A methodological approach for strategic evaluation - a response to water scarcity emergency

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Abstract. The goal of the Paris Agreement to limit the increase of temperature may become an illusion. Within 20 to 30 years, Southern Europe may experience hot waves and broad dry periods. Water scarcity may turn into reality, and the Defense structures of each country must prepare for it. The Scenario has high uncertainty as well as what the response to the hazards might be. The Dempster-Shafer theory (DST) allows to handle uncertainty, and the Axiomatic Design (AD) is a tool to do good designs. This paper presents a methodological approach to handle with forthcoming events. It defines what is a scenario using the structured AD frame, defined by constraints and needs. In addition, it presents an approach to compute information for different developments of the design. Thus, it describes a Defense strategy to "provide the basic water needs to the population". The DST method is used to achieve belief and plausibility measures of the probability of success. Currently, the belief in the success of a response to hazards is almost zero. Plausibility can go up to 0.65 by defining a reaction structure, improving the technology, manufacturing new products.

1. Introduction

In December 2015, the United Nations Framework Convention on Climate Change (UN-FCCC) matched the so-called Paris Agreement. Paris Agreement aims to hold "the increase in the global average temperature to well below 2 °C" and ask all Member States to make the necessary efforts so that the increase of temperature at the end of the century will be 1.5 °C above the average values of the pre-industrial era (art.2) [1]. The UN's scientific committee, the International Panel on Climate Change (IPCC), defined four possible climate pathways for this century. Each pathway, a Representative Concentration Pathway (RCP), is a possible evolution CO\(_2\) concentration in the atmosphere that increases the global temperature. The IPCC defined the RCP through many climate models of the earth depending on human behavior. The RCP index represents the balance between the average radiation received and emitted by the planet in W/m\(^2\) in 2100.

The CO\(_2\) concentration in the atmosphere might follow the RCP2.6. It leads to an average concentration of 400 ppm of CO\(_2\) and a temperature increase in the range of 0.9 to 2.3 °C. The current
carbon concentration is already 410 ppm, higher than the acceptable by the end of this century. The RCP2.6 urges the World to be carbon neutral in 2070 and capture about 3 GtCO$_2$/y in 2100.

The climate uncertainty for the end of this century remains high. The range of temperature to achieve with RCP2.6 is wide, the uncertainty of climate models is high, and human behavior is unpredictable. Some authors check if climate models can predict recent climate data using past events. The predictions often run over the interquartile level [2].

If we maintain the current trend (RCP8.5), humankind will envisage a climate catastrophe in the following decades. Changing will depend on the behavior of the world leaders. In 2019 nuclear, hydroelectricity, and renewables account for less than 16% of the total world primary energy [3]. US, EU, and China give out more than 55% of the World's carbon emissions. US and EU are reducing emissions regarding the previous years, and China is still climbing [3]. EU aims to achieve carbon neutrality in 2050 and wants to reinforce the climate commitment by lowering carbon emissions in 2030 by 55% regarding the 1990 level [4].

The policy of China is to become carbon neutral by 2060. However, China relies on carbon to supply 58% of the primary energy [3], and carbon gives China a safe energy means regarding availability, stockage, and technological knowledge [5]. Moreover, China has a massive amount of thermal coal power plants with ten years average working time. If all infrastructures remain working during the following decades, the Paris agreement will not be accomplished [6].

The US returned to energy autonomy. Oil and gas fracking and sand oil extraction in Canada allow the US to look to their internal energy policy rather than the Middle East [7]. Betting on natural gas, US reduced emissions in recent years. But it needs extra effort. Energy and economy need decoupling in an energy-independent region. On the other hand, policy success regarding emissions depends on the ability to remain in the world leadership without extra energy needs.

If the World remains in the laissez-faire pathway (RCP8.5), all countries will be affected. South EU will require 20% extra water and will suffer from depletion of water resources [8]. Even stabilizing the CO$_2$ concentration, central and southern Europe will have hotter days in Summer by 4 ºC and 20% rain reduction in South Europe [9]. The Mediterranean region will be one of the most affected areas by dryness in the globe. In a similar stabilization scenario, wetlands will reduce and may collapse by 2100 in the Western Mediterranean region [10].

In the RCP8.5, the international hydrological basins of the Iberian Peninsula will reduce water availability by 6% per decade [11], and dryness may feel a step increase by 2040-2050 [2]. Oddly, in the RCP2.5, rain may reduce in the Iberian Peninsula by 10% from the previous to the end of this century [12].

Dry periods and hot waves will be more common in the following decades. This work aims to define a defense strategy to provide water to the population. Countries in regions most affected by dryness variations need a force to act as the last warrant for the population survival. It is an adaptation measure that needs to be drawn despite infrastructure adaptation and reduction in carbon emissions.

The southern regions of Portugal, Spain, and Italy will be seriously damaged by dry periods. Similarly, Balkans counties, Greece, and Turkey will also await water problems.

In the next decade, these regions might undertake serious adaptation policies. The measures include water highways, river transfers, collect and recover grey waters, changes in agriculture water distribution, and in agriculture models. All adaptation actions that last for decades might apply.

Such uncertainty asks for the definition on how to create a scenario. Moreover, it is necessary to know how to handle uncertainty and how to define a strategy. Dempster-Shafer's theory (DST), described in section 2, is a recognized tool to handle uncertainty. Thus, section 3 presents the scenario creation calling for prospective thinking. Axiomatic Design (AD) can provide the means to define the high-level development of a design, called Strategy, in the context of this work. Using DST with AD allows computing the information content in the ill-defined design at a high decomposition level. Section 4 explains the theoretical framework to define a strategy using AD and DST for a specific scenario. Finally, section 5 shows how to define a force to fit the population’s water needs. The last section presents the conclusions.
2. The Dempster-Shafer Evidence Theory
At the AD high levels of decomposition, the problem is ill-defined. There are uncertainty and ignorance about the solution. AD expresses the design using \([FR]=[A]\cdot[DP]\) that describes the mapping between the functional and physical domains [13].

The design equation is a peculiar representation of a mathematic equation, as the design unknowns are the DPs, not the FRs. Therefore, the DPs regarding "how to achieve" the FRs is in fact about "is a DP responsible for fulfilling an FR?". This type of question represents abduction reasoning.

DST is appropriate for handling uncertainty and defining the antecedent of an implication by knowing the consequent [14]. Using combined evidence, DST helps to reach the belief in a solution. DST is used in medical diagnosis, failure evaluation, and criminal investigation. Epistemologically, the type of problem and reasoning is covered by DST evidence equals the DP choice to fulfill an FR in AD.

DST introduces the concept of belief and plausibility. Belief is the measure of preconceived knowledge of a set of events; plausibility is a measure of what is the possibility of knowing about the events. The events are defined in a frame of discernment \(\Theta\) with \(n\) mutually exclusive and exhaustive hypothesis, called singletons. The power set \(P\) of all subsets \(\Theta\) has \(2^n\) sets. Suppose a frame of discernment with three singletons \(\Theta=\{f_1,f_2,f_3\}\). Thus, the power set \(P\) has \(2^3=8\) sets, defined as \(P=\{\emptyset,\{f_1\},\{f_2\},\{f_3\},\{f_1,f_2\},\{f_1,f_3\},\{f_2,f_3\},\{f_1,f_2,f_3\}\}\).

Now, let \(A\) be a proposition in evaluation such as \(A \in P\). \(A\) is any set of sets \(Ai\) of \(P\).

The basic probability assignment (bpa) \(m(A_i)\), or mass probability, is the evidence. The \(Ai\) sets with non-zero mass are the focal elements in appreciation. The bpa is similar to the probability density function (pdf) in the sense that:

\[
m(\emptyset) = 0, \quad \sum_{A_i \in P} m(A_i) = 1
\]

However, the belief is defined over a power set and the probability over the crisp values of a universe. Moreover, the remaining probability of \(A\) is not the probability of \(\neg A\).

An expert can give evidence about \(A\) by defining the bpa to all focal elements \(A_i\). The focal elements can express different causes or consequences of a proposition. The belief in \(A_i\) is the evidence in all subsets \(B\) of \(A_i\), as \(B \subseteq A_i\):

\[
bel(A_i) = \sum_{B \subseteq A_i} m(B)
\]

The plausibility \(pl(A_i)\) is the evidence in \(A_i\), plus the evidence in all subsets of \(A_i\), plus the evidence in all sets \(B\) that intersect \(A_i\):

\[
pl(A_i) = \sum_{B \cap A_i \neq \emptyset} m(B)
\]

It makes \(pl(A) \geq bl(A)\) ensuring \(bl(A)\) and \(pl(A)\) are the lower and upper bounds of an evidential interval \(Ev=[bl(A), pl(A)]\). Plausibility is all we may know about \(A\). Therefore, it is the complement of belief in what is out of \(A\) \(pl(A) = 1 - bl(A)\). Ignorance is what is behind the belief of \(A\) and in the complement of \(A\) \(Ig = 1 - \{bel(A) + bel(\bar{A})\}\), or \(Ig = pl(A) - bl(A)\). If Ignorance is nil, plausibility is belief and both equal probability.

In the context of this work, belief and plausibility are the bounds for the probability of fulfilling an FR. The focal elements \(Ai\) create the universe of discourse of the FR.
Belief and plausibility are substitutes of the pdf. Therefore, they express a measure of probability and can help compute the information content of the design.

DST has been applied with AD to define the DP for a single FR-DP design [15]. It is necessary to stress the information content depends on the application of the AD first axiom. Therefore, the design equation influences the computation of the information content.

3. Methodological approach

Gaston Berger, in the 50s, was the father of "prospective thinking". Prospective thinking to "look at the future that disturbs the present". A look in the future needs to synthesize what we know about the future and create scenarios. Therefore, the idealization of a future scenario asks for innovative reasoning to synthesize ideas about the future [16]. Godet called scenarios the set of possible future events that asks for clarifying and define a decision point. The scenarios are "what could happen?". Scenarios and Strategy must not be confused. The Strategy is the way of solving a problem that asks for defining "what can I do?", the strategic options; "what will I do?", the strategic decisions; and "how will I do it?", the actions and operational plans [17].

This way, in what regards to AD, Strategy is the mapping between functional requirements (FR), design parameter (DP), and eventually process variable (PV) [19]. If Strategy asks for new PVs it will influence technology; the same way existing technologies help define the Strategy.

Scenarios are often seen as a cross of all future hypotheses. It raises multiple cases, most of them with scarce possibility. Consequently, it is better to choose the most plausible scenarios, or the risky ones, and work on them [18].

A strategy on climate change needs to consider adaptability to new conditions. In the future, it may not be necessary to maintain the same DPs, not even the same FRs. We must seek for needs and create the so-called "adaptive resilience", a creative transformation of functionalities to new environments, to create new opportunities [19].

The definition of a Strategy by Godet, as a means, has a counterpart in AD. AD maps between the Functional, Physical, and Process domains. Figure 1 shows the mapping between domains and Strategy thinking. Strategic thinking is the mapping at high levels of decomposition.

![Figure 1. Scenario and Strategic thinking](image)

The Scenario needs formulation regarding targets and time frame in evaluation. Moreover, it needs analysis of what concerns aggressors and hazards effects, evaluation points, and possible effects. Finally, the scenario characterization is the aggressors and receptor response. In what concerns to AD, the Scenario is the problem definition by the Customer attributes (CAs) and the input Constraints (Cs) of the design.
The description of a future scenario may contain available DPs that may help the design development. However, for AD a future Scenario needs to define:
- What are the customer attributes in the time frame in evaluation?
- The input Constrains of the design.

As an example, a CA can be "needs of drinkable water for the population". And the Cs defined by the climate conditions in the time frame in evaluation.

This paper intends to achieve a common purpose on how the bpa gives a measure of the fulfillment of the FR. Mapping between FRs and DPs regards how a DP fulfills an FR.

The DP may have various possibilities, say \{d1\}, \{d2\}, and \{nd\}. The basic solutions are called the belief nucleon. For this work, \{d1\} is a known physical issue, \{d2\} an improved one and \{nd\} is a non-existent or undetermined physical issue. Physical issues are decisions on the use of technologies or artifacts.

These technologies have images in the functional domain respectively \{f1\}, \{f2\}, and \{nf\} representing the modes of fulfilling the FR. The focal elements to choose are \{f1\}, \{f2\}, \{f1, f2\}, \{nf\} and \{all\}. The set \{f1, f2\} is a ill-defined solution that contains f1 and f2, the same way the \{all\} focal element is \{f1, f2, nf\}.

Regarding prospective thinking, the belief nucleon is our belief in fulfilling the FR at a certain level of decomposition in a time frame. The information of the design is the information content of the leaves FRs. Furthermore, DST helps to compute information for the different prospective solutions corresponding to each of the focal elements. It means that for the same mapping between functional and physical parameters, called the Design or the Strategy, there is more than one value for the information content. The information content - the probability of success of the design - varies according to the decisions on using physical artifacts, known or under development, for the same design equation.

The methodology proposed uses prospective thinking to define the future customers' needs and AD to stretch the Strategy. For the same Strategy, forthcoming decisions on the physical parameter decidedly influence the probability of success.

4. Application to water scarcity

In the future decades, a reduction in global pluviosity is expected, as well as a lower availability in underground water, the increase of higher temperatures than nowadays, and the occurrence of heatwaves.

The CA in the CN domain is "needs of drinkable water for the population". The design has the following Cs:
- Cs1: Unavailability of water in local rivers and in water wells;
- Cs2: Availability of water in nearby regions;
- Cs3: Sea bords a closer region;
- Cs2: Heatwave during the event;
- Cs3: Rural fires that ask for massive firefighters' intervention.

The Strategic Plan, or high-level design, has the following FRs and DP, according to table 1. FR2 and FR3 are decomposed until the second level of decomposition.

The Strategic plan needs a "System for water delivering" (DP0) to be created so that in extreme climate events population can adapt by receiving the basic water needs (FR0). The system gets (FR1), produces (FR2), transports (FR3), and delivers water (FR4). Get the water in dried dams, wells and rivers, pumps, and store the water (DP1). It filters and treats the water to remove contaminants and microorganisms (DP2). The system has transport means (DP3) and can distribute water in each village in small tanks and cisterns (DP4). The municipality services ensure a way to deliver the water flow to each family.
Drinkable water can be produced from available dams or the sea. This way, it can use "modular water treatment equipment" (DP21) or modular reverse osmosis (DP22). Moreover, water can be captured and produced in closer regions and transported by land in trucks or trains (DP31) or by sea (DP32).

| Table 1. FRs and DPs for "needs of drinkable water for the population". |
|---------------------------------------------------------------|
| **Functional Requirements**                                      | **Design Parameters**               |
| FR0 Deliver basic water needs to the population | DP0 System for water delivering |
| FR1 Get fresh water                                                 | DP1 Pumping and storing system |
| FR2 Produce drinkable water                                         | DP2 Filtration and water treatment |
| FR3 Transport drinkable water                                      | DP3 Transport means |
| FR4 Distribute water                                                | DP4 Small tanks and cisterns |
| FR21 Turn drinkable water in nature                                 | DP21 Modular water treatment equipment |
| FR22 Desalinate seawater                                            | DP22 Modular Reverse Osmosis |
| FR31 Transport water by land                                       | DP31 Tank trucks and tank trains |
| FR32 Transport water by sea                                        | DP32 Water freighter |

The strategic system described is the last line of defense of an adaptation policy that countries in southern Europe need to implement. Indeed, Member States need to execute large construction infrastructures, the same way they need to have a well-equipped and trained force to enter in action if necessary. Prevention pays well.

Equation 6 presents the design equation. It says it is compulsory to get the freshwater and then produce drinkable water. Transport and distribution can work independently. It is welcome to identify where to get the water and produce the water, as both induce the FRs at the second decomposition level. Therefore, DP at the second level of decomposition, modular system for treatment and osmosis, and transport means by land and sea depending on the quality of water captured and produced.

\[
\begin{bmatrix}
FR_1 \\
FR_2 \\
FR_3 \\
FR_4 \\
FR_{21} \\
FR_{22} \\
FR_{31} \\
FR_{32}
\end{bmatrix} =
\begin{bmatrix}
X \\
X \\
X \\
X \\
X \\
X \\
X \\
X
\end{bmatrix}
\begin{bmatrix}
DP_1 \\
DP_2 \\
DP_3 \\
DP_4 \\
DP_{21} \\
DP_{22} \\
DP_{31} \\
DP_{32}
\end{bmatrix} =
\begin{bmatrix}
\end{bmatrix}
\]

Table 2 presents the bpa defined in the mass probabilities m(Ai), the belief bl(Ai), and plausibility pl(Ai) for the high-level FR0 and the first level of decomposition, FR1, FR2, FR3, and FR4.

At the high level, suppose the water delivery has no legislation and no structure to handle it. The physical existence will give a mass probability for \{f1\} of 0,05. As the problem start to go on discussion it can make mass of \{f2\} equal 0,1 and a group \{f1, f2\} to be 0,1 as well. What is not yet known \{nf\} and \{all\} represents 0,75 of the mass probability.

Table 2 presents similar reasoning on the second to the fifth columns. FR1 and FR4 uses known, available and affordable technology. They depend on the willingness to put the system working. Therefore the mass probability of \{f1\} is high — the opposite occurs on FR2 and FR3. Regarding FR2, water treatment and reverse osmosis are known technologies that may undertake interesting developments.

Moreover, creating modular systems and putting them into action may take extra effort. Finally, FR3 asks for high investments and adaptations. It needs a huge quantity of tank trucks and personnel and the development of water freighters.
Table 2. Mass, belief, and plausibility for FR0 and the 1st level of decomposition

| FR0: Deliver basic water needs | FR1: Get freshwater | FR2: Produce drinkable water (subjected to get it) | FR3: Transport drinkable water (subjected to get and produce) | FR4: Distribute water drinkable (subjected to get and produce) |
|-------------------------------|---------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
|                               | m(A1)   | bl(A1)   | pl(A1) | m(A1)   | bl(A1)   | pl(A1) | m(A1)   | bl(A1)   | pl(A1) | m(A1)   | bl(A1)   | pl(A1) |
| {f1}                          | 0.05    | 0.05    | 0.6    | 0.7    | 0.7     | 0.85   | 0.4     | 0.4     | 0.7    | 0.3     | 0.3     | 0.7     |
| {f2}                          | 0.1     | 0.1     | 0.65   | 0.1    | 0.1     | 0.25   | 0.2     | 0.2     | 0.5    | 0.1     | 0.1     | 0.5     |
| {f1,f2}                       | 0.1     | 0.25    | 0.7    | 0.05   | 0.85    | 0.95   | 0.1     | 0.7     | 0.9    | 0.2     | 0.6     | 0.8     |
| all                           | 0.45    | 1       | 1      | 1      | 1       | 1      | 1       | 1       | 1      | 1       | 1       | 1       |

The belief and plausibility of the solution are the product of all conditional beliefs and plausibilities of FR1, FR2, FR3, and FR4. Table 3 show the results regarding the known and improved situations, respectively {f1} and {f1,f2}. The belief in the current situation {f1} is near zero. Improving the technology development, creating and manufacturing new artifacts, can lead to the plausibility of success of 0.65.

Table 3. Intervals of Information

| Information | 1st level decomp | Belief | Plausibility | From | To   |
|-------------|------------------|-------|--------------|------|------|
| {f1}        | 0.06             | 0.35  | 1.5          | 4.1  |
| {f1,f2}     | 0.30             | 0.65  | 0.6          | 1.7  |

5. Conclusions

The proposed methodological approach evaluates the future by prospectively envisage a disruption. The disruption event defines Constraints (Cs) and the population needs. The Strategy can determine how to accomplish the needs by mapping, at a high level of decomposition, between the Axiomatic Design (AD) domains. The mapping under the Cs is the design. For the same high-level design, known physical solutions or foreseen solutions give different probabilities of success. The Dempster-Shafer theory (DST) can define the bounds for the probability of success, between the belief and plausibility, for each solution.

In the prospective application, the World will see an increase in carbon in the atmosphere in the following decades. Despite EU, US, and China efforts, the climate will change in a couple of decades. The Mediterranean region will be one of the World's most affected regions. Hot waves, high temperatures, and low pluviosity will lead to water scarcity.

States need to focus on solutions to adapt to the new reality. It includes having a defense system to “deliver the basic water needs to the population”. The system needs to get, produce, transport, and distribute water to the population. There is a need to define the force, implement it, use existing technologies and means, and develop new ones.

For the moment, belief in a suitable response in the event of scarce water is almost nil. Future development and implementation can lead to the plausibility of 0.65. Being aware of the problem is the first step to create the necessary conditions to establish a defense force.
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