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Decision Support in uncertain contexts: Physics of Decision and Virtual Reality

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ABSTRACT

Virtual Reality (VR) is often used for its ability to mimic reality. However, VR can also be used for its ability to escape reality. In that case, on the one hand VR provides a visualization environment where the user's senses are still in a familiar context (one can see if something is in front, behind, up, down, far or close), yet on the other hand, VR allows to escape the usual limits of reality by providing a way to turn abstract concepts into concrete and interactive objects. In this paper, the dynamic management of a complex industrial system (a supply chain) is enabled in a VR prototypical environment, through the management of a physical trajectory that can be deflected by the impact of any potentialities such as risks or opportunities, seen as physical objects in the performance space.

Keywords

Data Visualization, Virtual Reality, Immersive Technology, Decision Support, Risk, Opportunities, Performance Management.

INTRODUCTION

The management of any system requires to deal in time with the state of the system as explained in Neely et al. (1995). Basically, this state evolves according to effort (mainly from the system components and managers) to reach objectives. These objectives can be associated with performances, and basically, there is a set of key performance indicators (KPI) that represents the state of that system with regards to time and identified objectives as stated by Neely et al. (1995). This paper considers that the vast majority of objectives and performances of a system may be represented using quantitative indicators (and especially KPIs), and thus focuses on these even though some objectives of the system might not be amenable to doing so.

Opportunities and risks (seen as potentialities) can be considered as events that, if they occur, will impact the overall performance of the observed system. Essentially, opportunities and risks may change the values of KPIs. Potentialities may be instantiated, either seized or inflicted, depending on the nature of the triggering conditions. Any instantiated potentiality is to have consequences on the considered system and these consequences will be visible. A system's performance can thus be defined as the multi-dimensional space which dimensions are its KPIs. The performance objective of the system can be defined as a precise location within that multi-dimensional space (a precise point or a more complex location like a hyper-volume or hyper surface, etc.). When observed in this system's performance space, an opportunity will bring the system to a location closer to the targeted KPI values of its objective, while a risk will carry the system to a location farther from that objective. These potentialities, be they opportunities or risks, can be conceptually seen as forces that push or pull the system, influencing its trajectory within the performance space. This, is the core principle of "Physics of Decision" as introduced in Benaben et al. (2019-1).

The system is indeed continuously moving in its performance space and these movements are due to the succession of events caused by instantiated potentialities. In this physics-based vision, opportunities can be seen as forces that push the system closer to its target objectives (KPIs values are globally getting closer to target values) while risks should be considered as forces that pull the system away from its target objectives (KPIs values are globally getting farther from target values).

This model, detailed in Benaben et al. (2020), relies on the ability to transform and value abstract potentialities on a system as physical forces in the system's performance space. This paper is positioned within this ambitious modelling framework and does not challenge it. The paper focuses on the dynamic visualization of the system's state, opportunities and risks in the performance space and on the interactive management of opportunities and risks through the action levers induced by the physics-based performance space representation.

Two key challenges associated to this vision of management are tackled in this paper:

- In a theoretical simple case where the goal would be to select the appropriate set of “forces” to be triggered in order to move the system from one point of the performance space to a predefined target zone, it is clear that, would the forces be identified and characterized, a calculation could provide the ideal combination of forces to be triggered, without any need to visualize that trajectory. However, the choices are usually more complicated. There may be some external factors to be considered, such as geopolitics, social or environmental factors. There may also be some personal reasons for the decision maker to select one potentiality or another. In all cases, the decision makers should have the last word on the decision and should be able to see and understand all the components of suggested decisions as shown in Moore (2017). So, the first challenge is ***to make the components of suggested decisions explainable and actionable for the decision makers.***
- The management of a real system (e.g., a community facing a crisis, a supply-chain, a sport team, a business, etc.) rapidly brings us to more than two or three KPIs as shown in Maestrini et al. (2017). Complementarily, the number of potentialities rapidly increases, each with impact on one or more KPIs, especially considering that the goal is to be as comprehensive and holistic as possible. So, the second challenge is ***to deal with the potentially huge number of performance dimensions, influenced by a potentially huge number of opportunities and risks to be considered.***

Combining both these challenges brings us to the main question this paper aims at answering: ***How should a multidimensional performance space framed by numerous KPIs, in which a lot of potentiality-induced force vectors be represented and visualized as a decision support tool, in an actionable manner?*** The initial orientation of the research work presented in this article is to explore Virtual Reality (VR) as a way to answer that question.

Moreover, if we focus specifically on the field of crisis management, the complexity and the intricacies between risks, stakes, degrees of freedom and consequences, bring decision-makers into a situation of very high tension mixed with very high uncertainty. The use of immersive technologies to make the POD approach discussed in this article accessible can provide the following benefits:

- Provide decision makers and crisis managers with upstream visibility and understanding of the situation encountered as they consider response plans.
- Allow decision makers and crisis managers, during the crisis situation, to have a clear vision and the most covering possible of the cross implications between the actual risks and the accessible decisions.

In this context, virtual reality as an immersive visualization tool, allowing not only to benefit from a 3D vision, covering 360 degrees, potentially rich in visual metaphors, but also allowing physical interaction with the concepts presented in virtual reality, offers an environment able to bring decision makers and crisis managers to a state of awareness never reached before in terms of decision support.

So as to answer the previous research question, the paper is structured as follows. Section 2 presents a short literature review about other works on the question of abstract visualization and decision making using Virtual Reality. Section 3 introduces the main principles of the underlying physics-based theory (POD for Physics of Decision). Section 4 presents the VR prototype that has been designed and implemented to deal with the visualization objective and describes its basic features and principles. Section 5 discusses the limits and perspectives of the current work. Then final section 6 concludes the paper.

VR AS AN ABSTRACT VISUALIZATION TOOL

Considering the topic of this article and the VR visualization it is focusing on, it has been decided to target on of the most prestigious VR conferences (if not the most prestigious conference) to conduct this background research work: IEEE VR. In the proceedings of past editions of IEEE VR, we used several research criteria to search for

articles that would provide us with a scientific background to support our proposal. The used criteria are the following:

(Visualisation OR visualization) AND (data OR information) AND analysis
Decision* Organisation* OR organization*

Based on this queries, four papers have been deeply studied, providing the following inputs.

First of all, Clifford et al. (2018) did study the different benefits of visualizing through HDTV, VR goggles and cylindrical simulation projection display. The results clearly include that HDTV is less efficient for situation awareness acquisition in the domain of air attack than VR devices. This result is the first legitimation of the approach presented in this paper: choosing VR as the vector of visualization in a complex, dynamic and unstable environment seems to be an accurate proposal.

The research results presented in Cavallo et al. (2019) basically shows the limits of classical 2D visualization and introduces new paths of data perception. The approach is ambitious and multi-technologies. It seems to confirm the positioning of our research work.

In Nguyen et al. (2019), the approach is very similar to the one presented in this paper. Abstract visualization paradigms are used to represent concrete data sets and interaction modes are described. The main difference is that the visualization detailed by Nguyen et al. (2019) is more or less static. There is no real evolution of the visualization while the purpose of the research results presented here concerns specifically the evolution of a situation (dynamic).

The results described in Huang et al. (2019) are truly fascinating because the purpose is to use abstract datasets and make them understandable and visualizable not by using abstract visualization (as for Nguyen et al. (2019) and for the current paper), but by using real subject reconstruction. This vision could be qualified from our perspective as a digital twin.

Finally, based on this simple study, the main conclusion is to legitimate the approach by considering that VR and abstract visualization might be used profitably as a way to apprehend abstract concepts and situations, particularly in a complex, dynamic and unstable situation.

BIG-PICTURE OF THE PHYSICS-BASED THEORY

In this section the *Physics of Decision* (POD) is rapidly presented and illustrated. The subject of this paper is not to discuss that approach (the question is really about visualization and interaction with the potential results of such an approach), however, these question of visualization and interaction cannot be discussed if the POD approach is not briefly presented.

Principle of POD

Basically, the main idea of the POD approach is to model opportunities and risks of a system as potential forces that could, if triggered, move the system in the framework of its KPIs.

The results presented in Benaben et al. (2020) and Benaben et al. (2021) focus on socio-technical systems such as organizations, network of organizations, supply-chain, collaborative networks, facing disruptive contexts (high impact risks or opportunities). Based on this research works, four types of potential forces have been identified:

- *Charges forces*: these forces are due to incompressible and fixed costs (salaries, maintenance costs, etc.) or incomes (rent, royalties). These forces cannot be avoided and should continuously be considered.
- *Collaboration forces*: these forces are due to exchange with suppliers, service providers, customers or partners. Their reactivity, their cost, their quality their certainly impact the KPIs of the system.
- *Contextual forces*: these forces are due to events or characteristics of the environment. It may be a change in the law impacting SMEs, a climatic event in a specific region, the tax rules of a country, etc.
- *Change forces*: these forces are due to internal changes and orientations that would affect the performance of the system. For an enterprise, it may be a change in the organization, acquiring a new resource with particular features, etc.

These forces are presented in an abstract 3D KPI framework on Figure 1. Spheres represent systems (for instance, enterprises), colored waves represent force fields (for instance, a seismic area or a business favorable condition), and colored vectors represent the forces as they applied on systems, due to their susceptibility to force fields.

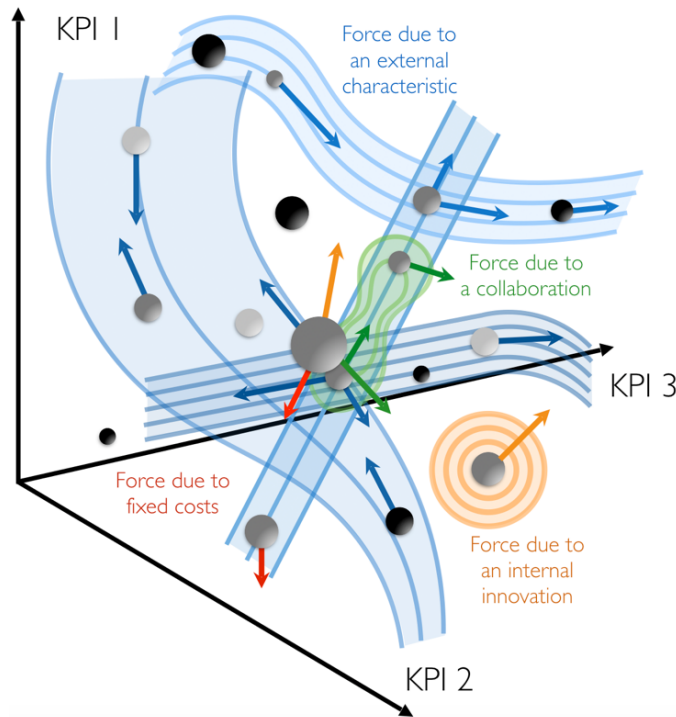


Figure 1. The four types of forces in POD

These forces can also be characterized according to three criteria:

- The forces can be “internal” or “external”: Basically, *Charges* and *Change* forces are internal while *Collaboration* and *Contextual* forces are external.
- The forces can be “inflicted” or “managed”: Some forces may be triggered by decisions (managed, e.g., buying a new machine, hiring someone, etc.), while some other are out of the decisional field (inflicted, e.g., climatic events, law changes, etc.).
- The forces can be “positive” or “negative”: depending on the impact on the system. Basically, if it brings the system closer to its objectives (opportunity), it is positive, while the opposite (risk) is negative.

This characterization space of forces is presented on the following Figure 2:

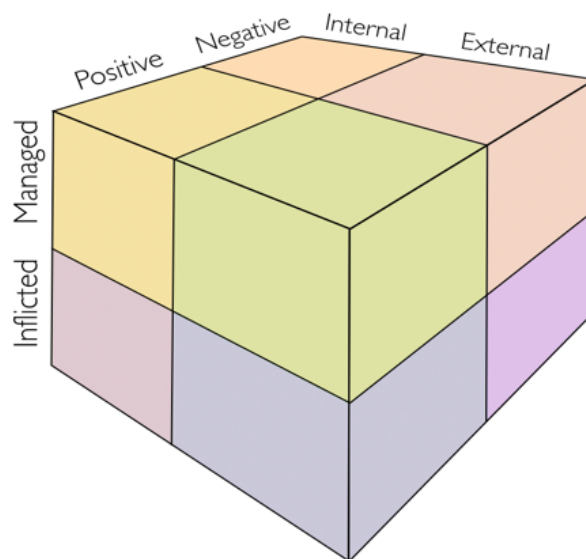


Figure 2. Three dimensions for the characterization of forces

Data Management Framework

POD is dedicated to being a decision support system. As such, and as discussed in Benaben et al. (2019-2), it should cover the four features of: perception, interpretation, exploitation and knowledge. On a data management point of view, POD relies on a three levels framework, inspired from Rowley (2007): (i) **Data**, covering the *perception* feature, (ii) **Information**, covering the *interpretation* feature, and (iii) **Decision**, covering the *exploitation* feature. Moreover, this ascent is also based on the interaction with a metamodel covering the **Knowledge** feature. This principle is illustrated on the figure 3:

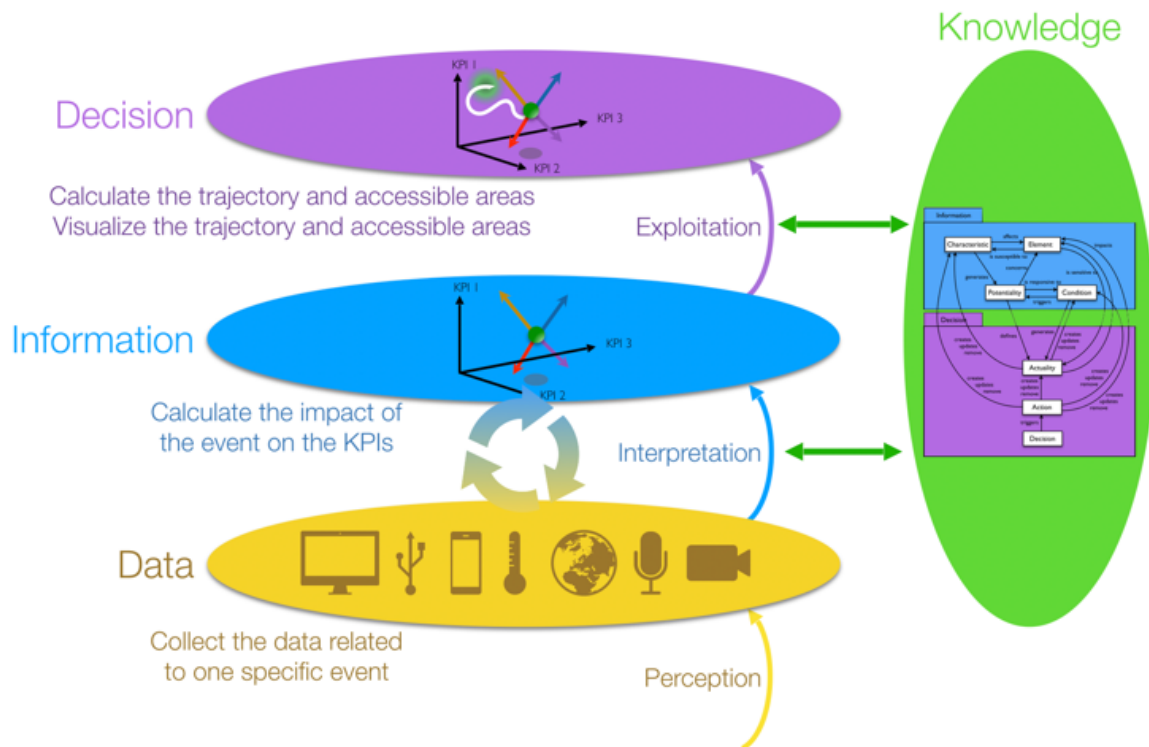


Figure 3. The data-information-decision-knowledge framework

Basically, the POD approach aims at climbing these abstraction levels by collecting data about the considered system and its environment (perception), then transforming the data representing micro-events into forces as macro-events (interpretation), then using these forces to study and determine the best trajectory according to KPIs and objectives (exploitation).

The question of decision in POD

In the POD approach as described in the previous subsections, the decision is supposed to be based on the way the system is intended to move within its KPIs framework. On a theoretical point of view, the studied situation (on which the decisions should be taken) is composed with several components: Basically, the **system** is susceptible to some **potentials** that may create **potentiality** (i.e., **forces**). These **potentialities** may be triggered by some **triggers** in order to engender **actualities** (i.e., **moves**). Besides there are **objectives** to be compared with the **actualities** in order to define appropriate **decisions**. At the end of the day, these components are structured according to three main chains:

- the causal chain shows the way from **potential** and **system** to **actuality** (through **potentiality** and **condition**). For instance, a city (**system**) is susceptible to a seismic area (**potential**), which creates risk of collapsing (**potentiality**) and if the tectonic plates actually slide on each other (**trigger**), there will be damage to the city's infrastructure (**actuality**).
- the propagation chain describes how **potentialities** and **actualities** may impact (create, update, destroy) **potentials**, **systems** and **triggers** in other causal chains. For example, a fragile electrical network (**potential**) impacting a city (**system**) and in the form of a risk of power failure (**potentiality**) triggered by an overload on the network (**trigger**) can create a power failure in a building (**actuality**), making this building sensitive to the danger of infringement (**potentiality**) because of the inoperability of its alarm system.

- the decision chain explains how **decision** could be taken in order to reach the **objectives** by affecting **potentials**, **systems** or **triggers**. For example, the decision to construct a building (**system**) on earthquake-resistant cylinders can significantly reduce its sensitivity to (**potential**) seismic hazard and thus increase its resistance to the risk of destruction by an earthquake (**potentiality**).

The Figure 4 illustrates these three chains:

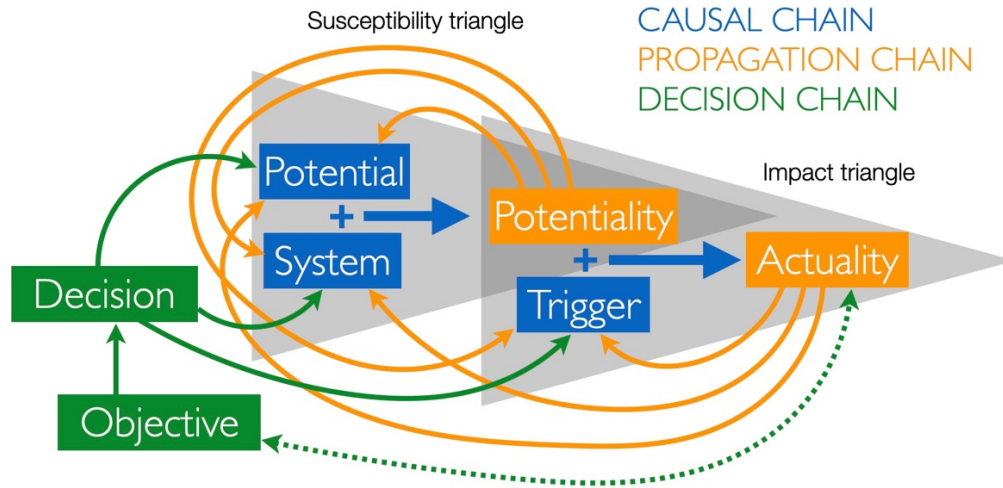


Figure 4. The three chains of the POD approach

Theoretically, the goal of a visualization environment dedicated to support the POD decision process should be to provide the user with a way to interact with the actual decision leverages, *i.e.*, **potentials**, **systems**, and **triggers**. Essentially these three components are the entry points to deal with **potentialities**: One can create or increase the susceptibility of the **system** to a **potential** by interacting with both these components and one can trigger a potentiality by interacting with the **trigger**. However, regarding the visualization and decision support issue, the nature of the cause of the occurrence of the potentiality will not be studied (is it by dealing with the **potential**, the **system** or the **trigger**?). The focus will be on the visualization of the consequences of the occurrence of a potentiality. Thus, the user should be able to see if (i) this uncontrollable event (in the case of an inflicted force) or (ii) if this decidable event (in the case of a managed force) actually occurs, what should be the consequence on the KPIs of the system. The user should then be able to decide if he wants to take measures to try to prevent or support the event to occurs (in the case of an inflicted force), and/or voluntarily trigger the event (in the case of a managed force).

Consequently, the next section will be based on the hypothesis that **the POD approach is actually able to deliver the model of the net of forces of an observed system (e.g., an enterprise or a network of enterprises) in its KPIs framework. However, this model is complicated and rich enough not to be manageable and understandable as it is (i.e., a mathematical representation of a vector space).**

ON THE USAGE OF VR FOR POD VISUALIZATION

This section is dedicated to make the connection between, on the one hand the expectations of the POD approach in terms of visualization and interactions, and on the other hand the capabilities of a VR environment.

General idea

The initial idea is to stick at the idea of the “management of a trajectory” and to concretely visualize a physical trajectory. In the following, for the illustration of the proposal, the considered system is a fictional supply chain composed as presented on figure 5:

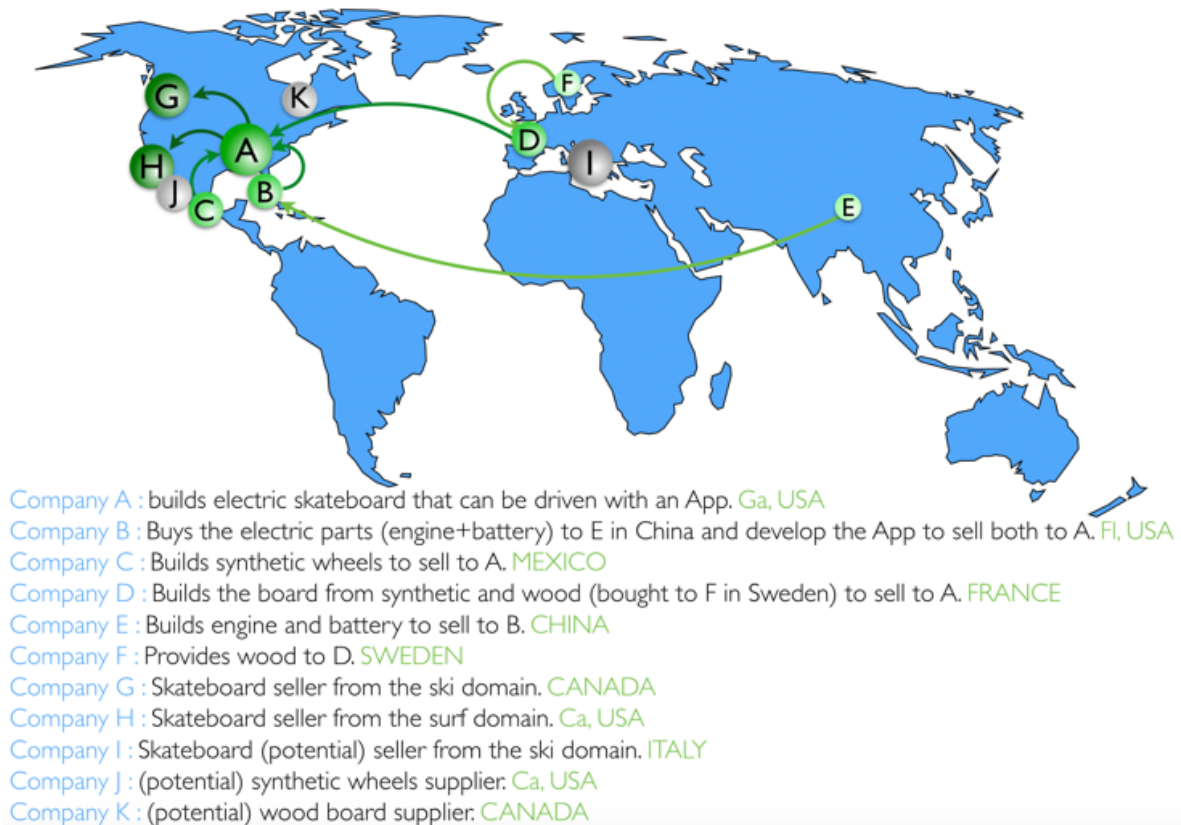


Figure 5. A fictional use-case of supply chain

The main principle is to assess the supply chain according to the following KPIs:

- Profit: the balance of money earned by A monthly.
- Quality: the rate of good product delivered to customers.
- Delay: the ratio of actual delivery time and planned delivery time.

These KPIs are illustrative ones and could be discussed. However, they have been chosen to provide tangible dimensions to the use-case.

The potentialities that have been selected for the use-case are the following (type *Collaboration*, *Contextual* and *Change*):

- New collaboration with company I as a new customer.
- New collaboration with company J as a new supplier.
- New collaboration with company H as a new supplier.
- Hurricane impacting companies B and/or C.
- Strike impacting company D.
- Improvement of the safety stock of A.
- Improvement of the processes of A.

Each of these potentialities have been modeled in terms of micro-events and these micro-events have been simulated (using the simulation tool Anylogic ®) in order to gather actual consequences and perform linear regression to evaluate the macro-consequences on the KPIs and translate the potentialities into forces on the system. Again, this mechanism is not the subject of this paper and has already been presented in Benaben et al. (2021).

The initial visualization idea, dedicated to tackle the two challenges presented in the introduction section, was the following, presented on figure 6:

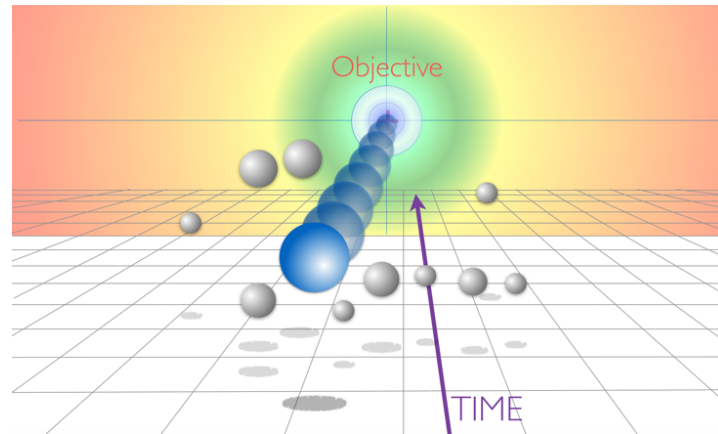


Figure 6. The initial vision of the VR environment

The principle is to see the time as the direction in front of the user. Then the ideal performance of the system is seen as the straight trajectory of the blue sphere representing the system. The potentialities are represented as grey spheres floating around the blue trajectory. The closer the spheres are, the more probable the potentiality. The larger the spheres, the bigger the impact of the potentiality on the system. Then, by selecting one or several potentialities (drag and drop a grey sphere – or a combination of grey spheres – into the blue sphere), one can see the impact on the supply chain as a deviation of the blue trajectory as presented on figure 7:

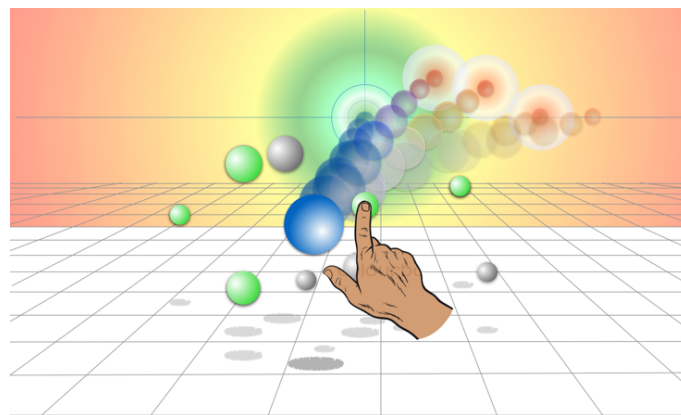


Figure 7. The visualization of impact of potentialities

One important aspect is that the deviation has no real meaning. The user should not try to interpret the deviation as “moving to the left means a loss in profit while moving up means a loss in quality”. The deviation just means “it deviates from the ideal trajectory”. The real qualitative and quantitative interpretation of the deviation should be measured using other dashboard tools, once the deviation is stated. One nuance however, the more the trajectory deviate from the ideal path, the more there is actually a deviation quantitatively.

Prototype

Based on the previous visions and expectations, A prototype has been designed using the Unity® framework. The supply chain can be visualized very artificially as a world map on which the network is described, as presented on figure 8:



Figure 8. The supply chain represented in the VR environment

The global landscape in which the user is supposed to take decision is presented on figure 9:

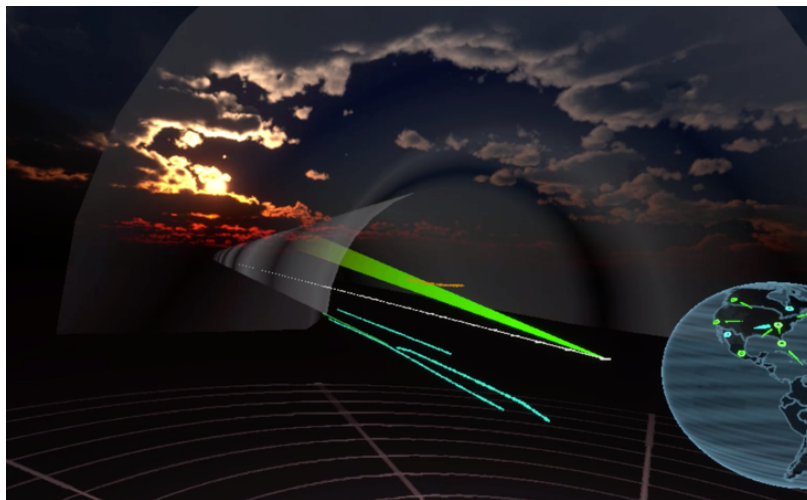


Figure 9. The global environment of the tool

A surrounding grey and semi-transparent vortex represents the acceptable zone for the trajectory (defined by KPIs boundaries). The white line represents both the timeline and the ideal (and potentially inaccessible) trajectory, while the green conic trajectory represents the actual trajectory of the system with regards to its KPIs. The conic shape is due to the uncertainty with time. Finally, the coloured flows (green, blue and orange) represent *Collaboration*, *Contextual*, and *Change* forces. The figure 10 presents all these elements:

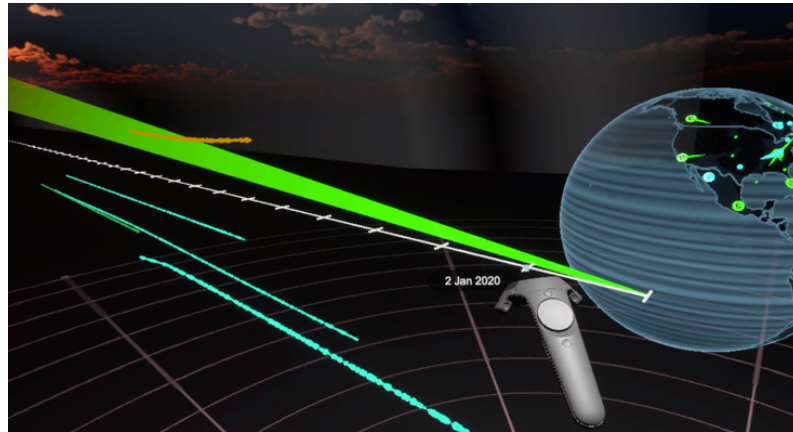


Figure 10. The components of the VR environment

It is noticeable that the distance between the timeline and the potentialities actually represents their probability. As can be seen on figure 11, the risk of a hurricane is strongly more probable in August and September. As a consequence, the flow representing the hurricane is closer to the timeline at this period.

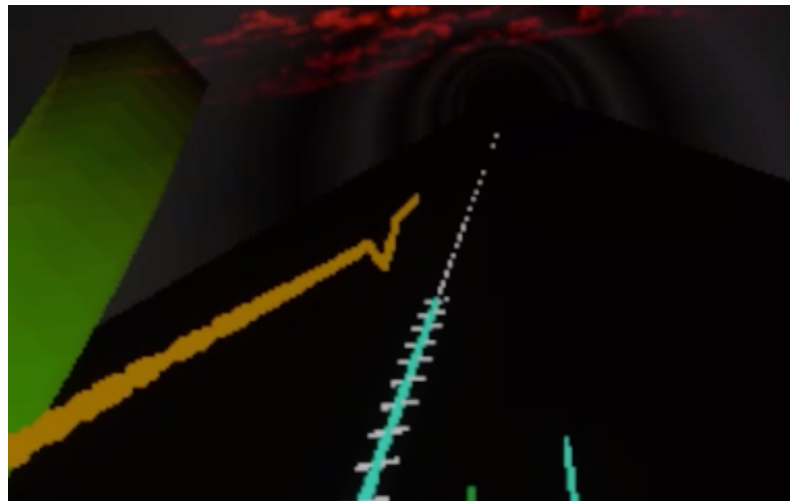


Figure 11. The increasing probability of a hurricane at a certain period of time

Then, by dragging one potentiality into the timeline, one can see the deviation as presented on figure 12 (the potentiality is the occurrence of a strike):

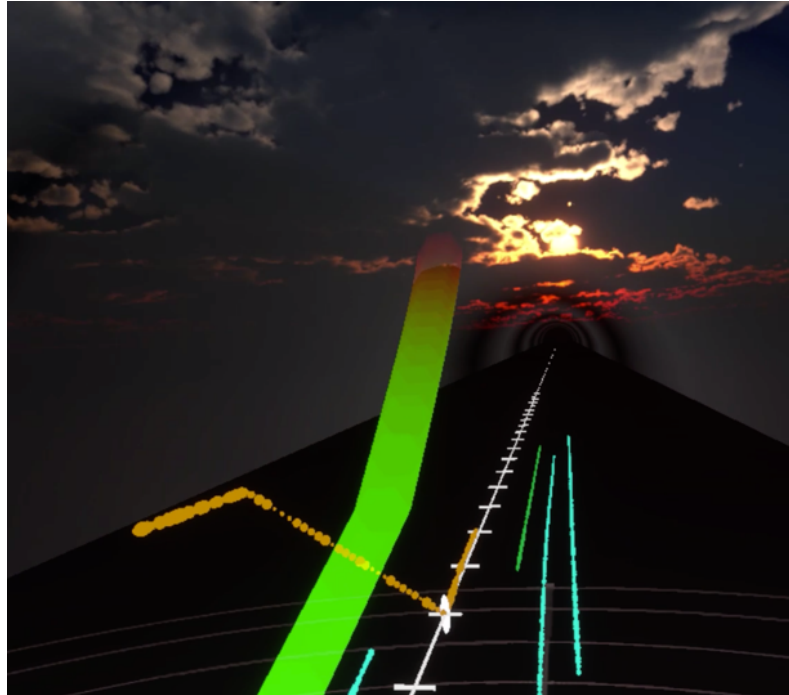


Figure 12. The visualization of impacts of potentialities

The green trajectory turns red when it goes out of the vortex. This deviation can be (partially) corrected thanks to adding a collaboration as presented on figure 13:

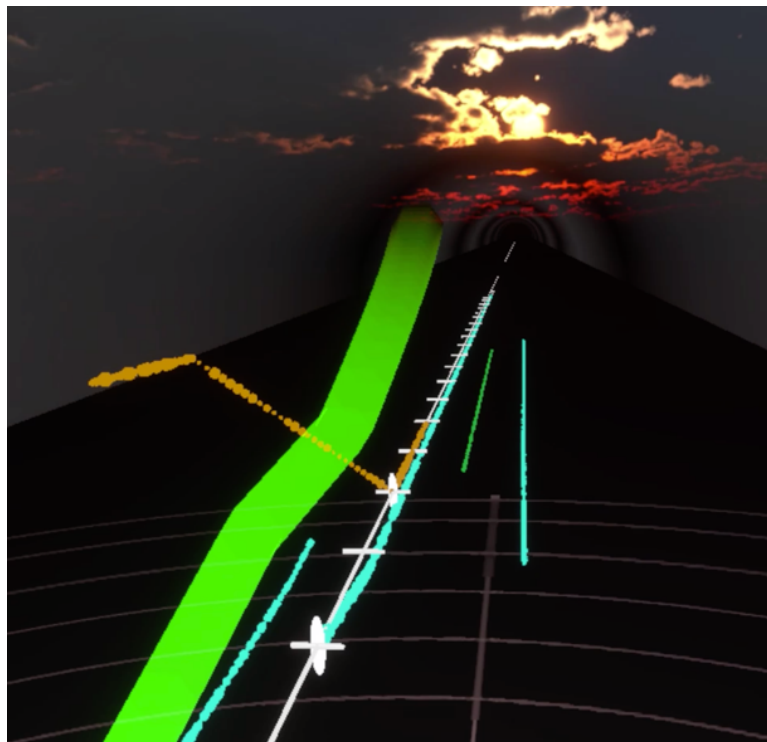


Figure 13. The visualization of the correction of impacts of potentialities

This first prototype aims at making understandable and actionable a theoretical approach that produces results very hard to apprehend and to manage. This is a first playable prototype that still require improvements but that shows the benefits of using VR to visualize these results. These results have been presented to four panels of industrial partners (two in the US and two in France), from different activity domains. They all approve the great interest of the approach and the indisputable benefit of using VR as a facilitator for the usage. The following

section discusses the limits and avenues of improvement.

Preliminary Evaluation and Future Work

After several demonstrations of the first prototype, the main identified limits (from the feedbacks of industrial testers) are the following:

- Obviously, the environment is very abstract and require apprehending very significantly all the presented concepts. Some users found it difficult to make the connection between trajectory and performance or between flows and risks.
- The number of flows may rapidly become hard to manage. This could be managed by “aggregation” of flows when they concern the same aspects. For example, one user expressed a concern about a situation with many victims for whom he would like to see the individualized risks
- The location of flows with regards to their impact of the trajectory is not as obvious as expected. The idea was that, even if the objective is not to give a meaning to the deviation, the location of flows with regards to the timeline should implicitly be diametrically opposed to the direction it is supposed to pull the trajectory in. Some users remained oriented toward the idea of growth and fall, and therefore were eager to push the performance trajectory up and were afraid to see it fall.
- Having the timeline merged with the ideal trajectory has been confusing for some users. Besides, on a visual point of view, this white graduated line does not give the expected idea of “ideality”. Users tended to focus on a goal in the distance (like the sun on the horizon) rather than seeing the white line as a representation of the ideal.
- There is still a lot to do to make the flows representing the potentiality more understandable. What about potentiality that may occur several times? What about the difference of impact with time? Etc.

These are a set of first limits that draws the perimeter and gives some avenues for the future work. Currently, the most relevant ambitions concern the following perspectives:

- Having the system represented as a world sphere is just a temporary solution. Especially because the system might be different than a supply chain. As a consequence, it would be interesting to represent the system as an object in the green trajectory, at the current location in time. Besides, by interacting with this object (for instance by double-clicking), it would be possible to open another room where the system could be represented more concretely (see Clifford et al. (2018) as a source of inspiration).
- Similarly, other rooms could be available and accessible to represent complementary information (dashboard detailing the nature of a deviation, all the KPIs, a potentiality editor, etc.) without perturbing the main space of trajectory management. For instance, a room to define and update potentialities.
- A work should be done on the perceived meaning of the deviation. It still remains an objective not to give signification to up, down, left or right but a better connection with the location of potentiality flows should be studied. For example, by touching the performance trajectory, one could have a more detailed representation of the observed system at the time corresponding to the touch point (whether it is a physical representation in the form of a 3D model or a quantitative representation in the form of a detailed view of the performance at that particular time).
- The flows representing potentialities should be improve on at least two aspects: (i) first, the thickness of the flow could be meaningful for instance by representing the intensity of the potential impact of the potentiality, (ii) second, the trajectory of the flow could be more representative of its probability of occurrence (more significant parabola could be more relevant).
- Finally, the visual, light and sound environment could be depending on the current performance and the appearing potentialities. For instance, more or less cloudy, more or less luminous. The music could be made of a stack of rhythms and sounds correlated with performance and the presence of potentialities.

All these limits and perspectives pave the way to the future works, but these avenues will certainly also and mainly depend on the results of the theoretical research on the Physics of Organization Dynamics.

CONCLUSION

The research results presented in this article basically introduce a virtual reality environment dedicated to visualize an abstract situation and interact with concepts and decision. The research activities are really abundant and

intense in the domain of VR for representing and mimicking reality. The question of digital twin for instance is concretely focusing a lot of interest. However, the use of VR for its ability to escape reality is not really at the center of the attention. Though, VR is able to provide an immersive environment where the usual and common physical senses can be drawn upon in order to improve the intelligibility of abstract concepts. This feature is not yet massively studied (it is used in several niche domain like airplane traffic), probably because of several reasons, including at least: (i) the potential of classic data visualization is not yet fully exploited and there are still a lot of benefits to get, and (ii) the feasibility of an everyday life usage, at the office is not obvious yet. However, the miniaturization and standalone trends should eventually tackle the second point, while time will probably deal with the first one.

The most important perspective of the presented VR environment is its ability to be used in an amazingly wide range of domain. It may be a dedicated to any field of management science as soon as potentialities could be calculated as impacts on KPIs. For instance, some current works are specifically dedicated to crisis management in order to deal with the crisis response in a more effective way.

Moreover, in the field of crisis management, this type of abstract visualization tool can facilitate collective decision-making. One can indeed imagine that several actors interact in this virtual environment. The significant benefit of such a "multi-player" functionality is to allow the participation of actors on the site of the crisis itself and of extremely distant actors in a decision-making phase with actors in the crisis cell.

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