SPRINCE

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Smart PRocess INdustry CranEs

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Smart PRocess INdustry CranEs

(project acronym SPRINCE)

Development of human factors indicators

Report activity WP2.2

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University of Messina **University of Belgrade** **University of Defence**

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Active partners: University of Messina (*UM*)
Faculty of Mechanical Engineering - University of Belgrade (*FME UB*)
University of Defence (*UD*)

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1. Objectives

The European Directive on Safety and Health at Work (Directive 89/391/EEC) and the following directives have the scope to provide a framework allowing workers to enjoy high levels of health and safety at work [1]. However, the society evolution and the changing of workplaces bring new risks and challenges for workers and employers [2]. The European Risk Observatory (ERO) of the European Agency for Health and Safety at Work (EU-OSHA) attempted to identify new and emerging risks by the conduction of four expert forecasts (for physical, chemical, biological and psycho-social risks), based on a Delphi methodology [3]. Such investigation pointed towards the following emerging ergonomics or human factors risks:

- Multi-factorial risks, derived from a combination of poor ergonomic design, poor work organization, mental and emotional demands
- Complexity of new technologies, new work processes and *human-machine interface* (HMI) leading to increased mental and emotional strain
- Poor ergonomic design of non-office visual display unit (VDU) workplaces
- Poor design of HMI (excessively complex or requiring high forces for operation)

Given that the aim of this report is to investigate the risk factors due to the use of the real-time object detection solution for cranes, developed within the *WP1*, and to understand the interaction that the crane-operator has with the software interface, the document is limited to the analysis of *emerging human factors risks*, which will be identified and investigated, when performing following activity *WP3.2*, by a questionnaire which will be the result of this work (*WP2.2*).

2. Description of performed activities

The use of risk-based early warning indicators is promoted by the project. These consist of technical and organizational factors, as earlier suggested by Øien et al. (2011) [4-5], but the challenge proposed by the SPRINCE project is the development of operator-specific indicators. It is expected that such indicators will have a huge impact on maintenance strategies and be able to predict the future safety performance of cranes with eyes.

The implementation of innovative models for the evaluation of organizational and human (operator-specific) factors is the objective of *WP2* of the SPRINCE project, which is divided in two activities *WP2.1* “Development of organizational factors indicators” and *WP2.2* “Development of human factors indicators”.

This report describes the activity related to *WP2.2*, for which *UM* is responsible; active partners are *FME-UB* and *UD*. The tasks included in *WP2.2* are listed below:

- *T2.2.1 - Definition of knowledge*
- *T2.2.2 - Derivation of knowledge dimensions*
- *T2.2.3 - Questionnaire development (part 2)*

The task *T2.2.1* is the definition of the six types of knowledge needed to be able to adequately manage the innovative solution; these typologies of knowledge include work domain, task, strategies, collaborations, cognitive resources and interface knowledge. Task *T2.2.2* consists of the description the of the knowledge dimensions as suggested by Ham et al. (2011) [6]. From previous tasks (*T2.2.1* and *T2.2.2*), adaptive factors and operator-specific factors are going to be delivered in the following *WP3* by means of data collected through a questionnaire, which will be created (*T2.2.3*). The questionnaire is the second part of a more extended one, which include also the part related to the assessment of technical and organizational factors (*T2.1.3*).

2.1. Background

The use of smart devices for the improvement of safety in workplaces is becoming more popular in particular in the process industry, even if this implies a widespread use of tools and machines, which have steadily grown in number and complexity. EU-OSHA reports that poor *human-machine interface* (HMI) can determine serious consequences, such as occupational accidents and diseases, including stress, its proper inclusion in design equipment and workplace is of utmost importance [3,7]. Therefore, HMI appears to be particular relevant to high-risk industries, such as the chemical, electric or nuclear energy industry and transport. During these last decades, it has been overcome the previous approach to the design of such devices, which took into account technical requirements and rarely included needs and characteristics of the operators. New design trends point towards a user-centred approach. Research and practical experience show that systems, which neglect the assessment of HMI, are more likely to give rise to occupational diseases, operating errors and accidents. By using such user-centred design approach, a system does not consist only of the machine, but it includes workers, tools, tasks and work contexts [8].

Human-machine interactions could be the cause of errors and also the environment might give rise to unpredictable dangerous situations [7]. In this context, the use of automation simplifies the process's control, even if the creativity and intuition of human beings have the flexibility to cope better with unexpected or unforeseen situations. This means that it is important to appropriately divide tasks between the operator and computer-operated technical system by accounting for the working situation and environment. In such frame, Koller et al. [9] have shown that the operator's opinion on HMI is essential in order to reduce emerging human factors risks. The involvement can be achieved by surveys, direct observations of workers at their workplace, structured discussions, participation in design workshop and feedback concerning prototype or products in usability tests. The involvement of users in the design process from the start allows a better adaptation of the product to the needs of the different target groups of users.

Some useful definitions for the purposes of this activity are given below (extracted from EU-OSHA [7]):

- Human factors

  Human factors *are the relationships and interactions between a system and its human elements and between the human elements themselves in a system or its adjacent organization. The integral of all human factors in a corporation constitutes the corporate psychology. This makes up the corporate culture and the social resources in the corporate competitive position* [10].
  To minimise human factors, it is essential the following: "*designing machines to accommodate the limits of the human user*" [11] by means of the definition of elementary objectives as the reduction of error, the increase of productivity and the enhancement of safety and comfort when the human interacts with a system.

- Human-machine interface HMI

  Baumann and Lanz [12], as well as by Charwat [13], describe HMI as the part of an electronic machine or device, which serves to exchange information between the operator/user and the machine/device. HMI consists of three parts which are (i) operating elements, (ii) display and (iii) an inner structure (hardware and software).

- Human-machine interaction

  Human-machine interaction should not be confused with the HMI, it regards how humans and machines interact and affect each other. The communication between them can be realised only by displays and operating elements (input devices, such as buttons, touch-screens, keyboards or mouse). Machines can give information, which are visual (e.g. as pictures and characters), acoustic (verbal or nonverbal) or physical (e.g. vibration). The interaction humans-machine is limited by the fact that whereas humans have natural intelligence, allowing the interpretation of situations according to the context, this ability is missing in most machines and very restricted in the most advanced ones. Nonetheless, humans often expect the machine to communicate in the same way as they do and get frustrated when this does not happen [14].

2.1.1. Human Complexity Factors

Even if it is well-known that human performance is affected by numerous factors, complexity is considered the most influential for human-system interaction [15]. A considerable contribution to this topic was provided by Ham et al. [6], whose work deals with solving problems related to the complexity of the interaction between humans and modern socio-technical systems, which also could include the innovative solution for operating cranes developed within this project. Ham et al. emphasized that, even though numerous studies have dealt with the research of complexity factors that affect the cognitive abilities of humans interacting with the system, a systematic approach to determine these factors is still lacking. To cope with such an issue, the authors have developed an approach themselves. They stated more complex is the system (more details, functions, possible choices etc.), weaker are its performances, especially those related to the strategy of the mind, use of cognitive resources, acquiring of cognitive skills, work overload and human error. However, the term of human-system interaction complexity itself is not clearly defined, i.e. there is a variety of different definitions which can be distinguished according to the criteria from which they were derived. Unlike the majority of researchers, Ham et al. focused on the problem of finding and organizing the complexity factors in a systematic way, which can be applied also in any other context. In order to better understand the complexity between a human and a system, a review of the existing literature on the subject is provided by the authors, then, they described the concept of complexity for human-system interaction as given in Figure 1. This figure shows that existing approaches are various [16]; some of them use available definitions that are fully examined with the intent of achieving a description of the human-system interaction. Definitions of complexity are so numerous as a consequence of the fact that each one focuses on a certain aspect of the human-system interaction. This is obtained by approaches that can be top-down or bottom-up, model-based or experience- based, etc. This unfortunately means that there is no a single method applicable to each case.

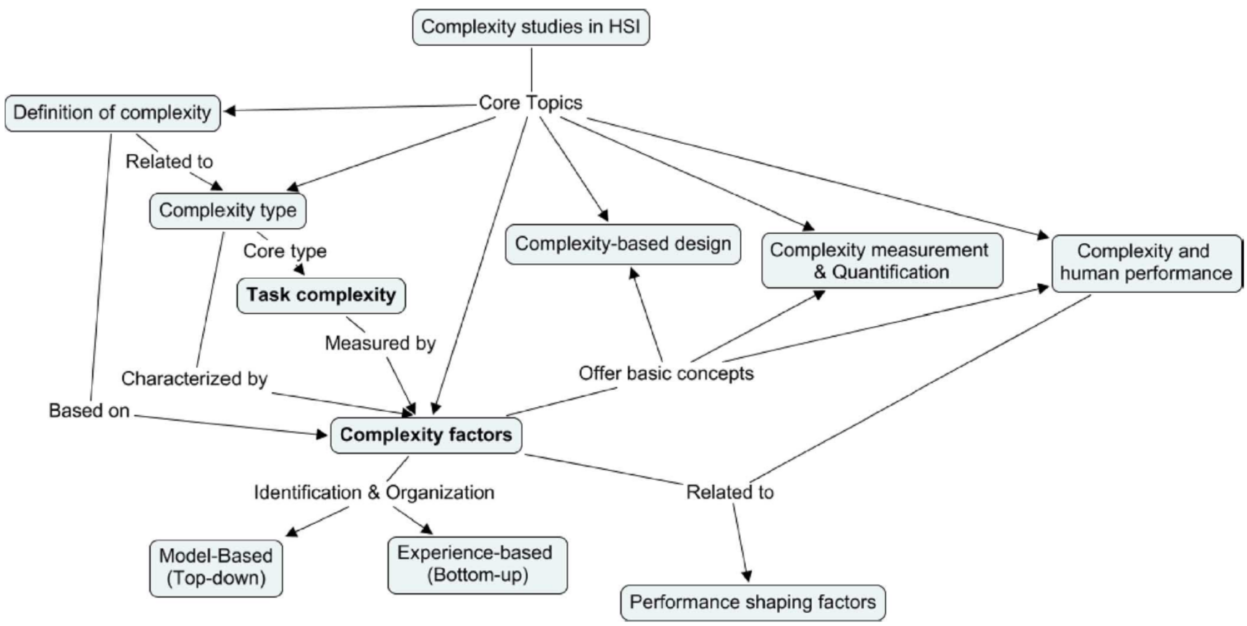

Figure 1. The concept of complexity for human-system interaction [16].

In earlier literature [17], a different number of complexity factors was defined and considered to provide an adequate description of the human-system interaction in a given system. It is also mentioned that these factors include both subjective characteristics, related to human knowledge, and objective characteristics, related to the technical solutions of the system itself. In this sense, it can be concluded that the complexity of the system can be reduced by providing humans with adequate and sufficient knowledge and skills related to that system. Objective system complexity can be quantitatively measured and it can be reduced by means of technical corrections to the system. Actually, the design of the interface (as a part of the system design itself) must be based and focused on the human for the purpose of taking advantage by technical innovation, enabling of optimal human-system interaction and enhancing the ability of humans to interact with their surroundings, as it was done by Carvalho [18].

It is clear that these two types of complexity (subjective and objective) are connected and it is necessary to properly distinguish between these terms within the research. The complexity of the task, which needs to be performed itself, is considered to be the connection between the task input and output relative to human capabilities and limitation, i.e. it is considered to be on the border between objective and subjective complexity. In their paper, Ham et al. [6] mentioned that there are various other complexity factor categorisations, such as by their structural complexity, functional complexity and interface complexity, or more detailed categorisations, which include multiple levels or layers within which different factors are distributed. Numerous researchers were focused on defining the factors related to cognitive tasks complexity. In addition, a number of papers [11, 15] involved the identification of complexity factors for a given system (for example, nuclear industry, process system control, traffic control, etc.). However, a method or a structured framework, according to which factors of human-system interaction complexity could be identified and organized for any given area, was not developed in any of these researches.

2.1.2. Model for identifying and organizing of complexity factors

Ham et al. [6] proposed a *conceptual framework*, which support in *identifying and organizing elements that contribute to the complexity of human factors*. Such conceptual framework specifies *principles and viewpoints* that should be kept in mind when establishing a complexity model. At the same time, the framework aims having a holistic vision of the problem which consists of five *views*, as given in Figure 2. Each one of these views gives a single unified dimension to identify and organize complexity factors.

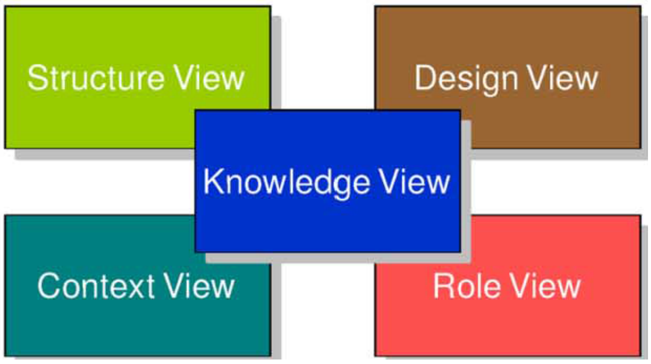

Figure 2. Conceptual framework as suggested by Ham et al.

Below a short description of each view is provided:

- *Knowledge view* relates to the types of knowledge that operators should possess and use to interact with socio-technical systems. According to Ham et al., it included five typologies of knowledge (work domain knowledge, task knowledge, strategy knowledge, collaboration knowledge and interface knowledge) and cognitive resources. Although cognitive resources do not appear as a form of knowledge, they need to be added to the *knowledge view* as the knowledge cannot be explained without relating to them. Studies on cognitive task analysis also support these distinctive knowledge types [17, 19]. Additionally, each knowledge complexity type has three aspects: spatial, relational, and temporal; thus, complexity factors for each knowledge type need to be identified in terms of these three aspects. Spatial aspect is related to a number and type of elements of which it consists, it defines the subject and scope of the knowledge itself. Relational aspect is related to functional relations between elements. Temporal aspect is related to the change of elements over the time. *Knowledge view* is linked to all other views, therefore as shown in Figure 2, it is placed in centre.
- *Structure view* reflects the possibility to model the interaction between humans and systems by means of five structural elements including work domain, task, interfaces, organization and human operators. Thelwell [20] was the first researcher that adopted the *structure view*.
- *Design view* identifies complexity factors that are originated during the design life cycle of things (systems, tasks or other kinds of artefacts). Complexity factors are into three types: unavoidable (inherent) complexity factors, designed complexity factors and situational complexity factors.
- *Role view* concerns the effect of some factors that, depending on the contextual situation, can act as mediator of moderator. Considering the relationship between complexity factors and human performance: (i) mediators are factor that play a role of mediating the effects of complexity on human performance and explain how or why

the effects of complexity occur; (ii) moderators moderate these complexity effects, by specifying when and how much the effects of complexity hold.

- *Context view* refers to the contextual information. In this frame, a context can usually be determined by task or work domain characteristics.

To identify complexity factors, it is possible to apply a bottom-up approach and top-down one. The bottom-up approach has been adopted by most studies and, based on it, complexity factors are derived from empirical studies, such as observation and questionnaire survey. Complexity factors from this approach well represent actual conditions of increasing complexity for a given context, even if it could be difficult to generalize them into other contexts. Xing and Manning [21] pointed out four lacks of a bottom-up approach and claimed the need to develop a framework or a set of objective measures, which are independent from contextual factors and include operators. This can be used for a top-down approach. A top-down approach should support to conjecture or assume a set of complexity factors, which then need to be validated with a bottom-up approach because they are just possible candidates influencing the complexity of HSI. It should be noted that both approaches have their own strengths and drawbacks. Therefore, the proposed framework prescribes the complementary use of two approaches and, depending on how the use of the five views or their combination, the process of identifying and organizing complexity factors can be characterized in several ways.

2.2. Development of human factor indicators

To develop human factor indicators, for the purpose of this study, a method has been developed. The *conceptual framework* of Ham et al. [6], which can be schematized as given in Figure 3, was firstly used to define the types of knowledge that can influence the interaction human-interface during the use of the developed solution.

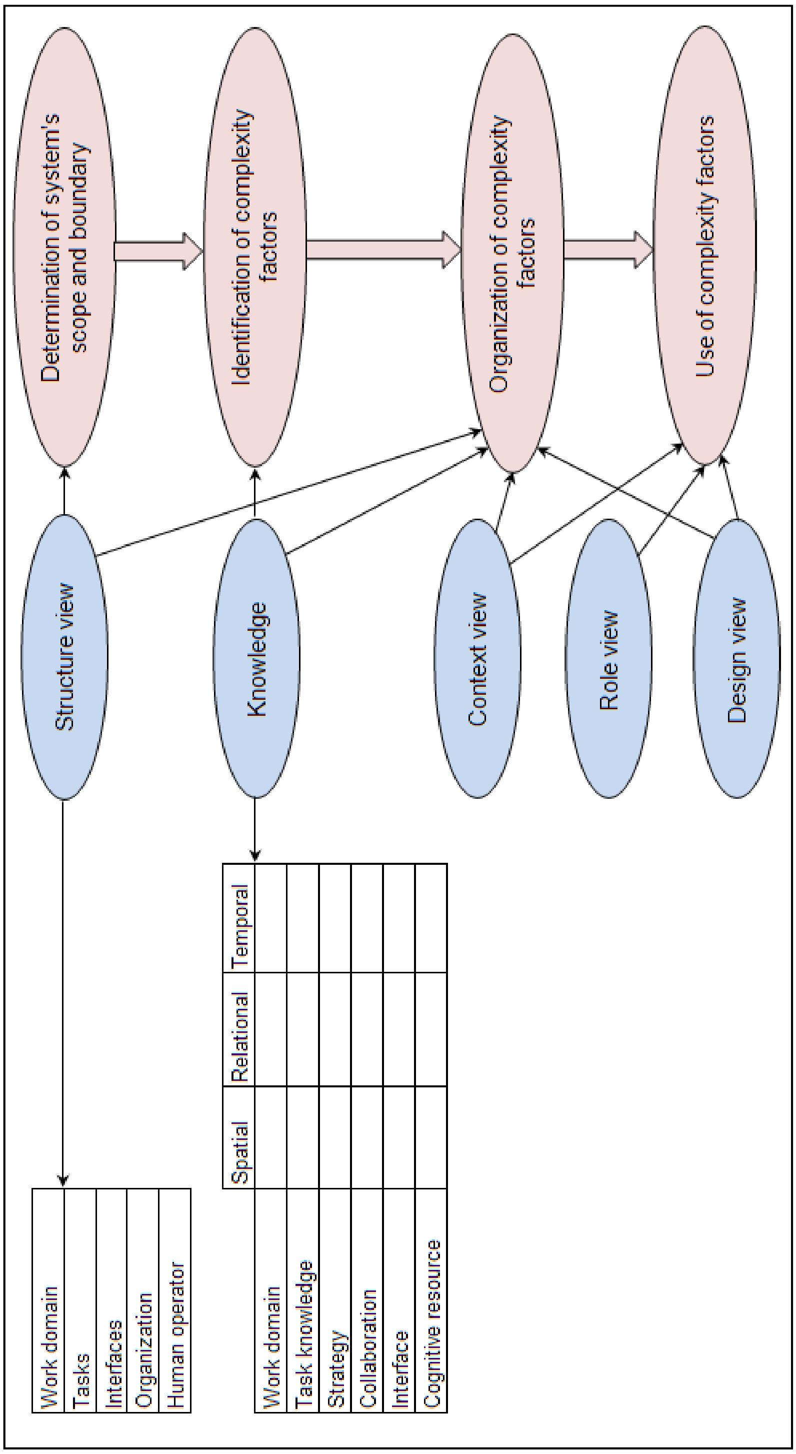

Figure 3. schematization of the conceptual framework of Ham et al.

The conceptual framework includes four steps that are: (i) the determination of system's scope and boundary, (ii) the identification of complexity factors, (iii) the organization of complexity factors and (iv) the use of complexity factors. The use of the five views or their combination gives a different characterization of the complexity factors. Based on the scope of the research, the analyst can give more emphasis on some views of such framework. Even if all the views can be used, Ham et al. stated that their use as suggested in Figure 3 can be sufficient to identify the greatest number of complexity factors.

The following step was to define the knowledge dimensions. As pointed by earlier studies [15, 21], the complexity has a multi-dimensional character; this means that to view the complexity of a system, it is needed to look at the complexity in several dimensions. This was also pointed by Xing [22] with the introduction of some *classification metrics* for the complexity factors, defined as given below:

- *Numeric size* – this metric refers to the number of groups.
- *Variety* – this is related to the variety of groups. Its increase causes an increasing complexity of the system [22].
- *Relations* – this metric represents the degree complexity of the system due to the relation amongst the elements of different groups.
- *Temporal variability* – this metric refers to the parameters that change over the time.

A further classification has been made based on the mechanism of information processing of the human brain, such processing includes three steps (i) perception, (ii) cognition and (iii) action (Figure 5). By combining the elaborated mental process and personal strategies, the observer is able to make a decision and then to convert it in action. The developed approach categorizes complexity factors with respect to each task and step of the mechanism of information processing of the human brain.

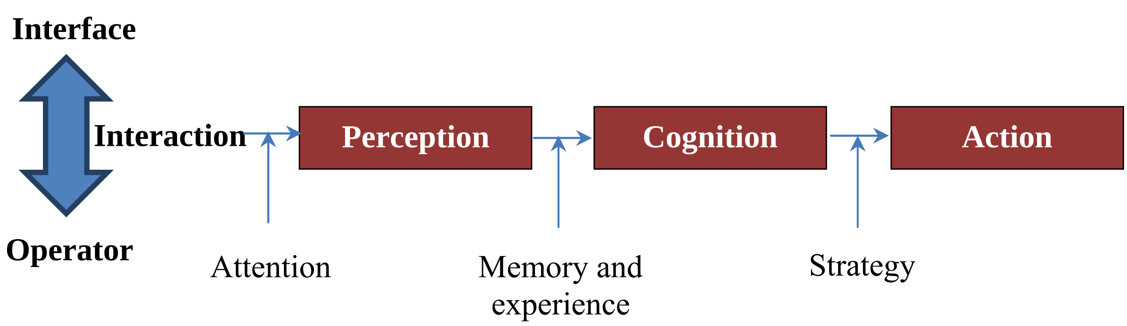

Figure 5. Mechanism of information processing of the human brain.

3. Results

The application of the *conceptual frame* proposed by Ham et al. (2011) [6] has been used to analytically identify the greatest number of complex factors. Although the literature states that such approach supports the generation of complexity factors, it is not guaranteed that the identification is complete. During this activity, a great contribution came from the experience, indeed some of the identified factors have been actually defined on the basis of the knowledge acquired during the entire system's design, i.e. by testing and discussing with the potential users (crane-operators). In the following sections, a description of the results obtained is given.

3.1. System's scope and boundary

The designed real-time object detection solution was developed with the goal of increasing safety in the use of cranes as it prevents incidents due to collisions between the load and an obstacle.

To determine the system's boundary of the real-time object detection solution, information related to the work domain, the interface, the organization, tasks and the human operator have been acquired with the aim to construct the *structure view*.

Work domain

The work domain refers to the number of elements that are included in the system. The developed solution currently is available in two configurations [23, 24], whose main elements (hardware) are given below:

- *Configuration 1* [25]: a box 36 cm x 29 cm x 12 cm (containing two Wi-Fi cameras, two power banks, a ruler and two usb cables) and a remote device (a laptop, two Raspberry, two ethernet cables and two adapters usb/ethernet).
- *Configuration 2* [25]: a box 36 cm x 29 cm x 12 cm (containing two usb cameras, a powerful laptop and a ruler) and a remote device (another laptop).

Both configurations use the same software to process the acquired images, which was developed in *WP1*.

Organization

The organization refers to the connection of the elements. The hardware placed in the box is located on the top of the crane. Below details, concerning the organization of elements, are given for both configurations:

- *Configuration 1* [25]: the remote device (a laptop) is used for the processing of the images and to show the results of the processing of the algorithms. This device receives a Wi-Fi signal from the cameras, contained in the box, by means of two Raspberry.
- *Configuration 2* [25]: the remote device (another laptop) is used to show the result of the processing of the algorithms, which are executed by the laptop contained in the box. This remote device receives a Wi-Fi signal from the laptop and allows remotely managing operations and setting the software.

Interface

The interface (Figure 4) is composed by a Graphic User Interface (GUI) of the application and a main window showing a real-time video of the operations taken by the image acquisition system. In the GUI, the *Start*, *Stop* and *Reset* buttons are respectively used to start, end and reset the monitoring process. The *Set Object area* and *Set Ignored area* are respectively used to select the area to be monitored, which includes the load, and that to be ignored during the processing. The *Settings* button is used to calibrate and set the system (this is an operation has to be executed before the use of the application). The *Beep on intrusion* checkbox enables or disables the acoustic signal alerting that an object is detected; the *debug* checkbox is inserted for debugging purposes.

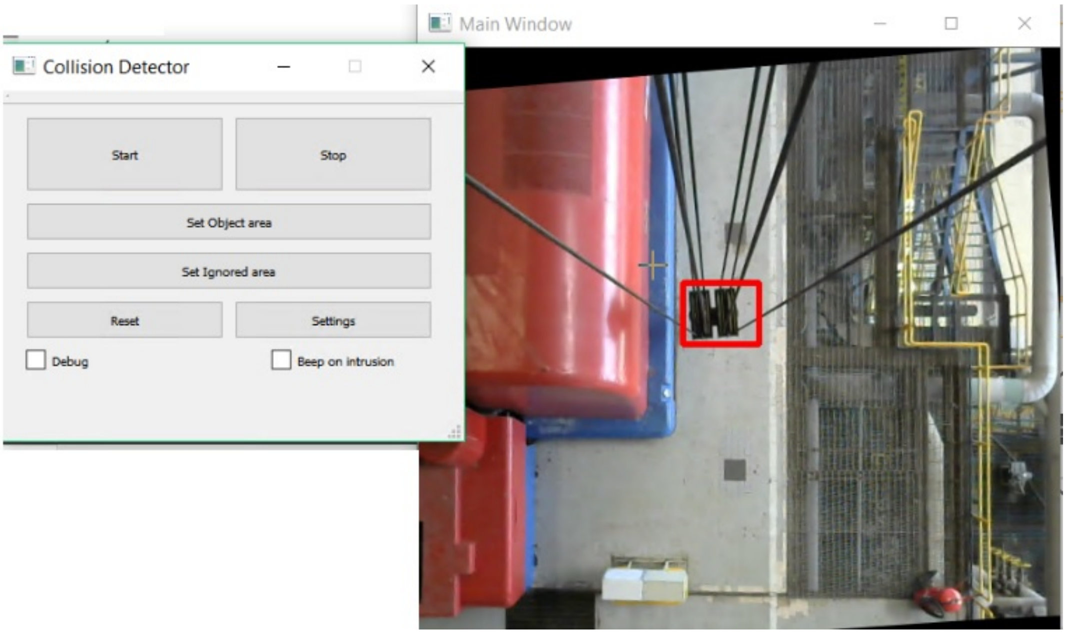

Figure 4. Human-machine interface of the real-time object detection solution.

Tasks

The main tasks for the crane-operator, which is using the real-time object detection solution, are the following:

- *Setting both the areas to be monitored and excluded*: this has to be done before to start the lifting of the load;
- *Starting the application*: this is required to run the application. To start the image acquisition, it is necessary to click on the *Start* button. After this operation, the load can be moved;
- *Observing the main window*: this must be done during the load navigation and the setting phases. An alarm will alert him/her if the distance load-obstacle reaches a previously set threshold. In such a case, he/she has to stop the operation and takes the proper actions to avoid the accident;
- *Stopping the application*: this is required to stop the application. To stop the image acquisition, it is necessary to click on the *Stop* button. After this operation, the load has already lifted;
- *Resetting the application*: this is required to reset the application and start a new operation.

Human operator

The human operator is the worker that uses the system, i.e. the crane-operator, that has to execute the tasks described above.

3.2. Identification of complexity factors

The use of the developed system implies a human-machine interaction which is realised through the display of the remote device (a laptop in both configurations). Given that this is the only interaction between the operator and the system, the investigation has been limited to the interface display-operator (study's boundary).

To identify the complexity factors, it must be understood the knowledge that the operator should possess and use to interact with the real-time object detection system. The five typologies of knowledge (work domain knowledge, task knowledge, strategy knowledge, collaboration knowledge and interface knowledge) and the cognitive resources have been investigated as suggested by Ham et al. [6] by analysing spatial, relational and temporal aspects and the metrics suggested by Xing [22]. A short description of the process investigation is given below and the list of the identified complexity factors is given in Table 1.

Work domain knowledge

The knowledge of the work domain relates to the knowledge of the interface and its included elements. It is assessed based on the spatial aspect, i.e. *monitor size* and the *visibility of the main elements* (*number of fixation groups*), and the temporal aspect, i.e. *the rate of acquisition of the overall view*. Given the small number of elements included in the work domain, no element has been identified related to the relation aspect.

Interface knowledge

Within the interface, an important aspect is related to the *variety factor*. Xing [22] states that switching amongst various *visual features* (colour, font, brightness, text dimension, workplace's lightning and dimension of the main window) increases the visual fatigue and could be a cause of stress. These features have been considered as spatial aspects; whereas the *change of workplace's lighting* has been assumed as part of the temporal aspect, which could affect the visual fatigue of the operator and cannot be eliminated or even mitigated. From the point of view of the relational aspect, the *degree of clutter* has to be considered. It is defined as the effect of masking the visual perception of the stimulus with the presence of other stimuli. The literature [26] shows that the clutter effects can be mitigated by reducing the amount of text in the display.

Task knowledge

Concerning the task knowledge, it has to be pointed that the display should provide information without doing many actions from the user. This is especially important for time-critical task, such as the prevention of collisions. From the spatial point of view, two factors are significant, i.e. the *number of required actions and mouse's movements*. The temporal aspect points the *time of response of the system to the ordered action* as a factor. Finally, the relational aspect refers to the *actions' hierarchy*.

Strategy knowledge

The knowledge of the strategy has been interpreted as the organization of actions and tasks in order to achieve the goal for which the system has been designed. In this case, the scope is the prevention of collisions, therefore the strategy concerns the setting issues, i.e. the *definition of the area to be monitored and of the threshold for the alarm* (spatial aspect). The complexity associated with the organization of actions and the setting has been analysed also from the temporal and relational point views and mainly refers to the *difficulty and the time required executing these operations* and the *management of unexpected situations*.

Collaboration knowledge

The collaboration knowledge is interpreted as the knowledge of actions and tasks, which involve more operators. The use of the developed system permits the crane-operator to lift the load without the need of the guidance provided by another operator. Given this feature for the system, the crane-operator is able to work alone, therefore, this type of knowledge has not been considered within the identification of complexity factors.

Cognitive resources

The cognitive resources refer to the mental representation of the process, these resources are needed to deal with complex tasks. Even if they are not a form of knowledge, in any case provide support in explaining the knowledge view. The representation of mental process is supported by the memory and the previous experience; it is well-known that the cognitive processing is categorized in pierces of information (so-called *functional units*) and each one represents an independent dimension that the operator comprehends [22]. Based on these elements, the following complexity factors can be defined: *number of functional units* (spatial aspect), *dynamics of the change in the category of information* (temporal aspect) and the *number of variables to be considered to achieve the goal* (relational aspect).

Table 1. List of identified complexity factors.

Type of knowledge	Spatial aspect	Temporal aspect	Relational aspect
Work domain	▪ No. fixation groups ▪ Monitor's characteristics	▪ Rate of acquisition of the overall view	--
Interface	▪ Variety of groups	▪ Change of workplace's lighting	▪ Degree of clutter
Task	▪ No. of required actions ▪ No. of mouse movement	▪ Rate of response	▪ Hierarchy of actions
Strategy	▪ Setting of the area to be monitored ▪ Setting of the threshold for the alarm	▪ Time for the area setting	▪ Complexity of the setting operation ▪ Management of unexpected situation
Collaboration	--	--	--
Cognitive resources	▪ No. of category of information	▪ Dynamics of change in the category of information	▪ No. of variables to be considered to achieve the goal

3.3. Organization of complexity factors

To organize the complexity factors, the context view has been constructed. When discussing about this type of view, Ham et al. [6] refer to the examination of the complexity in relation to the contextual information. The context is usual determined by tasks or work domain. Given that in this case the work domain is limited to the interface system-operator, the human visual information processing has been considered as most relevant criterion for the organization of complexity factors for each task previously discussed and numbered as below:

- *task 1* - Setting both the areas to be monitored and excluded
- *task* 2 - Starting the application
- *task* 3 - Observing the main window
- *task* 4 - Stopping the application
- *task 5* - Resetting the application

In the following, the classification of the complexity factors is given for each step of the mechanism of information processing of the human brain and on the basis of the *classification metrics*.

<u>*Perception*</u>

The perception step concerns to the acquisition of information about the current status and the process of filtering out unwanted data.

1. <u>Numeric size:</u> In the context of the perception aspect, the metric refers to the number of fixation groups, which is the set of visual stimuli that can be grabbed with one eye fixation. The time of a fixation is about 600-700 ms [27] and average time to search for an element on the display increases with the number of fixation groups. The parameter aims assessing the ability to capture the main parts of the interface. Moreover, the effect of the display size on fixation capacity has been considered.

Number of visual elements of the interface
Display size (monitor's characteristics)

2. Variety: The parameters that have been considered in this frame refer to the difference in visual features. The list of parameters is given below.

Text size
Main window size
Brightness and contrast
Workplace's lightning
Colours of groups

3. Relations: The assessment of relations, from the point of view of the perception aspect, concerns the definition of the degree of clutter. The clutter is intended as the effect of masking the visual perception of a stimulus with the presence of other stimuli. This effect can increase the searching time and reduce the text readability [26]. The parameters that have been considered to assess the clutter effects are listed below.

Masking effects
Visual clarity
Comfort
Degree of confusion
Degree of clutter
Signal/noise ratio
Physical and psychological strain during the use of the system

4. Temporal variability: It has been assessed the rate of identification of the main parts of the interface (overall view). The effect of the workplace's lightning, uniformity and heterogeneity variability over the time has also been considered within this metric.

Rate of acquisition of the overall view
Change of workplace's lightning
Uniformity and heterogeneity of the working space

Cognition

In the cognition step, the perceived information is integrated with that derived from the observer's memory and experience (construction of mental process).

1. Numeric size: For the cognition aspect, the parameters included in this metric assess the number of basic and independent elements in a given mental representation. The aim is the comprehension of the acquired information and the support that is provided to the crane-operator by the developed solution.

Load navigation by the use of the GUI
Acquisition of the reality by the real-time video
Terminology used by the interface
Amount of information to be memorized during the work (short-term memory)
Amount of information from the existing knowledge to be used during the work (long-term memory)

2. Variety: The parameters, to be taken into account for the assessment of this metric, from the cognitive point of view, regard the different stimulation of the mental processing mechanism with respect to the different reception mode of the alarm. The alarm is provided through the main window and the red blinking of the GUI.

Response to the alarm through the main window
Response to the alarm through the red blinking of the GUI

3. Relations: It has been assessed the logic of the organisation of the elements supporting the tasks and the degree of difficulty in achieving the goal (prevention of collision and crashes of the application) by using the developed system.

Organisation of elements
Level of comprehension on how to prevent the collision
Level of comprehension on how to recovery from crashes of the application
Learning process to operate the system

5. Temporal variability: The parameter assesses the time for the information updating on the display with the respect to achievement of the goal (i.e. the prevention of collisions).

Time for the information update with respect to the prevention of the collision
Disturb when receiving the alarm due to the update of information on the main window

Action

The action is the result of combination of the elaborated mental process and personal strategies to formulate a decision.

1. Numeric size: The parameters refer to the number of actions to be done per each step of the execution of the application and configuration of the system before its use. This metric aims defining the complexity of tasks in term of number of actions.

Number of mouse movement per action (task)
Number of steps per operation
Number of preliminary steps before the execution of the operation (task)

2. Variety: The metric aims comparing the variety of actions included in each task.

Variety of actions amongst tasks

3. Relations: Within the action aspect, this metric aims assessing the hierarchy of actions to be executed to use the developed solution, the complexity in terms of steps in setting the alarm, the criterion adopted for the selection of the area to be monitored and the task uncertainty.

Hierarchy of actions
Criterion adopted for the setting of the area to be monitored
Complexity of the selection of the area to be monitored
Task uncertainty

4. Temporal variability: the parameters aim assessing the time required for the updating of the information.

Time for the area setting
Rate of response of the application

3.4. Use of complexity factors: Questionnaire development

The identified complexity factors have been used to construct a questionnaire for the assessment of the interaction human-interface relate to the developed real-time object detection solution. The questionnaire will be used to assess human factors and its validation will be done in *WP3.2*.

The questions have been formulated per category and sub-category (metric), as mentioned above; these are presented in Table 2 and have been divided in the following 14 groups:

1. Overall reaction to the interface
2. Screen
3. Variety of elements
4. Clarity of the information perception
5. Dynamics of the perception
6. Understanding of the information provided by the interface
7. Understanding the alarm
8. Comprehension of the interface's elements and goal
9. Dynamics of the comprehension of the alarm
10. Complexity of tasks in terms of number of actions
11. Complexity of tasks in terms of variety of actions
12. Hierarchy and relations amongst actions
13. Dynamics of actions
14. System capabilities

Table 2. List of questions for the assessment of human complexity factors.

Category	Sub-category (metric)	Complexity factor	Group of questions
1. Overall reactions to the interface			
Perception	Numeric size	Display size (monitor's characteristics)	1a – Is the display large enough to allow a comfortable viewing?
2. Screen			
Perception	Numeric size	Number of visual elements of the interface	2a – Can you capture at a glance the most important parts shown on the screen? 2b – Can you clearly distinguish the elements shown on the screen?
3. Variety of elements			
Perception	Variety	Text size	3a – Are the elements of the interface readable with respect to the text size?
Perception	Variety	Main window size	3b – Are the elements of the interface readable with respect to the main window size?
Perception	Variety	Brightness and contrast	3c – Are the elements of the interface readable with respect to the brightness and contrast?
Perception	Variety	Colours of groups	3d –Are the elements of the interface readable with respect to their colours?
Perception	Variety	Workplace's lightening	3e – Are the elements of the interface readable with respect to the workplace lightening?

4. Clarity of the information perception			
Perception	Relations	Masking effects	4a – In the case of complex environments, is the view of the working-area through the main window clear?
Perception	Relations	Visual clarity	4b – Do the elements, provided on the display, appear distinct (that means there is no perception of masking effects)?
Perception	Relations	Comfort	4c – Are all the windows of the interface always in the foreground?
Perception	Relations	Degree of confusion	4d – Is each window clearly displayed on the screen?
Perception	Relations	Degree of clutter	4e – Does the overall information, provided by means of the screen, appear comfortable? 4f – Does the overall information, provided by means of the screen, appear confused? 4g – Does the overall information, provided by means of the screen, appear cluttered?
Perception	Relations	Signal/noise ratio	4h – How would you rate the signal/noise ratio during the execution of the application?
Perception	Relations	Physical and psychological stress during the use of the system	4i – In your opinion, how much physical stress does the use of the system cause? 4l – In your opinion, how much psychological stress does the use of the system cause?
5. Dynamics of the perception			
Perception	Temporal variability	Rate of acquisition of the overall view	5a – In your opinion, is the identification (perception) of the most important parts of the interface rapid?
Perception	Temporal variability	Change of workplace's lightning	5b – How much does the change of illumination of the working area affect (over the time) the perception of the information through the interface?
Perception	Temporal variability	Uniformity and heterogeneity of the working space	5c – Depending on if the working area is uniform or heterogeneous, how much does the area's complexity affect the perception of the information through the interface?

6. Understanding of the information provided by the interface			
Cognition	Numeric size	Load navigation by the use of the GUI	6a – Are the interface tools sufficient for the execution of the operation (load navigation)?
Cognition	Numeric size	Acquisition of the reality by the real-time video	6b – Does the information acquired at the screen allow the understanding of reality?
Cognition	Numeric size	Terminology used by the interface	6c – Is the interface's terminology appropriate (that is it does not create misunderstandings)?
Cognition	Numeric size	Amount of information to be memorized during the work (short-term memory)	6d – In your opinion, how much is the amount of information that must be memorized to perform the work?
Cognition	Numeric size	Amount of information from the existing knowledge to be used during the work (long-term memory)	6e – In your opinion, how much is the amount of from the existing knowledge to be used during the work?
7. Understanding of the alarm			
Cognition	Variety	Response to the alarm through the main window	7a – How much would you rate the effectiveness of alarm through the main window?
Cognition	Variety	Response to the alarm through the red blinking of the GUI	7b – How much would you rate the effectiveness of alarm through the red blinking of the GUI?

8. Comprehension of the interface's elements and goal			
Cognition	Relations	Organisation of elements	8a – Are the interface's elements well-grouped?
Cognition	Relations	Level of comprehension of how to prevent the collision	8b - If a potential collision is occurring, are there enough elements that permit its prevention? 8c – In your opinion, what is the level of difficulty associated with the management of potential collisions?
Cognition	Relations	Level of comprehension of how to recovery from crashes of the application	8d – If a problem occurs during the running of the application (e.g. crashes), are there enough elements that permit its recover? 8e – In your opinion, what is the level of difficulty associated with the reset of the system?
Cognition	Relations	Learning process to operate the system	8e – How easy was to learn operating the system?
9. Dynamics of the comprehension of the alarm			
Cognition	Temporal variability	Time for the information update with respect to the prevention of the collision	9a – Is the information returned on the screen updated in an appropriate manner that is in real time or at least in a time acceptable for the prevention of undesirable events?
Cognition	Temporal variability	Disturb when receiving the alarm due to the update of information on the main window	9b – How much disturb is given by the information updating over the time in the main window (that is disturb when receiving the alarm by the red blinking of the GUI)?

10. Complexity of tasks in terms of number of actions			
Action	Numeric size	Number of mouse movement per action (task)	10a – How many mouse's movements do you need to configure the application before to press the button "Start application"? 10b – How many mouse's movements do you need to start the application? 10c – How many mouse's movements do you need to stop the application? 10d – How many mouse's movements do you need to reset the application?
Action	Numeric size	Number of preliminary steps before the execution of the operation (task)	10e. Are there preliminary actions to execute before using the application?
Action	Numeric size	Number of steps per operation	10f – How many actions do you need to start the application? 10g – How many actions do you need to stop the application? 10h – How many actions do you need to reset the application? 10i – In case of warning from the interface, how many operations must be undertaken to safely restore the situation?
11. Complexity of tasks in terms of variety of actions			
Action	Variety	Variety of actions amongst tasks	11a – Is there a clear distinction between the actions to execute when configuring, starting, stopping and resetting the application?

12. Hierarchy and relations amongst actions			
Action	Relations	Hierarchy of actions	12a – In your opinion, are the steps to perform an operation hierarchically organized?
Action	Relations	Criterion adopted for the setting of the area to be monitored	12b – Based on the experience gained with the use of the application, which extension for the area to be monitored would you select? (that means do you feel safe in using the application?)
Action	Relations	Complexity of the selection of the area to be monitored	12c – Is the operation (task) for the selection of the area to be monitored complex?
Action	Relations	Task uncertainty	12d – Which are the elements, operations, etc. that make, in your opinion, uncertain the interaction with the interface?
13. Dynamics of actions			
Action	Temporal variability	Time for the area setting	13a – Is the task for setting the area time-demanding?
Action	Temporal variability	Rate of response of the application	13b – In your opinion, does the system quickly respond to the commands (with mouse)?
14. System capabilities			
Impressions on system capabilities			14a – Which score would you give to the whole system? 14 b – In your opinion, can the system provide benefit to the crane-operator when he/she is lifting loads? 14c – Which suggestion would you give to the developer based on your experience?

4. Major encountered problems and corrective actions

The main problems, encountered when creating the questionnaire for the evaluation of the interface (questionnaire part 2), were related to the lack of a valid and well-articulated approach for the identification of factors of complexity. The method of Ham et al., as stated by the authors themselves, does not guarantee the complete and exhaustive identification of all complexity factors. For this reason, during the progress of the activities, reference has been made also to the experience of the developer and the user of the system (intended as hardware and software). This experience has provided significant contributions to the identification of human factors both in the phase of the prototype design and assembling, as well as during it its application that and the subsequent testing.

Moreover, to provide a more detailed analysis of these factors, the integration of other approaches based on classification metrics has been proposed in the study.

5. Deviations from the work plan

No deviations from the working plan have been done.

6. Produced publications

Concerning the activity *WP2.2* "Development human factors indicators", a journal is going to be submitted before the end of the project.

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