 3.2).

3.1 Forecasting

This approach aims at foretelling the future [26]. Like all future planning approaches, it is used when decisions have to be made to answer specific questions more than to conduct a wider reflection (i.e., fixing prices or production level, giving advice on investment or policies). In particular, these methods aim at optimizing the path to reach a given objective, most often by minimizing the risks. They can also be related to event or failure prediction.

Forecasting is mostly based on modeling through planning tools or specific models to assess a small number of probable relevant futures [27]. Each model is usually built to answer a specific question (i.e., demographic, economic, meteorological or epidemiological models). Models rely on a very wide range of computational tools such as statistical methods, machine learning or model combination [28]. They all depend on data sets composed of current and past knowledge to determine historical patterns leading to future trends. Moreover, methods using these models often include guidance to evaluate the results and the quality of the predictions. In fact, even if exact predictions are not

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[1] [21] points out that these categories may overlap.

expected, the use of probabilities to quantify the risks and uncertainties is recommended and often represented as intervals.

Scenarios are one of the results computed by forecasting models. They are defined as "*narratives about conceivable futures that are likely to happen*" [27]. They are considered as a tool for organisations to share information and stimulate reflection and discussion. This definition highlights the main bias of forecasting which is to focus on probable scenarios, keeping business as usual and not considering radical changes. Aircraft manufacturers or the ICAO build these kinds of scenarios (see 2).

3.2 Foresight and scenario generation

The foresight approach is more exploratory but still mostly aims at decision aid. This approach deals with the future uncertainties by anticipating different situations. These possibilities are usually explored through participatory methods but also thanks to quantitative models. Foresight is a multidisciplinary approach to identify the major issues of a system (a particular business field for example) through collective reflection and action. It is also a proactive strategy through which a stakeholder can consider different possible futures leading to a previously defined objective.

Scenario planning [29] is one of the most popular methods of the foresight approach. [30] provides a definition that is mainly in line with the point of view proposed by the Intuitive logic school (see subsection 3.2.1): a scenario is future-oriented, often on a global subject. It is composed of a narrative description, can be possible and even plausible. It is usually part of a set of systematically generated scenarios (generated through the same process). We can notice that there is no mention of the term "likely" contrary to the forecast definition of a scenario. Scenario generation does not always rely on past data and the emphasis is put on uncertainties and wild cards (nonlinear events with huge impacts that cannot be predicted).

The three main schools of scenario generation are divided into two groups and were developed in parallel in the 60s:

- American schools
  - Intuitive Logic school;
  - Probabilistic Modified Trend school;
- French school of La Prospective.

3.2.1 American schools

Intuitive Logic has been popular in the industry since it was promoted by the Shell Group [31] and is today widespread for the prospective studies across the world. It has been used for transports in Europe [32] or to evaluate the development of smart environments and their relation to the elderly in the United States [33]. This method focuses on sequences of events and the decision making process. It is mostly based on participative workshops, a qualitative and deductive analysis of a system, and almost never relies on mathematical and formal models. The process, however, is based on specific steps (from 5 to about 15) depending on the method. A workshop is usually animated by a qualified animation team which plays a huge part in the commitment and the understanding of participants. The latter are mainly members of the organization that has initiated the study. Experts outside the organization may also be involved [34].

Probabilistic Modified Trend is another school of scenario generation and analysis that involves two matrix-based methodologies, Trend Impact analysis and Cross Impact Analysis [35]. It involves both quantitative and qualitative models. Quantitative trends are first generated, often with forecasting tools. When no data are available, qualitative trends are implemented. In the Trend Impact Analysis, these extrapolations are then modified by the addition of qualitative factors and uncertain breakpoints to enrich the analysis. Cross Impact analysis focuses on the relationship between key drivers. It uses conditional probabilities to characterize the causal link between the occurrences of several factors and return matrices answering what-if exercises and importance of possible events. There are not many examples of recent use of these methodologies but we can cite [36] applied to the hospital development and its supply chain.

Intuitive logic almost always produces scenarios. But, even if both methods can do so, Probabilistic Modified Trend does not systematically, as results are often given as matrices. However no formal model is implemented to generate them or to define the issues and systems.

3.2.2 French school of La prospective

The *French school of "La Prospective"*, also known as the *French school of foresight*, was initiated from a philosophical point of view by G. Berger [37].

It is based on the *Scenario Method* [38] and even if it claimed to provide participatory methods to support the decision-making process and lead to strategic actions and changes, in practice, the production of scenarios has often been seen as an end and no concrete applications of the results have come up [39].

The Scenario Method is composed of specific steps and relies on the use of scenaring tools. Knowledge is gathered through workshops involving members of the organisation funding the study, a qualified animation team and sometimes external experts.

The first step is the definition of the system whose possible futures are studied. A system is modelled as a set of elements interacting with each other, all organized to reach a common goal [38], including variables, actors and objectives. The most important features of the system are the key variables: actors influence the system through the variables characterizing their actions and which they can monitor to a greater or lesser extent [40]. The key variables reflect the actors' objectives, and may highlight the actors strategies and power games inside the system. Supporting tools as MICMAC (Matrix-based Multiplication Applied to a Classification) or MACTOR (Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations)[2] are provided with this method to help in the workshops. These tools allow the computation of information regarding the link between variables, their importance and the dependencies between actors; however the scenarios resulting from the combination of different hypotheses are handmade. Thus, although clearly structured, the method requires restricting the number of variables taken into account. Indeed, too many actors or variables make the work of the group long, complex and tedious. These computational tools are less used today.

Morphological analysis [41] is one of the tools that are still used. It allows a more detailed analysis of the system by decomposing it into dimensions. Unlike other methods of scenario generation, it allows easier consideration of disruptive factors. Its objective is to pay particular attention to the formulation of the problem, especially the definition of the system's limits and the questions a stakeholder wishes to answer.

The French school of foresight's method is today more considered as a structuring tool for debate and a larger room is allocated to the consequences and follow-up of the studies, helping through the process of changing policies and managing strategies inside companies and other organisations. The emphasis is put on the link between scenarios and actions and high priority is given to mobilization inside organisations [42]. Moreover companies often need fast, reactive and adaptive answers when

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[2] These tools, which are included into the Scenaring tools suite, have been developed by the LIRSA-CNAM (Laboratoire Interdisciplinaire de Recherches en Sciences de l'Action) formerly called LIPSOR.

they have questions about the future of their field, that are unlikely to be provided by the Scenario Method, which requires long workshops.

3.3 Typology of scenarios generation

The typology presented by [43] provides criteria to classify the different methods based on scenario generation. Below, we will select only the criteria we consider relevant to contextualize our work. This will allow us to specify the nature of the scenarios we want to generate (see section 4).

- the criterion *Value/Reality* evaluates the "desirability" of the scenarios:
  - *descriptive* scenario: the scenarios are generated through exploration without any desirability consideration (they can be divided in two categories: *hypothetical* if the exploration is wide and sometimes far from reality, and *plausible* if the notion of probability is involved);
  - *normative* scenario: the scenarios are generated to reach specific goals (two extreme categories exist: *active* if the focus is put on some stakeholders actions and strategy during the scenarios or *passive* if the stakeholder has only an observational role).
- the starting point of the scenario [44]:
  - the present, therefore inductive reasoning (*likely-futures*: trend scenarios or *what-if scenario*: exploratory scenarios) is involved;
  - the future (an ideal or a feared situation), therefore abductive reasoning (*backcasting*) is involved.
- the time horizon of the scenarios;
- the way time is taken into account: continuous or discrete time;
- the scale of the variables: internal or external to the system;
- the number of scenarios: less or more than two;
- the study participants: the members of the organization initiating the study, the shareholders and decision makers (referred to in the sequel as the "users");
- the place of the organization initiating the study over the system and its environment (internal or external to the system, actor or spectator, etc.). This criterion can help to define the limits of the studied system.

Table 2 summarizes the methods presented in this section against some of these criteria.

Table 2. Sample of methods for future planning that usually rely on scenario generation

Approach	Objective	Process/ Scenarios	Organisations	Tools	Data type
Global forecast [27]	Guidelines and advice	One scenario or some thematic scenarios with uncertainty intervals	International organisations (i.e. ICAO), independent agencies	Global quantitative forecasting models	Quantitative
Strategic planning	Help stakeholders' decision-making	One forecasting scenario with uncertainty intervals	Companies (i.e., Airbus, Boeing)	Specific quantitative forecasting models	Quantitative
Intuitive Logic [31]	Decision-making, scenarios producing	Focus and data collection among experts, workshops to develop logic exploratory scenarios (from 2 to 4)	All types of organisations	-	Qualitative
Probabilistic Modified Trend [35]	Guidance, trend generation, causality highlighting	Key factors determination, trend extrapolations or probability on events, matrices of exploratory scenarios	Mostly companies	Trend Impact Analysis, Cross Impact Analysis	Quantitative with some qualitative additions

French Prospective (before 2015) [40]	System understanding	Workshops, system definition, key variables and relationships between components, exploratory scenarios (from 3 to 6)	All types of organisations	MICMAC, MACTOR, MORPHOL	Qualitative
"New" French Prospective [42]	Focus on mobilization and results implication	Workshops leading to exploratory scenarios (from 3 to 6)	All types of organisations	Morphological analysis, SWOT analysis	Qualitative
Massive Scenarios Generation (MSG) [45]	Strategic planning	High number of scenarios	Companies, military organisations	MSG generator (Ordinary sensitivity analysis, filtering)	Quantitative

We can notice from the approaches listed above that there is no formal model associated with qualitative data, except calculation tools such as MICMAC. Approaches dealing with forecasting models use only quantitative data to produce one scenario on a specific issue. Approaches dealing with qualitative data generate from 2 to 6 scenarios; they also aim to guide organisations of a sector or to support the decision making process of governments or companies : to our best knowledge this use is not much documented.

In the typology of [43], a distinction is made between a number of generated scenarios lower or higher than two. We can however make another distinction between the majority of methods that produce a number of "hand-made" scenarios between four and six, and the "massive" generation of scenarios that was proposed by [45]. Massive generation uses quantitative data and aims at exploring more than "*the obvious possibilities that are already in mind*" (p.13).

As far as analysis is concerned, the link between BigData and scenarios has been highlighted by [46] with potential common points such as: statistical method, modeling and simulation, multi-criteria decision analysis. BigData approaches could help to generate and analyze scenarios (especially massively) by being used for continuous variable discretization, real time consideration, heterogeneous data integration or alerts for invalidation of key assumptions. However, that paper notices that there is a need for "*formal theoretical foundation in the scenario domain*" and rigorous definitions for computational models which are applied in the generation and analysis of foresight scenarios.

4. Objectives of the work and positioning

4.1 Objectives

The objective of the work is to design a method and a formal tool to generate and analyse foresight scenarios automatically. It aims to systematize the reflection preceding the decision making of a stakeholder of the system whose possible futures are being studied, and who would be a user of the tool.

The expected outcomes of our approach are the following ones:

- use a formal mathematical language in order to:
  - express the required knowledge and try to reduce ambiguities due to the natural language;
  - systematize the generation of scenarios;
  - automatically compute the scenarios.
- use qualitative data;
- reduce some biases:

  - cognitive biases: the above described methods using qualitative data are performed in workshops where participants' opinions and backgrounds can influence them;
  - methodological biases:
    - data selection: using past data may not produce scenarios outside the trend;
    - limited number of generated scenarios: the determination of the scenarios paths could unintentionally avoid disruptions or possible conflicts;
    - use of probabilities
- bridge the gap between technical forecasting and anticipating the relationships between actors of a system, by considering both in the same study, e.g. in the aviation sector: consider technical progresses like hydrogen fuel or blended wing body, and relationships like between a government and aircraft manufacturers;
- answer various strategic questions faster than with workshops often lasting several months;
- validate the initial knowledge and the consistency of the results.

4.2 Positioning

Referring to subsection 3.3 we will work on *descriptive* and *hypothetical* scenarios. However, the decision support objective could lead to the simulation of precise paths leading to some desired situation, which would place our work in a *normative* and *active* perspective. The generation of exploratory scenarios requires positioning oneself in a logic of *forward-casting* but should not exclude working in more detail on a future which would be chosen in advance. Regarding the time horizon of our scenarios, they will be limited by stopping criteria defined in section 7. Time will not be modeled explicitly, the scenarios being constructed as a sequence of states and events building the history of a possible future. Finally, as in [45] we wish to generate a large number of scenarios. However, we differ from that work as the nature and analysis of the scenarios will not be quantitative.

In section 2, we have described forecasting scenarios on the future of the air transportation based on quantitative data. We have also presented foresight global scenarios relying on qualitative data describing what the aviation sector could become. As was said in section 2, the aviation sector is no exception when it comes to future planning and scenario generation: in fact, we could not find in this sector any use of models dealing both with qualitative data and generating a large amount of scenarios automatically.

In this paper, we will use our formal model to generate scenarios on the future of aviation, based upon knowledge representing a simplified air transport system (see next section). Then we will introduce an analysis of these scenarios, answering specific questions that could be raised by a stakeholder of the sector.

5. Initial knowledge

The issues the aviation sector has to deal with (section 2) can be considered from many points of views. In this paper we consider the viewpoint of a fictitious airline company *Easyflight* wondering how to adapt to potential future changes and how to anticipate another possible crisis. This company will be the user of the foresight tool.

This company is part of the aviation system, therefore let other considered agents be:

- Customer;
- GovernmentX;
- SuperFuel: a conventional fuel supplier;
- SARS-CoV-2: an external troublemaker who represents the sanitary crisis.

Each agent takes stand on the following moral principles:

- Wealth Creation;
- Environmental Protection;
- Customer Satisfaction.

Finally, we define variables of interest, representing key points of the aviation system. These variables allow to characterize the limits of the chosen system.

The variables are:

- Flight supply;
- Ticket price;
- Flight demand;
- Fuel supply;
- Limitation policies;
- Sanitary crisis.

Each agent is associated with one or several variables and can make decisions to change their values (i.e. *FlightEasy* can decide to increase the *Flight Supply*). Because all agents make decisions at the same time, conflicts can happen. For example, if *FlightEasy* chooses to increase the *Flight Supply* and *SuperFuel* decreases the *Fuel Supply*, it is considered as a conflict of a logical nature. Moreover, a single agent can face internal conflicts when they have no other choice but to decide against one of their moral principles or policies. For example, *GovernmentX* has to choose between creating *Limitation Policies* therefore going against the *Wealth Creation* moral principle, or not creating *Limitation Policies* and therefore going against the *Environmental Protection* principle. *GovernmentX* is in favour of both moral principles: so whatever decisions they make, a conflict of a moral nature will appear.

Generating scenarios on the future of aviation requires initial knowledge, which is used to instantiate the model and start the foresight exercise. They will be described in section 6 as an illustration for our model and processed with an algorithm to generate foresight scenarios on the future of a simplified air transport system. The results will be described in section 7.

6. Model and application to a use case

Our formal model has already been published in [47] and is updated in this paper. It is based upon some concepts which are supported by the French school of Prospective (see 3.2.2) such as agents and variables. In addition, moral principles to which agents are committed are added, which is generally not considered with existing scenario methods [3].

6.1 System definition

Definition 1. *(***Principle** *- Set Π) Π is a set of elements π called principles.*

Example

$$\Pi = \{WealthCreation, CustomerSatisfaction, EnvironmentalProtection\}$$

Definition 2. *(***Variable** *- Set $\mathcal{V}$) $\mathcal{V}$ is a set of elements v called variables, each of them takes its values in a discrete set noted $\mathcal{W}_v$. We write $\mathcal{W}_{\mathcal{V}} = \bigcup_{v \in \mathcal{V}} \mathcal{W}_v$.*

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[3] « *Values play a powerful role as motivating ideals in shaping policy measures and legal norms. While the set of values [...] inspires desirable behaviour and represents the foundations of principles, the principles unpack the values underlying them more concretely so that the values can be more easily operationalized in policy statements and actions.* » [48]

Example

$$\begin{array}{rl} \mathcal{V} = \{FlightSupply, FlightDemand, TicketPrice, & \\ FuelSupply, LimitationPolicies, SanitaryCrisis\} & \end{array} \quad with \quad \begin{array}{l} \mathcal{W}_{FlightSupply} = \{Low, Steady, High\} \\ \mathcal{W}_{FlightDemand} = \{Low, Steady, High\} \\ \mathcal{W}_{FuelSupply} = \{Low, Steady, High\} \\ \mathcal{W}_{LimitationPolicies} = \{Yes, No\} \\ \mathcal{W}_{TicketPrice} = \{Low, High\} \\ \mathcal{W}_{SanitaryCrisis} = \{Yes, No\} \end{array}$$

Definition 3. *(**Laws of the domain** - Set C) Expression of the system constraints.*

Among the laws of the domain are variable/value pairs that are incompatible with each other: the function *incompatible* return « True » if a set of pairs (*variable*, *value*) are incompatible.

Definition 4. *(Function **incompatible**)*

$$incompatible : P(\mathcal{V} \times \mathcal{W}_{\mathcal{V}}) \longrightarrow \{True, False\} \tag{1}$$

with P the power set of all the subsets of $\mathcal{V} \times \mathcal{W}_{\mathcal{V}}$

Example

$$C = \{incompatible((FlightSupply, High), (FlightDemand, Low)) = True\}$$

Definition 5. *(**Agent** - Set $\mathcal{A}$) An agent a is defined by its identifier i_a and by the set $\mathcal{V}_a$ of variables it can control (in particular through decision-making).*

$$\forall a \in \mathcal{A}, a =< i_a, \mathcal{V}_a > \tag{2}$$

The following simplifying assumptions is made here :

- there is no variable that no agent can control.

Given these elements, we can define the system as:

Definition 6. *(**System** Σ) A system is a quadruplet composed of a set $\mathcal{A}_I$ of agents which will be called internal, a set Π of moral principles, a set $\mathcal{V}$ of variables and a set of laws of the domain C.*

$$\Sigma =< \mathcal{A}_I, \Pi, \mathcal{V}, C > \tag{3}$$

The following simplifying assumptions are made here:

- the system is closed (the system's components cannot change);
- closed-world assumption (what is not known to be true, is false (see [49])).

We make a distinction between agents that are inside and outside the system.

Definition 7. *(**External agent** - Set $\mathcal{A}_X$) An external agent can initiate disturbances by acting on variables in the system. It doesn't belong to the system: $\mathcal{A}_I \cap \mathcal{A}_X = \oslash$*

Example $\mathcal{A}_X = \{SARS - CoV - 2\}$

Definition 8. *(**Internal agent** - Set $\mathcal{A}_I$) An internal agent a_I is a stakeholder of the system. It is characterized with several attributes which will be defined later on.*

Example

$$\mathcal{A}_I = \{EasyFlight, SuperFuel, GovernmentX, Customer\}$$

with *EasyFlight* an airline company, *SuperFuel* a conventional fuel supplier, *GovernmentX* the government of a country X and *Customer* a customer of air transport.

A system state is defined as follows:

Definition 9. (**State of the system** - *Set* **E**) *A state e of the system is composed of a set $\mathcal{P}_e$ of the positions (definition 10) of the internal agents on the principles, a set $\mathcal{O}_e$ of the opinions (definition 11) of the internal agents and a set $\mathcal{I}_e$ of the instantiated variables. The initial state of the system is given.*

$$e =< \mathcal{P}_e, \mathcal{O}_e, \mathcal{I}_e > \tag{4}$$

We admit that a variable cannot have two different values in a given state.

$$\begin{gathered} \forall v \in \mathcal{V}, \forall (w_v, w'_v) \in \mathcal{W}_\mathcal{V}, \\ (v, w_v) \in \mathcal{I}_e \land (v, w'_v) \in \mathcal{I}_e \land w_v \neq w'_v \Rightarrow incompatible_e((v, w_v), (v, w'_v)) = True \end{gathered} \tag{5}$$

Example

Let e_0 be the initial state of the system,

$$\begin{aligned} \mathcal{I}_{e_0} = \{&(FlightSupply, Steady), (FlightDemand, Steady), (LimitationPolicies, No), (FuelSupply, Steady), \\ &(TicketPrice, Low), (SanitaryCrisis, No)\} \end{aligned}$$

An internal agent is qualified with the following functions:

Definition 10. *(Function* ***position****) The function position specifies the view of the internal agent a_I on the moral principles of the system in a given state e (see definition 9). The agent can support (+), be indifferent to (=) or be opposed to (−) a principle.*

$$position_{a,e} : \Pi \longrightarrow \{+, =, -\} \tag{6}$$

The set of the values of the positions of the agents on the moral principles, that are given by the function *position* in a state e, is written $\mathcal{P}_e$: $\mathcal{P}_e \subset \mathcal{A}_I \times \Pi \times \{+, =, -\}$
The subset of all the positions of a unique agent a in a state e is written $\mathcal{P}_{a,e}$. All the internal agents must have a position (even if indifferent) on each of the principles. The set of positions depends on the state e of the system: for example, in a sanitary crisis situation, the *Health* principle will have more importance than in a regular situation.

Definition 11. *(Function* ***opinion****) The function opinion returns the stated opinion of an internal agent a_I on how the value of a variable is positioned with respect to a principle in a given state e. The agent may consider that the value of the variable is in line with the principle (1), that it is not related to the principle (0) or that it is in contradiction with the principle (−1).*

$$opinion_{a,e} : \mathcal{V} \times \mathcal{W}_\mathcal{V} \times \Pi \longrightarrow \{1, 0, -1\} \tag{7}$$

The set of the stated opinions of the internal agents, given by the function $opinion_a$ in a state e, is written $\mathcal{O}_e$ and the subset of the opinion of a unique agent a in a state e is written $\mathcal{O}_{a,e}$.

Example

Let us have :

$$\begin{aligned}&e\ \textit{a given state (see } 9\text{)},\\ &position_{EasyFlight,e}(CustomerSatisfaction) = +\\ &opinion_{EasyFlight,e}((FlightSupply, Low), CustomerSatisfaction) = -1\end{aligned}$$

Which means that: in the state e, the company *EasyFlight* is in line with the moral principle *CustomerSatisfaction* and considers that if the value of variable *FlightSupply* is *Low*, it does not respect the principle *CustomerSatisfaction.*

6.2 Decision and Action

Internal agents can decide to modify (or not) the values of the variables they can control. They can perform actions and contrary to the external agents, they have the ability to make decisions.

Definition 12. *(**Decision** - Set $\mathcal{D}$) A decision $d_{a,v,e}$ is the choice of an internal agent a_i to do something about a variable v in a state e.*

A decision can be:

- a desire to act (change or maintain the value of the variable);
- do nothing about this variable (i.e. let the other agents do what they want). In the case where an agent is the only one who can act on a variable, the decision to do nothing is equivalent to the decision to maintain the state of the variable.

Let $\mathcal{D}_e$ be the set of decisions considered in state e, $\mathcal{D}_{a,e}$, the subset of decisions considered only by the agent a in the state e and $\mathcal{D}_{a,v,e}$, the subset of decisions considered by agent a on variable v in state e.

Example

$$\mathcal{D}_{FlightEasy,FlightSupply,e_0} = \{IncreaseSupply, DecreaseSupply, DoNothingSupply...\}$$

Definition 13. *(Function **h**) Function h returns the result of a decision $d_{a,v,e}$ to change the value w_v of a variable v with the value w'_v.*

$$h : \mathcal{D} \times \mathcal{V} \times \mathcal{W}_{\mathcal{V}} \rightarrow \mathcal{V} \times \mathcal{W}_{\mathcal{V}} \tag{8}$$

Definition 14. *(**Action** - Set $\mathcal{A}_c$) An action is the achievement of a decision. It allows to switch from instance (v, w_v) to instance (v, w'_v).*

The actions of the agents modify the state of the system.

Definition 15. *(**Event**- Set $\mathcal{E}$) An event is a variation of the state of the system by a change of values of one or more variables as a result of an action, or as a result of a change of positions of the internal agents on the principles or of opinions on the values of the variables.*

The following simplifying assumptions are made here:

- an internal (respectively external) agent is limited to one decision (respectively action) per variable in each state of the system;
- an internal (respectively external) agent knows the current values of all the variables they can control;
- in each state, an internal (respectively external) agent must make decisions (respectively actions) on all the variables it can control;
- there is no dynamics specific to the system: a variable value only changes under the action of an agent (definition 14); therefore, the variables are independent of each other.

Main assumption
An internal agent cannot make decisions that go against the principles they support. They can, however, change their positions and opinions during the course of the scenario.

Special case of the user

It is assumed that the internal agent that is initiating the foresight study, i.e., the user, may make decisions that are contrary to their own views on the principles. In our example, agent *EasyFlight* is the user. Indeed, the user, in addition to acting according to principles, may be guided by goals (see definition 16 below) :

Definition 16. *(***Goal** $\mathcal{G}_u \subset (\mathcal{V} \times \mathcal{W}_{\mathcal{V}})$*) Set of the values the user wants the variables to reach.*

Example

$$\mathcal{G}_{EasyFlight} = \{(TicketPrice, High), (FlightSupply, High)\}$$

6.3 Conflicts

As a result of their decisions in a given state, agents may face logical conflicts or moral conflicts.

6.3.1 Logical conflict

A logical conflict occurs between two or more variables when:

- agents seek to instantiate the same variable with different values or
- agents seek to instantiate variables in a way that is defined as incompatible (see def4).

Definition 17. *(***Logical conflict***) :*

$$\forall e, \forall \mathcal{D}_e, logicalconflict(\mathcal{D}_e, e) = True \iff \left[\begin{array}{l} \exists \mathcal{H}_e, \exists n, 0 < n \leq |\mathcal{V}|, \exists (v^1, {w_v}^1), ..., (v^n, {w_v}^n) \in \mathcal{H}_e, \\ incompatible((v^1, {w_v}^1), ..., (v^n, {w_v}^n)) = True \end{array} \right. \tag{9}$$

with $\mathcal{H}_e$ the partial state of the system resulting from the decisions of some agents in state e.

$$\mathcal{H}_e = \{h(d_{a,v,e}, v, w_v), a \in \mathcal{A}, v \in \mathcal{V}, w_v \in \mathcal{W}_v, d_{a,v,e} \in \mathcal{D}_e\} \tag{10}$$

Example

Let us consider company *EasyFlight*'s decision to *IncreaseSupply* in the initial state e_0 where *FlightSupply* is *Steady* :

$$d_{FlightEasy,FlightSupply,e_0} = IncreaseSupply$$

If agent *EasyFlight* makes this decision, the value of variable *FlightSupply* will switch from *Steady* to *High*.

$$h(IncreaseSupply, FlightSupply, Steady) = (FlightSupply, High)$$

Let us now consider the *Customer* agent in the initial state where *FlightDemand* is *Steady*:

$$d_{Customer,FlightDemand,e_0} = DecreaseDemand$$

If agent *Customer* makes this decision, the value of variable *FlightDemand* will switch from *Steady* to *Low*.

$$h(DecreaseDemand, FlightDemand, Steady) = (FlightDemand, Low)$$

The law of the domain :

$$C = \{incompatible((FlightSupply, High), (FlightDemand, Low)) = True\}$$

means that these two pairs are incompatible, therefore, *EasyFlight* and *Customer*'s decisions result in a logical conflict.

6.3.2 Moral conflict

The definition of a moral conflict is inspired by the one provided by [50]. A moral conflict focuses on the principles and opinions of one single agent. An agent faces a moral conflict in a state e when each decision they could make on a variable is either contrary to their principles by nature or has negative consequences. These two possibilities will be defined respectively through the function *NegPrinciple* and the function *BadConsequence*.

Function *NegPrinciple* returns the Boolean « True » when the decision of an agent a is by nature against the principles supported by this agent in a state e :

Definition 18. *(Function* ***NegPrinciple****)*

$$NegPrinciple_{a,e} : \mathcal{D}_{a,e} \times \Pi \rightarrow \{True, False\} \tag{11}$$

The fact that an agent's decision is contrary to a principle is specified in the laws of the domain.

Example

Apart from the initial knowledge (5), one could consider for the demonstration that:

$$NegPrincipe_{Users,e_0}(PromoteAviationThroughGreenwashing, Honesty) = True$$

The agent *EasyFlight* considers that the decision *PromoteAviationThroughGreenwashing* is against the moral principle *Honesty* in the initial state e_0.

Function *BadConsequence* returns the Boolean « True » if the action resulting from a decision has negative consequences for an agent a in a state e. "Consequences" here means a partial state $\mathcal{H}_a$ with instances of variables that go against at least one principle the agent adheres to.

Definition 19. *(Function **BadConsequence**)*

$$BadConsequence_{a,e} : \mathcal{D}_{a,v,e} \times \Pi \times \mathcal{P}_{a,e} \times \mathcal{O}_{a,e} \rightarrow \{True, False\} \tag{12}$$

Example 1

$$h(DecreaseSupply, FlightSupply, Steady) = (FlightSupply, Low)$$

with the position and the opinion specified below according to definition 11

$$BadConsequence_{FlightEasy,e_0}(DecreaseSupply,\ WealthCreation, +, -1) = True$$

In the initial state e_0, agent *EasyFlight* is in line with the principle *WealthCreation* (+). However, they have a negative opinion (-1) about this principle being respected by value *Low* of variable *FlightSupply*. The consequence of the action corresponding to the decision to instantiate the variable by this value is negative for agent *EasyFlight*.

We could also have a situation where an agent is against a moral principle (-) but acts according to it (1). The decision resulting in this situation would have negative consequences too.

Example 2

Apart from the initial knowledge (see 5), one could consider for the demonstration that:

$$h(MakeProfits, Profits, No) = (Profits, Yes)$$

with the position and the opinion specified below according to definition 11

$$BadConsequence_{NotForProfitOrganization,e_0}(MakeProfit,\ WealthCreation, -, 1) = True$$

Let us consider another initial state e_0, where the agent *NotForProfitOrganization* is against the principle *WealthCreation* (-). They have however a positive opinion (1) about this principle being respected by value *Yes* of variable *Profits*. The consequence of the action corresponding to the decision *MakeProfits* to instantiate the variable *Profits* by this value *Yes* is negative for agent *NotForProfitOrganization*.

Definition 20. *(**Moral conflict**) :*

$$\begin{array}{l} moralconflict(a, \mathcal{P}_{a,e}, \mathcal{O}_{a,e}, e) = True \iff \\ \exists v \in \mathcal{V}, \forall d_{a,v,e} \in \mathcal{D}_{a,v,e}, \exists \pi \in \Pi, \left[\begin{array}{l} NegPrincipe(d_{a,v,e}, \pi) = True \vee \\ BadConsequence(d_{a,v,e}, \pi, position_{a,e}(\pi), opinion_{a,e}(h(d_{a,v,e}, v, w_v), \pi)) = True \end{array} \right. \end{array} \tag{13}$$

Example

Apart from the initial knowledge (see 5), let us consider for the demonstration, the agent *EasyFlight* in the initial state e_0 where *FlightSupply* is Steady:

$$\mathcal{D}_{EasyFlight,e_0} = DecreaseFlightSupply, PromoteAviationThroughGreenwashing$$

However, we previously stated that:

$$\begin{array}{l} NegPrincipe_{Users,e_0}(PromoteAviationThroughGreenwashing, Honesty) = True \\ BadConsequence_{FlightEasy,e_0}(DecreaseSupply,\ WealthCreation, +, -1) = True \end{array}$$

Whatever the decision, agent *FlightSupply* will compromise their moral principles either by nature or by consequences, it is a moral conflict situation.

6.4 Scenario definition

A scenario is defined by the initial state of the system e_0, a final state of the system e_f, and a path c from e_0 to e_f.

Definition 21. *(***Scenario** *- Set* $\mathcal{S}$*)*

$$\forall s \in \mathcal{S}, s =< e_0, e_f, c > \textit{ with } e_0,\ e_f \in \mathbf{E} \textit{ and } c \textit{ the path.} \tag{14}$$

c is a list composed of:

- the different states of the system during the scenario;
- the events associated with the changes of states;
- information such as: decisions to do nothing so that the set of instantiated variables of a system state is not modified, or the justification for stopping a scenario.

7. Scenario generation

7.1 Algorithm

The generation of a scenario (see algorithm below) consists in the generation of a succession of states. The transition from one state to another results from the aggregation of the decisions made by the different agents of the system. Indeed, each internal agent compares their opinion (see definition 11) with the value of the variables in the the state of the system which would result from the decisions considered by the agents (defined in the model as $\mathcal{H}_e$ (see definition 17)). Decisions that are either opposed to an agent's principles or lead to negative consequences are rejected (moral conflict). The remaining possible decisions of the internal agents are then aggregated with the disturbances (actions made by the external agents) and compared, which may lead to logical conflicts. Once the aggregation is completed, the corresponding actions are performed and a new state of the system is reached.

Algorithm 1 Scenario Generation

```
Require: initial knowledge, initial state of the system
  function SCENARIO(knowledge, previous state)
      for all Agents do
          for all Variables that the agent can control do
              List of the possible decisions the agent can make in this state
              Cancel the decisions that are either against the moral principles of the agent or that have bad consequences
              if Moral conflict (Empty list of possible decisions) then
                  return Scenario
              else Choice of a possible decision
              end if
          end for
          Choice of a possible decisions combination
      end for
      Aggregation of all agents combination
      if Stopping criteria (see below) then End of the scenario
      else
          Realisation of the actions corresponding to each decision: Next state
          Application of the function SCENARIO to the next state
      end if
  return Scenario
  end function
```

The stopping criteria of a scenario are :

- the convergence of the scenario towards a state, characterized by :
    - a stabilization (two successive identical states);
    - a logical conflict between two or more variables;
    - a moral conflict for a single agent;
    - the achievement of the user's goals;
    - the reaching of a predefined state of interest.
- the convergence of the scenario towards a limit loop.

This model has been implemented with Python 3.8. The code execution can be divided in three steps:

- data gathering: they can be provided by the user and be the result of a morphological analysis, they could also be retrieved numerically;
- generation of scenarios;
- analysis of the results.

The automated scenario generation is computed thanks to a tree structure where nodes are the system states and edges are the decisions made by the agents. We have applied the stopping criteria but also an arbitrary criteria on the tree depth to limit the number of generated scenarios. Since it is assumed that the initially defined agents, variables and principles cannot change during scenarios generation, the number of possible scenarios is finite.

In fact, the number of scenarios is provided by the formula:

$$\mathcal{N}_{dep} = \Delta^{dep} - \phi \sum_{i=0}^{dep-1} \Delta^{i} \ avec \ \Delta = \prod_{v=1}^{\mathcal{V}} \delta_{v} \tag{15}$$

and :
$\mathcal{N}$ *the number of scenarios*
dep *the depth of the tree structure*
δ_v *the number of decisions that can be made on variable* $\boldsymbol{v}$ *in a state*
$\mathcal{V}$ the set of variables
ϕ *the number of scenarios that have been stopped in the previous depths*

This highlights that the complexity of the problem is exponential in the number of decisions that the agents can make thanks to the recursive function.

7.2 Results

When we compute the knowledge presented in section 5, the algorithm returns scenarios shown below.

Example

```
    Scenario :
State (1): ’FlightSupply’: ’Steady’, ’LimitationPolicies’: ’No’, ’TicketPrice’: ’Low’,
    ’FuelSupply’:’Steady’, ’SanitaryCrisis’: ’No’, ’FlightDemand’: ’Steady’
Decisions : ’EasyFlight’: [’DoNothingSupply’, ’IncreaseTicketPrice’],
    ’GovernmentX’: [’EstablishPolicies’], ’SuperFuel’: [’IncreaseFuelSupply’],
    ’Customer’: [’DoNothingDemand’], ’SARS-CoV-2’: [’StartSanitaryCrisis’]
State (2): ’FlightSupply’: ’Steady’, ’LimitationPolicies’: ’Yes’, ’TicketPrice’: ’High’,
    ’FuelSupply’: ’High’, ’SanitaryCrisis’: ’Yes’, ’FlightDemand’: ’Steady’
Decisions : ’EasyFlight’: [’IncreaseSupply’, ’DoNothingTicketPrice’],
    ’GovernmentX’: [’DoNothingPolicies’], ’SuperFuel’: [’ReduceFuelSupply’],
    ’Customer’: [’DoNothingDemand’], ’SARS-CoV-2’: [’EndSanitaryCrisis’]
End of scenario : logical conflict between variables [’FlightSupply’, ’LimitationPolicies’]
```

In this example, the scenario stopped because of a logical conflict, after the system reached two different states. The logical conflict is due to agent *EasyFlight* wanting to *IncreaseSupply* and to agent *GovernmentX* wanting to *DoNothingPolicies* and therefore keep limitation policies on the air transport, which is incompatible with having a *High FlightSupply*.
With a tree depth of three, 26358 scenarios are generated. Among them, 11026 end with a logical conflict and 25 with a loop. 435 of them reach the goals fixed by the user (see 16). Only 27 states (combination of variables and values) are reached out of 216 possibilities resulting from the combination of all the variables and their different values. This is due to the limitation of the tree depth and the fact that agents cannot make decisions compromising their moral principles.

8. Analysis

The analysis of the scenarios consists in answering the user’s questions (here *EasyFlight*). The will of the user can be to reach a specific goal (see definition 16) or to have a global view of the possible futures of the system for anticipation or guidance.

8.1 Achieving goals and avoiding conflicts

We can first retrieve the values of the variables that are never reached. They may be the first explanation for objectives that cannot be achieved.

Example

Never reached values : $\{FuelSupply : [Low],\ FlightDemand : [High]\}$
However, these values do not have any impact on the achievement of the user’s goals, which are to have a *High FlightSupply* and a *High TicketPrice*.

The next question that can be asked is: Do any moral principles have to be compromised to achieve a given goal? By retrieving the scenarios ending with the achievement of the user’s goals (specified in the initial knowledge) we can focus on the moral principles that are compromised in these specific scenarios.

Example

Percentage of scenarios reaching the goals in which a principle is compromised:
$\{WealthCreation : 92\%,\ CustomerSatisfaction : 100\%,\ EnvironmentalProtection : 0\%\}$

That means that, to satisfy the complete set of their goals, the user must go against principle *Customer Satisfaction* and in 92% of the scenarios, they must go against *Wealth Creation*.

A user could want a more global overview of the produced scenarios to guide themselves or others in the next years or to be prepared to deal with major changes. By browsing the set of generated scenarios, we can retrieve the variables and decisions that can be often found directly in conflict situations. The actual occurrences of the variables and their values in conflict situations do not always match the occurrences of the variables in the incompatibilities made explicit in the laws of the domain (see definition 4). Indeed, some conflicts do not appear as often as expected, due to assumptions that agents, except the user, cannot compromise their moral principles and due to the maximal depth arbitrarily defined for the tree. Both reasons limit the final number of scenarios.

Example

> Percentage of the occurrences of the variables in conflicts:
> {*FlightSupply* : 100%, *LimitationPolicies* : 32%, *SanitaryCrisis* : 8%, *FlightDemand* : 16%, *TicketPrice* : 46%}
>
> Percentage of the occurrence of the decisions right before conflicts happen:
> {*IncreaseSupply* : 53%, *EstablishPolicies* : 16%, *StartSanitaryCrisis* : 4%, *DecreaseDemand* : 8%, *DoNothingSupply* : 17%, *DoNothingPolicies* : 15%, *DoNothingSanitaryCrisis* : 4%, *DecreaseSupply* : 30%, *DecreaseTicketPrice* : 30%, *DoNothingDemand* : 8%, *DoNothingTicketPrice* : 15%}
>
> This means in particular that increasing the aircraft flight supply is responsible for 53% of the conflicts.

This last result allows to say whether a given decision is necessary for a conflict to happen (when the percentage is equal to 100 which is not the case here) but nothing can be said on its sufficiency.

We can then retrieve more meaningful results by using open-source data mining algorithms [51]. We focus here on the algorithm RuleGrowth [52], which allows to discover sequential rules in the sequences of a database. In our situation, the sequences are the scenarios already generated. We can therefore find one or more set(s) of decisions that are responsible for the occurrence of a conflict. A set of decisions is said to be sufficient to cause a conflict, when the rule *{set of decisions}->conflict* is valid, which means that the probability of the set of decisions to cause a conflict equals to 1. If there is no sufficient set of decisions, we can retrieve the smallest set of decisions with the maximum probability to give a conflict. We can finally check if the occurrence of this set is necessary for a conflict to happen, which means that this set of decisions is included in every scenario ending with a conflict.

Example

> Using the algorithm RuleGrowth with a minimum support (occurrence rate) of 0.005 and a minimum confidence of 0.6, we can find that there is no set of decisions that is sufficient for a conflict to happen. Therefore, the smallest set with the maximum probability to produce a conflict is:
> {*IncreaseSupply*, *DecreaseSupply*, *EstablishPolicies*, *DoNothingTicketPrice*, *DecreaseTicketPrice*, *StartSanitaryCrisis*, *DecreaseDemand*} ==> *logicalconflict* : *SUP* : 659, *CONF* : 0.92
>
> The above set leads to a conflict with a confidence of 92%. Because its support equals to 659 and the number of conflicts is 11026 (which is given by general statistics returned at the end of the generation), this set causes only 6% of the total number of generated conflicts. Therefore it is not necessary for a conflict to happen.

The algorithm used above can only give indication on a set of decisions without any order consideration inside of it. Such information can be given using PrefixSpan [53] algorithm.

Example

Using the algorithm PrefixSpan with a minimum support of 0.1 we can find the sequence leading to most of the conflicts : *IncreaseFuelSupply* → *DoNothingFuelSupply* → *logicalconflict* : *support* = 11004 (meaning 99,8% of the scenarios ending with a conflict)

We can use the same algorithm to retrieve complementary information about the decisions causing a conflict. In fact we can have a relationship between conflict and decision including not only decisions made just before the conflict but all the decisions made in the scenarios. However, this algorithm gives no information on the sufficiency of the set of decisions to cause a conflict.

Example

Using the same algorithm, we can find the decision leading to most of the conflicts : *IncreaseFuelSupply* → *logicalconflict* : *support* = 11026 (which is equal to the total number of scenarios ending with a conflict). One decision is necessary for a conflict to happen: *IncreaseFuelSupply*.

We can also make the same analysis with a set or sequences of decisions that are sufficient or/and necessary to reach the user's goals. It however requires more computational resources because there are much fewer scenarios ending by the achievement of the objectives than scenarios ending by a conflict. Therefore the sequences of interest are generally rare.

8.2 Graphical representation of the scenarios

We can also offer the user the possibility to represent the set of calculated scenarios on a graph (see figure 1).

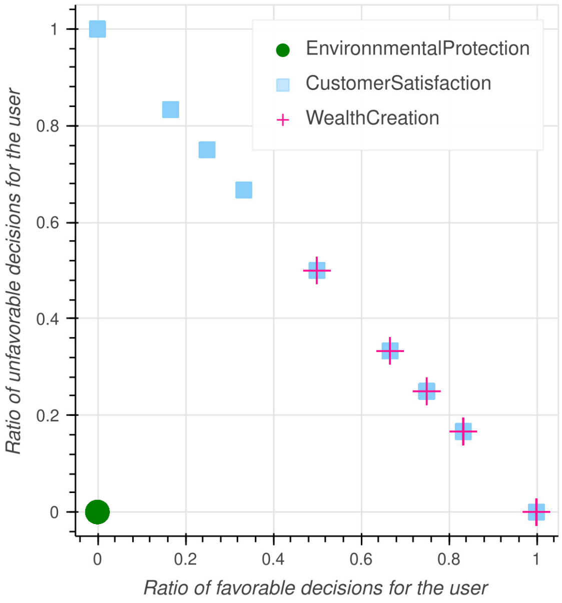

Figure 1. Scenarios representation according to moral principles

The scenarios are represented according to the number of positive or negative decisions for the user regarding their moral principles (see definition 19) as a proportion of the total number of decisions made by the user in each scenario. This representation allows to find ideal scenarios regarding one or more moral principles for the user, e.g., with the minimal proportion of unfavorable decisions. The overlapping blue squares and pink crosses at the bottom right of the figure (located at (1,0)) can be seen as the best scenarios for the user *EasyFlight* regarding respectively the *CustomerSatisfaction* and the *WealthCreation*. Indeed, at this location, all the decisions of the user meet the principles (x=1) and none break them (y=0). However, these "best scenarios" are not necessarily the same for both principles, therefore some balance may need be needed between them. This representation could be generated for each agent of the system by considering them as the "user" in turn. We could then compare their points of view, retrieving the scenarios of best interest for each of them. The set of scenarios represented could also be limited to the scenarios ending with the achievement of the user's goals: this allows to retrieve the principles that need to be compromised to reach the goals.

This representation of the scenarios based on the moral principles of the agents could also question the initial knowledge and the way the moral principles and the decisions were chosen and written. We can see in the example that the scenarios are distributed over almost all possible combinations of the ratio of positive and negative decisions for the *CustomerSatisfaction* principle, i.e., the blue squares. It means that we have scenarios that are very unfavorable to this principle (with only negative decisions) for the user, others that are very favorable and some of them that are more balanced with as many positive as negative decisions. Therefore, regarding *CustomerSatisfaction*, various possibilities are explored. Moreover, the location of the scenarios regarding *WealthCreation*, i.e. the pink crosses, shows that in the example there are no scenarios that break this principle (located at (0,1)), as they can all be found in the diagonal, between the coordinates (0.5, 0.5) and (1,0). This is due to other agents who cannot compromise their principles (see main assumption of the model in section 6.2). This results in decisions that cannot be taken and states of the system that will never be reached. Therefore the situations where the user would take unfavourable decisions never happen. Finally, all the scenarios regarding the principle *EnvironmentalProtection*, i.e. the green circles, are at the origin of the graph. Indeed, the user *EasyFlight* is neutral towards this principle, therefore their decisions cannot be positive or negative towards *EnvironmentalProtection*. This assumption could be changed to observe the possible evolutions of the system.

9. Discussion

This section deals with the issues raised by this approach whether caused by biases in the formal model, in the knowledge used, in the questions addressed in the analysis or the methods offered to solve them.

9.1 About the initial knowledge

The choice of the initial knowledge is not part of the work presented here but is worth discussing. It has been said earlier that in a foresight process, knowledge comes either from the past (usually to generate trends) and/or from workshops. In workshops it can be chosen by experts, stakeholders, researchers or a combination of those. These participants may have cognitive biases that come from their previous experiences and opinions and may be, intentionally or not, purpose driven. Whatever the composition of the group, it is also worth noticing that knowledge cannot be exhaustive and describe perfectly a system of agents because no one is omniscient.

Our model also relies on initial knowledge that can be the results of workshops and affected by the biases mentioned above. In most of the situations, the user, i.e., the stakeholder that has initiated the foresight study, provides this initial knowledge. They select the variables, agents and decisions of the system they want to explore. They can give their own positions (definition 10) on the moral principles and opinions (definition 11) but have to make assumptions on other agents situations. The user may know the positions or opinions of some other agents of the system but they can also deduce this information from their past actions for example.

To generate the scenarios introduced in section 7, we have chosen initial knowledge based upon facts and scenarios published in the aviation sector. In doing so we may be influenced by the same biases than those described above. Moreover, we have arbitrarily attributed positions and opinions to the user and the other agents, taking into account what is expressed on their websites or their various publications; in particular, their internal and maybe "hidden" beliefs cannot be considered. We have also assumed the nature of a decision to illustrate the function *NegPrinciple* (see 18). Here, the action related to the decision is judged, rather than its consequences. This judgment has been

arbitrarily made and is influenced by our point of view. In the example, the decision *PromoteAviationThroughGreenwashing* has been considered against the principle of *Honesty* even if the consequences of this decision would be to increase the *FlightSupply* and not to go against any moral principles. This reflects a deontological point of view.
In addition, because there is no causal effect between the variables (this subject will be discussed in the next section), it is easier for us (or the stakeholder gathering the knowledge) to assess the consequences of a decision for each agent. Such information is then used in a moral conflict situation when the function *BadConsequence* is called (see 19). In fact, only the direct consequences of a decision are considered. For example, the decision *IncreaseFlightSupply* only changes the variable *FlightSupply* to the value *High* and has no impact on the increasing of the value of the variable $SARS - Cov - 2$.

Finally, three different issues can be noticed concerning the choice of the moral principles:

- the difference between values, principles and goals is thin and there is no consensus in the literature, which can confuse the provider of the knowledge;
- it is difficult to select universal principles, as principles usually depend on the cultural and social context;
- the choice may also be reduced to principles confirming the purpose of the foresight study (confirmation bias). We could have a situation where the user only selects principles they are supportive of.

To conclude it is worth keeping in mind that the generated scenarios reflect the perspective of the provider of the initial knowledge.

9.2 About the formal model

The formal model presented in this paper has been designed in a team of researchers coming from aviation research labs. Some concepts such as system, variables or values rely on the Scenario Method of M. Godet, which has been used in various studies and fields. Our model has been tested to generate scenarios about the future of the air transport sector, however, it is intended to be general and to support initial knowledge describing any sector. Nonetheless, for some applications, it might be difficult to represent some concepts that have not been initially considered.

Several assumptions may be discussed (see section 6):

- *"There is no system dynamics"* and *"there is no variable that no agent can control"*: The first assumption implies that there is no causal effect between the variables and their changes of values, the variables are independent from one another. Therefore, they need the action of an agent to change their values. The second assumption prevents the current model from including a variable that could not change its values.
  Changing these assumptions would allow new features to be considered:
  - breaking the independence of the variables may allow the model to get closer to the reality where usually an action has consequences that are not limited to the values of the variables directly involved;
  - including variables whose values can be changed by causal effects could also be another way to represent disturbances in the system or global actions (such as the global warming);
  - considering additional global variables may give the analysis a higher level of abstraction. For example a global value *FlightSupply* could summarize values changes in *ShortFlightSupply* and *LongHaulFlightSupply*.
- *"The system is closed"* means that no variable, decision or principle can be added during the generation of the scenarios. However, in the real world, new decisions that have never been considered before can be made in a crisis situation, e.g., new variables can be considered after

a technological breakthrough; new moral principles may be important in a war situation for example or after a deep change in a society.

- *"The closed-world assumption"* [49] means that what is not known to be true is false. Indeed, there are no consequences of actions that are not written in the initial knowledge. This is different in the real world where unpredictable consequences of actions may happen.
- *"In each state, the internal agents must make decisions (respectively actions if the agent is external)"*. In the real world not making a decision differs from making a decision to do nothing. However, we choose to formally consider them both as decisions. This choice results in considering the decisions to do nothing the same as other decisions and they are included in the scenario path. This information could be used afterwards to identify the agents who caused a conflict (see 8). Indeed deciding not to do anything or not deciding involves the responsibility of the agents and can have consequences that are worth noticing.
- *"Internal agents other than the user cannot make decisions that compromise their principles"*. As discussed in the previous section, the user, which is usually the knowledge provider, can attest to their own opinions and positions. However, they have to make assumptions on other agents information such as their positions and opinions, to provide enough knowledge for the model to work. This supports the choice we have made to assume that no agent but the user could compromise their principles. Otherwise, it could increase the complexity. Indeed, much more scenarios would be generated upon these assumptions but it would be complicated to capture foresight conclusions.

We have also assumed that the decisions made by the agents, apart from the decisions to do nothing, will always be turned into actions as no agent can change their mind or prevent another agent from performing an action after the aggregation of all decisions. This may reduce the uncertainties faced in the real world where agents can both change their minds and/or prevent other agents from performing actions.

Moreover, we have chosen not to model uncertainties through probabilities to avoid the bias introduced by the attribution of arbitrary probabilities to decisions and events (see definition 15).

External agents

It can be noticed (see definition 7) that all external agents are put on the same level. A realistic viewpoint would be however to make a difference between a disturbance (e.g., a sanitary crisis, a natural disaster, a terrorist attack, etc.) and an external organization constraining the system (e.g. an international organization, a government, a company whose business sector would be external to the studied system, etc.).

Conflicts

A logical conflict (definition 17) is an incompatibility between two or more variables. These incompatibilities of values are specified in the initial knowledge. However, no formal difference is made between an incompatibility defined by physical laws and an incompatibility judged as such by the knowledge provider. The latter may be subject to the biases discussed in the previous section.

A moral conflict (definition 20) focuses on a single agent who cannot make a decision on a variable in a given state without compromising their moral principles. It is based on [50] who already discussed its formalisation. The updated definition we have proposed does not offer the agents, but the user, the opportunity to solve the moral conflict (by ordering the principles for example) during the scenario generation. As far as the user is concerned, if they are in a moral conflict situation, they can compromise their principles; indeed, when they face such a situation, every possible resolution of the conflict is explored and a scenario is generated for each outcome.

9.3 About generation and analysis

Positions and opinions of the agents

Even if the model allows it, the positions and the opinions of the agents (see definitions 10 and 11) do not change during the generation of scenarios. This could be questioned, for example, in a sanitary crisis, more importance could be given to the moral principle *HealthPreservation*. An interactive interface would help to change this piece of knowledge while computing the scenarios.

Time

Time is not explicitly considered in our model. Indeed, we have chosen to consider sequences rather than attributing a duration to each state. The stopping criteria within the scenario generation are therefore specific events like conflicts and scenario patterns like loops, rather than the definition of any time horizon.

Complexity

An obvious limitation of this type of algorithm is its complexity which is exponential. Due to limitation in the computational resources, we have limited the depth of the scenario tree to three for the aviation scenarios generated here. Options will be presented in the next section. However, this high complexity may or may not be an issue depending on the use of the provided tool. Indeed, the tool could be used in two ways. The first one is the generation of scenarios to explore the possible futures of a system. In this situation a high computational time to generate the scenarios may not be an issue. The second one is when an organisation wants a quick answer to make a decision or wants to be able to interact with the tool and explore possibilities by modifying or adding initial knowledge. In such a case, the high complexity of the algorithm may be an issue as fast results would be needed.

Analysis

The causes of a logical conflict can be analyzed in two ways: (i) considering the variables or decisions right before the conflict; and (ii) considering all the variables and decisions included in the whole scenario paths leading to the conflict. These two types of results can be different. The order of appearance of the decisions in the scenario could also be considered.

When the analysis aims at recovering the scenarios leading to goals achievement, it must be highlighted that every result illustrates the point of view an agent, particularly the user. Indeed, it is generally not possible to globally qualify a scenario as ideal for all agents. This notion will always depend of their opinions as each of them can consider a decision as favorable or not to a principle.

Numbers

Attention must also be paid to the representation and the meaning of numbers. Indeed, a user should be very careful when manipulating and using numbers in the analysis section because the same number may have different meanings and be subject to interpretation. For example, considering the intent to find the best scenarios for the user, we had to characterize the term of "best scenario" and how to calculate it. For instance, the ratio between the number of favourable decisions and the number of unfavourable decisions towards a principle for the user in a scenario, could be used to identify the best scenarios (see 8.2). Consequently, a scenario A with 3 favourable decisions and 5 unfavourable ones and a scenario B with 6 favourable decisions and 10 unfavourable ones will be judged the same; however in scenario B, more negative decisions have been taken. Therefore such metrics must be supplemented by other considerations on the scenarios.

Validation

Few foresight studies include a validation process in their work. However, many questions should be raised:

- Do the generated scenarios include the "true" future? Some ideas suggest to model a past sit-

uation, generate the scenarios from it and see if the generated scenarios include the real past events. However, the aim of our model is not to foretell the future; it is almost certain that the generated scenarios will not include the real future. They may however help decision-makers to consider new strategies to reach their goals or to anticipate crises. Therefore, it may be more useful to validate the actual utility of the scenarios.
- Don't we miss a really important situation? How can we be sure that we browse all the possible futures? It will first always depend on the initial knowledge. The exhaustive generation we offer here could then be a first answer, if the required computational resources are available. Another one could be the implementation of an empirical validation by experts. It would however be subject to the biases of those experts.
- How can we assess the quality of the scenarios? Some criteria have been used in the literature to validate scenarios [43], they have however no formal definition. Formally defining our own criteria to validate our own work seems moreover risky and biased.
- How can we assess the actual impact of the scenarios inside organisations? The impact of foresight methods in companies is indeed an research subject. Studies are made on how to measure the mental shifts of stakeholders after participating in a foresight study [54], but also how to measure the profit for a company using such work [55].

To conclude, let us stress again the fact that the results are knowledge-dependent and should not be taken as a reliable prediction of the future or the consequences of particular actions. As part of the foresight domain, this approach only intends to guide, prepare and take a new perspective on a particular subject.

10. Conclusion and Future works

We have introduced in section 2 of this paper a sample of reports and methods focusing on the generation of scenarios on the future of the air transportation system. For both main future planning approaches, namely forecasting and foresight, we have highlighted the different biases included in the existing methods and results:

- biases coming from the initial knowledge: using past data may not produce scenarios outside the trend (e.g., no mention of a possible decrease in the aviation sector in the scenarios of airline companies);
- methodological biases: a limited number of scenarios is usually produced, however, their combination is likely to answer a user's expectations (e.g. Ademe's scenarios);
- cognitive biases: they go with the opinions and experiences of the participants, whether they are experts or not.

We have presented a formal and automated method for generating scenarios about the future of the air transportation system. This tool can be used for decision-making, guidance or risk and conflict anticipation. Scenarios are produced as successions of states and decisions sets constituted of qualitative data. They are enriched by the consideration of the moral principles of the stakeholders, which is usually not considered in decision support. Our goal was to overcome existing biases in the current methods. Generating an exhaustive set of scenarios prevents from excluding, intentionally or not, controversial scenarios, i.e. crisis scenarios.

As far as the scenarios analysis is concerned, the results representation highlights the potential imbalance inside the resulting data: such situation can easily be discussed and/or changed by modifying the initial database. Moreover, the formally generated data allow to use data mining and data representation algorithms for results analysis. We can therefore give answers to some user about how they can achieve their goals and avoid conflict situations due to some decisions. This type of results is usually not provided in qualitative scenarios because their production is usually seen as the objective, leaving the analysis to the user alone.

Considering the results themselves, the scenarios produced here show that the user, i.e., the stakeholder who has initiated the foresight process, must go against the principle *Customer Satisfaction* to achieve their goals, especially to have a *High TicketPrice*. This result can be obvious here but in a more complex system, it could reveal contradictions and a need to prioritize some goals. The performed analysis allows to say that the decisions directly responsible for conflict situations and under the control of the user (the airline company *Easyflight*) are *DoNothingTicketPrice* and *DecreaseTicketPrice*. However, these decisions must be related to the other agents' own decisions. In fact, with the algorithm PrefixSpan, the whole paths of the scenarios are taken into account and it reveals that the decisions causing conflicts are mostly taken by the agent *SuperFuel*.

For future works, our assumptions for the formal model may be subject to change. A first modification could be on time consideration: creating a timeline could answer the question of a defined horizon. It would then be possible to change the stopping criteria of the scenarios. Furthermore, one could imagine, for instance, adding agents or variables during the course of a scenario. However, generating scenarios with a much higher number of data (compared to the system studied here) raises new issues. As the complexity is exponential, it requires a lot of time and computational resources. Several leads can be considered to overcome this challenge, if the usage of the proposed tool requires so (see section 9.3). A first one would be to generate a given number of random scenarios (stochastic sampling). Another one would be to define metrics to qualify whether a user gets closer to the achievement of their goals and to use methods such as Monte Carlo Tree Search also used in decision making. Overcoming this challenge could allow to generate scenarios on the future of the air transport system with much more details and including more agents. Giving a final analysis of the produced scenarios by grouping them thanks to a similarity criteria could also be a way to see the big picture by considering a small number of groups of scenarios.

From a more global perspective, a user friendly interface could also be designed, to help the user gather the initial database but also to allow interactions in the analysis process to answer their specific questions more precisely.

Finally, the validation of the model is still to be done. It however raises many questions (see section 9.3). There is no consensus in the literature on how to answer some of these questions. The definition of validation criteria or the use of alternative approaches to answer them need to take into account the possible introduction of new and unanticipated biases. It must be done keeping in mind that foresight is not looking into a crystal ball, but implementing a thinking process and helping to make decisions considering possible futures.

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Open data statement

The initial knowledge to elaborate the scenarios presented in this paper can be found on github : https://github.com/onera/GAFS.git

Reproducibility statement

The source code can be found on github : https://github.com/onera/GAFS.git it is available with the process used to elaborate the scenarios presented here.

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