# Digital twin design requirements in downgraded situations management

Stélian Camara Dit Pinto, Eric Villeneuve, Dimitri H. Masson, Guy Andre Boy, Thierry Baron, Laetitia Urfels

# Digital twin design requirements in downgraded situations management

S. Camara Dit Pinto*,**, E. Villeneuve**, D. Masson**, G. Boy*,**
T. Baron***, L. Urfels****

** Université Paris-Saclay, CentraleSupélec, Laboratoire Génie Industriel, 91190 Gif-sur-Yvette, France.*
***UNIV. BORDEAUX, ESTIA INSTITUTE OF TECHNOLOGY, F-64210 Bidart, France.*
**** TOTAL SA, R&D, Program Gas & Sustainable developpement, 64000 Pau, France.*
***** TOTAL SA, R&D, PERL Research center, 64170 Lacq, France.*

Abstract: The oil-and-gas industry is known to be part of the most safety-critical domains. Safety culture has prompted such companies to implement new systems to support decision-making. In this paper, we explore the use of digital twins to support situation awareness as a crucial part of real-time decision-making processes. Therefore, this paper presents requirements for the development of an eight components digital twin. Human-centered approach contributes to add useful information based on user needs and user experience to the usual theoretical process. This user-centered information helped shape both digital twin components and the situation awareness model.

*Keywords:* Manufacturing System Engineering; Decision Support System; Business Process Modeling.

## 1. INTRODUCTION

The Oil-and-gas industry is known to be one of the domains most concerned by safety (O'Dea and Flin, 2001). Industrial safety is supported by a safety culture within the company, that has been incrementally implemented, and updated through regulations and rules. New technologies (Kemp et al., 2016) are developed to improve on-site safety and reduce risks. In this study, we focus on risk reduction (Bigliani, 2013) in downgraded situations. A downgraded situation can be defined as an abnormal situation, where a facility is operating outside its context of definition, resulting in an increase in operation-related risk.

Downgraded situations are currently detected through monitoring by:

- operators in the control room who manage the industrial process. However, if the situation has no impact up on the process (up to a fixed limit), it will not be relayed.
- Manned patrols organized regularly during the day and night. These patrols cannot be exhaustive due to the size and complexity of oil-and-gas facilities.
- Stationary sensors located appropriately on the facility (e.g., fire and gas detection, CCTV, etc.) which, for most of them, if not directly in contact with source of the incident or its direct effect (a leaking pipe, the gas cloud) can fail to detect situations (McGillivray and Hare, 2008).
- Inspection and maintenance campaigns that are conducted regularly but sparsely due to the availability of equipment, the mobilisation of personnel and the quantity of equipment.

The reliability limits of these detection methods may delay the identification of downgraded situations. Reaction time, and thus, the ability to make early decision is a critical factor to correctly address anomalies and prevent disasters (Sheffi, 2015). New techno-centered solutions, such as detection systems using sonic sensors and image processing are currently being tested to improve early detection of downgraded situations, such as leaks (Kemp et al., 2016). However, in complex systems composed of interconnected functions of functions allocated to interconnected structures of structures (Boy, 1998) the addition of new detection capabilities brings out new functions. This leads to an increasing complexity of the oil-and-gas site for human operators. We argue for a human-system integration (HSI) approach to support human experts in handling downgraded situation.

Among the emerging functions, the ability to act on an early detection of a downgraded situation has an impact on the decision-making (DM) process. In order to perform this decision-making process, various data must be accessible. These data must reflect the situation and can be related to industrial site states, the number of workers and their locations, weather forecast and safety recommendations. Digital twins (DT) of oil-and-gas industrial sites have been identified to support access, visualization, and interaction with these data (Grieves, 2014).

Consequently, the goal of this study is to propose requirements for designing a digital twin that supports decision-making for early detection of downgraded situations.

The following section focuses on exploring DT and decision-making literature. Based on resulting state of the art, Section 3 highlights DT design requirements. These requirements will be challenged in Section 4 by confronting them to the results of a field study conducted with oil-and-gas experts within the TOTAL company[1]. The last section concludes this article and proposes some perspectives for future work.

## 2. STATE OF THE ART

### *2.1 Digital twins*

Based on previous work in the context of Product Life-cycle Management (PLM) (Grieves, 2014), NASA has defined DT as "an integrated multi-physics, multi-scale, probabilistic simulation of an as-built vehicle or system that uses the best available structural models, sensors update to mirror the life of its corresponding flying twin" (Glaessgen and Stargel, 2012). Three main parts compose this seminal definition: a physical system; a virtual system; and a data flow between the two (Grieves, 2014).

In our context, a DT is defined as a dynamic representation of a physical system using interconnected data, models, and processes to enable access to knowledge of past, present, and future states to manage action on that system.

When used as a virtual system that has the same behavior as the real system (Haag and Anderl, 2018), DT rely on two different components: (1) a conceptual and digital model of the real physical system where the behavior of the virtual system is implemented as a structure-function digital models (e.g. Computer Aided Design, Finite Element Method, Computational Fluids Dynamics) (Tuegel et al., 2011), and (2) a set of sensors collecting data about the real system to feed the models (Rosen et al., 2015). This data can be used to ensure quality of the link between the twins. They can be processed in DT artificial intelligence capabilities to support elicitation of system knowledge (Min et al., 2019). DTs gather data and make it accessible within a single tool via its user interface.

When used in real-time operation, decision-making depends not only on the understanding of what the system is doing in its environment (i.e., using external data sources such as weather forecasts or human knowledge), but also on its ability to process and synthesize all available data into a form that is understandable by a human decision-maker (Villeneuve et al., 2018).

The following section introduces core concept about decision-making process necessary to design a DT that supports this decision-making in real time.

### *2.2 Situation awareness in human decision making*

The decision-making process is defined as a “set of actions and dynamic factors that begins with the identification of a stimulus for action and ends with the specific commitment to action” (Mintzberg et al., 1976). Due to the increasing complexity of dynamic systems, such as those that can be found in the oil-and-gas industry, situation awareness (SA) is increasingly important in the decision-making process (Endsley, 1995).

SA has been modelled with respect to three sub processes (Endsley, 1995) (*Fig 1*):

1) Perception of elements of the current situation. In industry, this process deals with data related to system states, technical data and environment components.

2) Comprehension of the current situation. This process provides make sense of the elements perceived by the previous process.

3) Projection of future status. Once the situation is understood, this process provides scenarios and future states of the system.

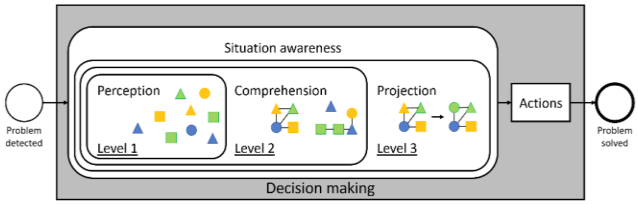


Fig 1 Situation awareness levels inspired by Endsley. (Endsley, 1995)

According to (Endsley, 1995), SA mechanisms are based on the notion of attentiveness which characterize the ability of the decision-maker to focus on the situation, and on three types of memory. The short-term memory is involved in the acquisition of data during the perception process. The long-term memory is linked to the models and patterns learned through experience and contains links between situations and solutions. It enables the selection of appropriate patterns for recognition and provide recommendations to the decision-making process. The working memory is actively used in the processes of comprehension and projection to store and process information.

To improve SA, studies have looked for different ways such as improving data acquisition by using other sources of information (Herfort et al., 2014) or display systems (Aggarwal et al., 2012). Using the models and work already achieved in this field, the objective of this work is to propose a DT that enhances these SA processes.

## 3. DIGITAL TWINS’ REQUIREMENTS FOR SITUATION AWARENESS

Based on this literature review and more specifically the review of the roles digital twins performed in (Negri, Fumagalli and Macchi, 2017), we decompose the DT into several components and highlight the human SA processes they principally support (Table 1):

[1] www.total.com

- The **real system model** handles the replication of its physical twin's behavior;
- The **sensors** capture the current state of the physical twin and provide real time data;
- The **contextual data** includes all data external to the system, and allows the decision-making process to be performed in context;
- The **interface** allows the user to visualize and interact with the data;
- The DT **memory** stores the data for access through life cycle and support of human memory;
- The **data management** component allows the orchestration of data flows across all components. It can be decomposed in three main sub-components working together: (1) **data reduction** to summarize data; (2) **data selection** to elicit specific data when needed; and (3) **data processing** to obtain general knowledge.

**Table 1 Likely impact of DT components on human SA levels**

| **DT components** | **Human SA levels impacted** |
|---|---|
| Real system model | Perception and projection |
| Sensors data | Perception |
| Contextual data | Perception |
| Interface | Perception, comprehension, and projection |
| Memory | Comprehension |
| Data reduction | Perception |
| Data selection | Comprehension |
| Data processing | Comprehension and projection |

While most of these components have been defined in the literature, there is a need to further develop what they cover:

- **Contextual data** needs to be included in DT, to encapsulate the situation around the system and contextualize the decision. The real system under consideration develops at a larger scale than currently considered. This notion is important in downgraded situation such as gas leaks for example where the strength and direction of the wind (contextual data) might directly impact the situation.
- **Data processing** must produce knowledge. This extends beyond usual data management to further support the user's decision-making. Better data processing capabilities allows the stored information to be linked together to create knowledge for the operator. Using the same gas leak example, linking an operator's work position to a leak position can allow control room operators to infer the danger to the worker.

This knowledge production capability of the DT implies that the **memory** capabilities of the DT allow for the storage of data, information, and knowledge. This opens up the possibility for introspection inside the DT by building knowledge about its use in decision-making processes. As stated above, the DT should support the three stage of the SA process:

- **Perception**: requires access to **sensor** and **contextual data** to give direct access to every available component of the situation. Due to the large amount of data, the ability to synthesize usable and useful data through data reduction is critical for the DT.
- **Comprehension**: requires assisting user's long-term **memory** with experience-feedback mechanisms, the DT enables the generation of user knowledge in reaction to specific situations as well as the storage of pattern of situation elements. The **data management** process should be used to link specific situations to past experiences and support the user's comprehension in creating new model of the situation.
- **Projection**: requires a simulation capability from the **physical model**, that enables the extrapolation of future system states.

In order to validate the use for contextual data, data processing and memory in current decision-making process, a field study has been conducted.

## 4. FIELD STUDY

This section presents a theoretical process of downgraded situation management extracted from official guideline about oil-and-gas sites safety. It is compared with process, tools and methods used in operations by domain experts. These have been extracted by interviewing experienced operators at TOTAL.

### *4.1 Theoretical process of downgraded situation management*

The theoretical process model of downgraded situation management, proposed in this section, is based on official safety recommendation documents. This process (*Fig 2*) involves multiple actors (not represented) and can be decomposed in four phases: (1) a situation identification and initial risk assessment step, an iterative sub process of (2) implementation of corrective actions, and (3) residual risk assessment. In parallel of this sub-process, (4) a status reporting activity is performed.

This model gives the theoretical process that is to be compared to the real control room process.

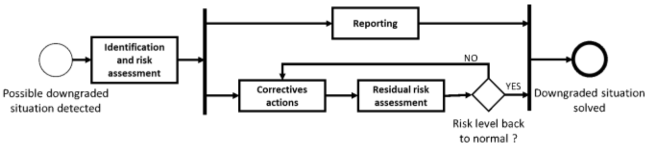


Fig 2 Theoretical process of downgraded situation management.

### 4.2 *Actual process of downgraded situation management in control room*

In order to understand the process actually implemented in an operational situation and needs of the users in terms of methods and tools for decision support in these situations, a semi-structured interview protocol was defined.

This protocol allows to identify: (1) the tools used to solve downgraded situations, (2) the accessible data on current tools and the data that are used in resolving downgraded situations, (3) the actions conducted during downgraded situations, (4) the knowledge necessary and generated as well as the way to access and transmit it, and (5) the human interactions. The semi-structured interview model allowed interviewees to express themselves freely and without bias on the selected general themes (Unger and Chandler, 2009).

Eleven interviews with operators experienced with at least 5 years in field operations, control room operations, control room management and site management have been conducted for 45 minutes average long sessions. Interviewees had worked on both on-shore and off-shore and in African, Asian, or European sites. The interviews were recorded and scripts produced to enable the analysis. Management process of downgraded situation in the control rooms has been formalized using BPMN formalism to synthetize the interviews. Therefore, the process (formalized in *Fig 3*) is decomposed in five steps. (1) The nature of the downgraded situation is identified, and its validity is confirmed. (2) Once confirmed, the field operators who may be impacted are directed to safety. (3) Then the industrial process is partially stopped if necessary. (4) The problem is referred to the adequate department to be solved. (5) Once the problem is solved, the reporting is done on shift books.

Differences between the theoretical and the actual processes have been noted. The next section will focus on analyzing these differences in order to determine the user needs relevant to the digital twin design.

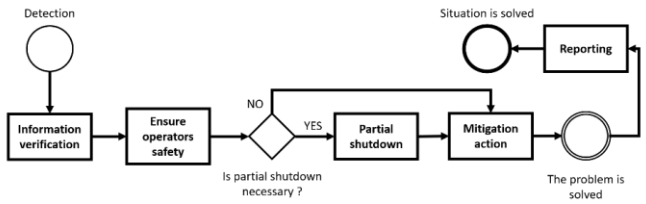


Fig 3 Downgraded situation management process performed in control room.

### 4.3 *Results analysis*

We present here, the three majors differences identified between processes introduced in section 4.1 and section 4.2.

First, the management process in the control room is usually 24 hours long when the theoretical downgraded situation management process can take up to two to three months. In fact, the goal of the control room process is to take mitigation action and then delegate the task to the qualified personnel for correctives actions.

Regarding formal reporting, it is usually done once the situation has returned to normal and is not regularly updated. However, reporting is also theoretically done on an internal reporting tool whereas, in reality the reporting is first written on shift book to be used by other operators. A memory component is therefore already implemented but cannot be easily used to extract knowledge as the current support is not digital.

Due to a difference in time constraints, the management process in the control room uses less information and tools than the theoretical one. Control room operators are therefore limited to using system data and have little time to access contextual data as is done during the theoretical process.

Interviews have also highlighted user needs. Data is accessible but from many different tools, which make data centralization a priority. Moreover, too much data is accessible which makes selecting the relevant one difficult and requires a better data management with ability such as data reduction, data selection or data processing. Reporting is done on another separate tool, which makes it less useful when dealing with a downgraded situation and memory use.

The results of these interviews show a real link between the users' needs and DT components highlighted by the requirements. A DT should centralize data and, through data management components, make information and knowledge accessible. The memory associated with the capability to formalized experience feedback could implement the reporting phase directly in the process. In addition, experience feedback should be usable through data management capabilities. System and contextual data are already being used in the decision-making.

## 5. CONCLUSION AND FUTURE WORK

This work focuses on the use of digital twins and their ability to support situation awareness, and therefore decision-making processes. It presents requirements for the design of a digital twin and its components within the scope of an oil-and-gas process and experienced workers. This study confirms that the digital twin, as defined in this article, could help supporting decision-making processes with respect to the currently investigated process and user needs.

We are currently working on an extension of the presented digital twin concept to a multi-layer model based on Rasmussen's model (Rasmussen, 1983) as a tool supporting the skill-based level through the physical model and the rulebased level through reasoning capabilities. The knowledge level will be based on Endsley's levels of situational awareness (Endsley, 1995). Obviously, current digital twin capabilities need to be expanded. Among other possibilities that we are exploring, tacit knowledge could be acquired from experience feedback to enhance decision making performance.

AKNOWLEDGEMENTS

This study was performed thanks to the technical and financial support of TOTAL company.

REFERENCES

Aggarwal, M., Hanna, K., Sawhney, H., Paragano, V., Kumar, R., Samarasekera, S., Arpa, A., Germano, T., Zhao, T., Kalokitis, D., others (2012). Method and apparatus for total situational awareness and monitoring. *United States Patent no. US8289390B2.*

Bigliani, R. (2013). Reducing Risk in Oil and Gas Operations. *IDC Energy Insights.*

Boy, G.A (1998). Cognitive function analysis for human-centered automation of safety-critical systems, in: *Conference on Human Factors in Computing Systems - Proceedings*. pp. 265–272.

Endsley, M.R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems, in: *Human Factors Journal*. pp. 32–64.

Glaessgen, E., Stargel, D. (2012). The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles, in: *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA. American Institute of Aeronautics and Astronautics, Reston, Virigina*.

Grieves, M. (2014). Digital Twin: Manufacturing Excellence Through Virtual Factory Replication.

Haag, S., Anderl, R. (2018). Digital twin – Proof of concept, in: *Manufacturing Letters* 15, 64–66.

Herfort, B., de Albuquerque, J.P., Schelhorn, S.J., Zipf, A. (2014). Exploring the geographical relations between social media and flood phenomena to improve situational awareness, in: *Proceedings of the 17th AGILE Conference on Geographic Information Science*. pp. 55–71.

Kemp, C.E., Ravikumar, A.P., Brandt, A.R. (2016). Comparing Natural Gas Leakage Detection Technologies Using an Open-Source "virtual Gas Field" Simulator, in: *Environmental Science and Technology* 50, 4546–4553.

McGillivray A., Hare J. (2008) ‘Offshore hydrocarbon releases 2001-2008’, pp. 1–67.

Min, Q., Lu, Y., Liu, Z., Su, C., Wang, B. (2019). Machine Learning based Digital Twin Framework for Production Optimization in Petrochemical Industry, in: *International Journal of Information Management* 49, 502–519.

Mintzberg, H., Raisinghani, D., Theoret, A. (1976). The Structure of "Unstructured" Decision Processes, in: *Administrative Science Quarterly* 21, 246–275.

Negri, E., Fumagalli, L. and Macchi, M. (2017) A Review of the Roles of Digital Twin in CPS-based Production Systems, in: *Procedia Manufacturing. Elsevier, 11, pp. 939–948.*

O’Dea, A., Flin, R. (2001). Site managers and safety leadership in the offshore oil and gas industry, in: *Safety Science* 37, 39–57.

Rasmussen, J. (1983). Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models, in: *IEEE Transactions on Systems, Man and Cybernetics SMC*-13, 257–266.

Rosen, R., von Wichert, G., Lo, G., Bettenhausen, K.D. (2015). About the importance of autonomy and digital twins for the future of manufacturing, in: *IFAC-PapersOnLine*. Elsevier, pp. 567–572.

Sheffi, Y. (2015). Preparing for disruptions through early detection, in: *MIT Sloan Management Review* 57, 31–42.

Tuegel, E.J., Ingraffea, A.R., Eason, T.G., Spottswood, S.M. (2011). Reengineering Aircraft Structural Life Prediction Using a Digital Twin, in: *International Journal of Aerospace Engineering 2011*, 1–14.

Unger, R. and Chandler, C.(2009) A Project Guide To Ux Design.

Villeneuve, É., Abi Akle, A., Merlo, C., Masson, D., Terrasson, G., Llaria, A. (2018). Decision support in precision sheep farming, in: *IFAC-PapersOnLine* 51, 236–241.