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Canvas as a Design Tool for Autonomous Operations

With application to net inspection of a sea based fish farm using an underwater vehicle

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***Abstract*— Several design methods and principles have been proposed in the literature in order to guide the design of autonomous operations. Putting the required efforts into learning and using the methods is a daunting task, and experiences have shown that the use of methods meant to the help the design process are often ignored. The reason could be that the design guidelines are too complex and contain information that is not relevant for the project at hand, and that there is no easy way to distinguish what is important from what is not. In this article, we propose a *canvas* as a tool to support the use of Autonomous Job Analysis (AJA). The authors have previously developed AJA as a structured method for designing an autonomous operation by breaking it down in to sub-operations in order to reveal challenges, needs and limitations regarding autonomous behavior. The canvas contains the categories of the AJA method on a single page *-the canvas-* and each category is supported with questions to be asked during the design procedure, as well as example answers. We will describe the AJA canvas in detail, and show how it can be applied to design an autonomous operation for inspection of the net of a sea based fish farm using an underwater vehicle.**

Keywords*— *Design for autonomy; Maritime operations; Underwater vehicles; Aquaculture

I. INTRODUCTION

Autonomy is getting more and more attention since it is believed to be one of the game players that will affect the development of technology in the future to come. Although the word autonomy has seen several definitions throughout, we will be referring to the one presented in [1], *the ability of an engineering system to make decisions about its own actions while performing a task, without the direct involvement of an exogenous system or operator*. We emphasize that autonomy is not all or none, but can vary across a continuum of intermediate levels, between fully manual and fully autonomous at the two extremes. Particularly well known examples of projects with a high Level of Autonomy (LOA) include the Mars space missions [3] and the development of self-driving cars [4]. The possibilities gained through increased LOA can possibly revolutionize the maritime industry. Futuristic visions include trans-oceanic unmanned cargo ships [5]; inspection, maintenance and repair (IMR) of subsea oil- and gas infrastructure carried out by permanently residing autonomous underwater vehicles[6][7]; unmanned airplanes surveilling the oceans for ice-bergs threatening oil- and gas installations [8]; IMR of aquaculture fish farms at exposed locations using autonomous underwater vehicles [9].

By itself, the design of such types of autonomous operations and systems is a complex task. Our experiences has shown that there is a need for coherent, structured and scientifically rooted methods and tools when it comes to design of autonomous technologies and operations for industrial use. This was the background for the SEATONOMY methodology presented in [2]. The methodology provides a structured approach for design, development and validation of industrial autonomous maritime operations and systems. A key component in SEATONOMY is a tool called Autonomous Job Analysis (AJA), which is a method for breaking down an autonomous operation into sub-operations or sub-goals to reveal the needs and limitations that are linked with the autonomous behavior [10].

In this paper we present a collaboration tool in form of a canvas to facilitate the use of AJA within a group of people and for individuals. The canvas contains the categories of the AJA method on a single page - *the canvas* - and each category is supported with questions to ask during the design as well as example answers, see Figure 1. The full canvas is presented in Figure 2. The purpose of the AJA canvas is to gather all needed information that is needed for the design of an autonomous operation into a single page. This single page gives the subcategories and the essential questions that are needed so that the AJA is fulfilled with success.

This paper is organized as follows: In Section II we support our claim of usefulness of a canvas for designing autonomous operations and systems. In Section III we will describe the AJA method briefly. The AJA canvas will be described in detail in Section IV and in the following Section V, an example is presented on how the AJA canvas can be used to design a net inspection operation at sea-based fish farms using an underwater vehicle that is enhanced with autonomous functionalities. The conclusions are presented in Section VI.

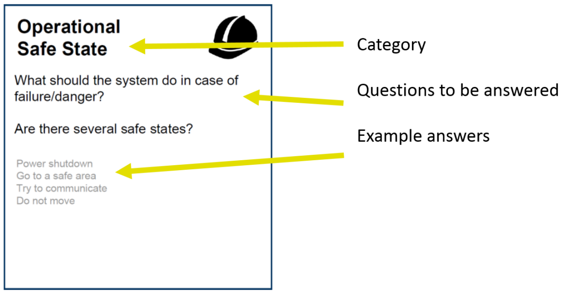
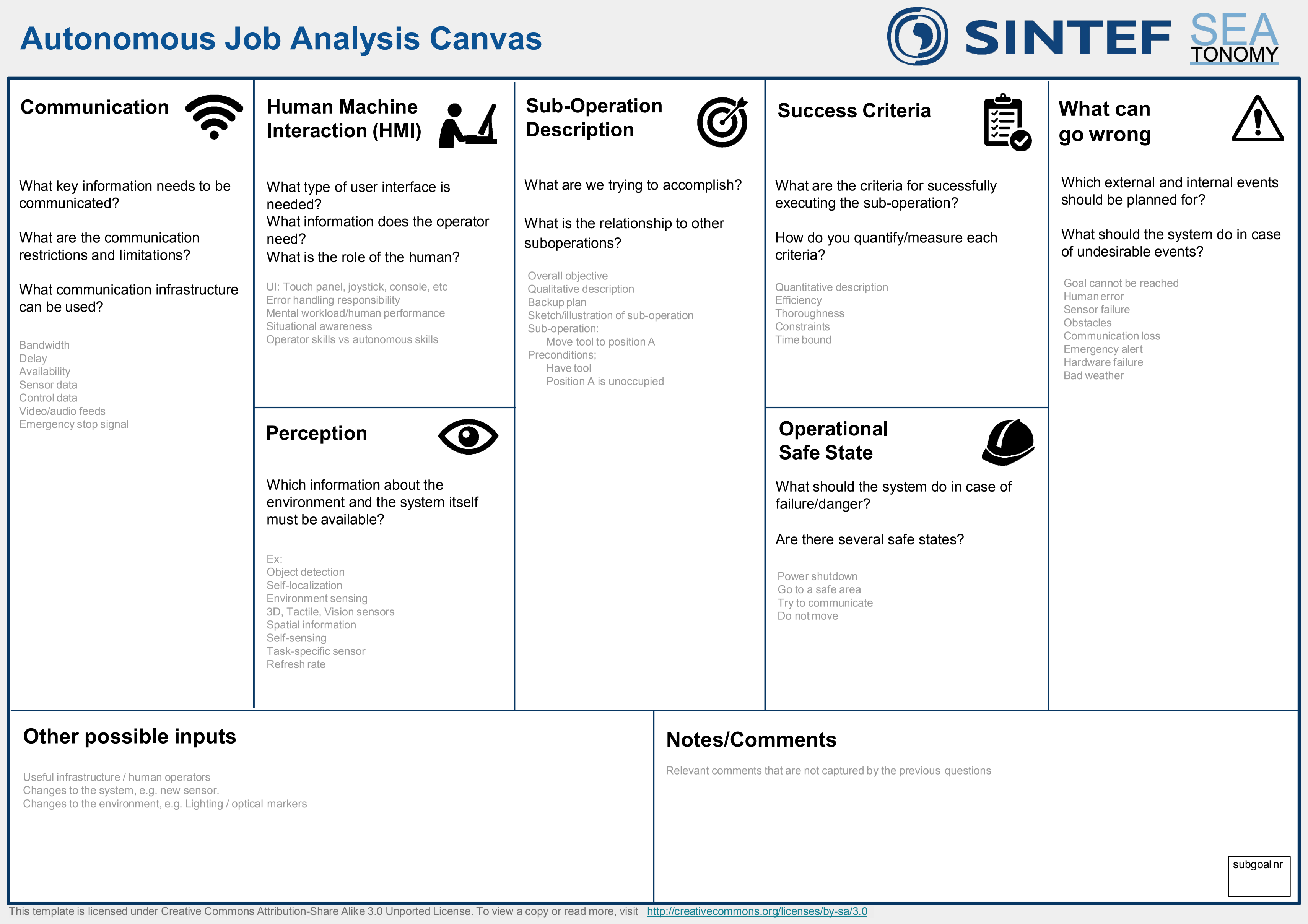


Figure 1: Canvas example: Category, questions to be answered and example answers.



Autonomous Job Analysis Canvas

SINTEF SEATONOMY

Communication

What key information needs to be communicated?

What are the communication restrictions and limitations?

What communication infrastructure can be used?

Bandwidth
Delay
Availability
Sensor data
Control data
Video/audio feeds
Emergency stop signal

Human Machine Interaction (HMI)

What type of user interface is needed?
What information does the operator need?
What is the role of the human?

UI: Touch panel, joystick, console, etc
Error handling responsibility
Mental workload/human performance
Situational awareness
Operator skills vs autonomous skills

Perception

Which information about the environment and the system itself must be available?

Ex:
Object detection
Self-localization
Environment sensing
3D, Tactile, Vision sensors
Spatial information
Self-sensing
Task-specific sensor
Refresh rate

Sub-Operation Description

What are we trying to accomplish?

What is the relationship to other suboperations?

Overall objective
Qualitative description
Backup plan
Sketch/illustration of sub-operation
Sub-operation:
    Move tool to position A
Preconditions;
    Have tool
    Position A is unoccupied

Success Criteria

What are the criteria for sucessfully executing the sub-operation?

How do you quantify/measure each criteria?

Quantitative description
Efficiency
Thoroughness
Constraints
Time bound

Operational Safe State

What should the system do in case of failure/danger?

Are there several safe states?

Power shutdown
Go to a safe area
Try to communicate
Do not move

What can go wrong

Which external and internal events should be planned for?

What should the system do in case of undesirable events?

Goal cannot be reached
Human error
Sensor failure
Obstacles
Communication loss
Emergency alert
Hardware failure
Bad weather

Other possible inputs

Useful infrastructure / human operators
Changes to the system, e.g. new sensor.
Changes to the environment, e.g. Lighting / optical markers

Notes/Comments

Relevant comments that are not captured by the previous questions

subgoal nr

Figure 2: The AJA Canvas.

II. MOTIVATION FOR THE AJA CANVAS

During the process of developing the SEATONOMY methodology we found that putting the efforts into learning and using the full methodology and the suggested methods is a daunting task. Experiences has shown that the use of methods meant to the help the design process are often ignored. The reason could be that the design guidelines are too complex and contain information that is not relevant for the project at hand, and there is no easy way to distinguish what is important from what is not so important. Design guidelines may be described over several hundreds of pages, be too complex and might require too much resources compared to what can be expected in smaller projects. Also for larger projects there might be insufficient resources set aside for a structured design process. Time and money could be spent elsewhere, for instance on a specific technological development, independent of whether this is a good or bad solution to the operation at hand. It could also be that short term projects, or immediate deadlines draw the focus from a thorough design development, to work on functional behavior [12].
key. We believe that the canvas can be a tool both to ease the application of AJA, but also to increase the likelihood of AJA actually being used as a part of the design process of an autonomous operation.

III. AJA METHOD

We describe the AJA method briefly here, where as a thorough description of the AJA can be found in [10]. An important preliminary step of the method is for the involved (e.g. client and operation designer) to have some common understanding of the main goal(s) of the operation and agree on a context definition. Once they have agreed on a description of the concepts and concept alternatives, the main steps of the method are:

1. Describe the main goal of the operation.
2. Re-describe into sub-goals or sub-operations, based on e.g. sequence, parallel behavior, etc.
3. Answer a list of questions related to each AJA category in succession. The categories and the corresponding questions can be found in [10], but also on the canvas in Figure 2.
4. For each sub-goal, go to step 2 and repeat until sub-goals or sub-operations become trivial tasks.

This type of hierarchical decomposition of the operation is inspired by the Hierarchical Task Analysis (HTA), see for instance [11]. A successful design typically requires that experts within several fields are being consulted in the application of the method. We also highly recommend the operation design to be an iterative process.

IV. AJA CANVAS

The canvas contains the categories of the AJA method on a single page - *the canvas* - and each category is supported with questions to ask during the design as well as example answers, see Figure 1. The AJA Canvas is shown in Figure 2. The canvas should be printed out, one copy for each sub-operation to be treated, and used in meetings between customers, operation designers and field experts (e.g. experts in the area of risk management, robotics, autonomy, instrumentation etc.). This way they can jointly start sketching and discussing the autonomous operation.

V. CANVAS FOR DESIGN OF INSPECTION OPERATION

To illustrate the application of the AJA canvas, we are designing an autonomous net inspection operation at exposed sea-based fish farms. An example of a fish farm can be seen in Figure 3.

Figure 3: Fish farm with feeding barge (right), and fish cages (left).

In modern aquaculture using gravity net cages, holes in the net and other type of net failures constitute a challenge with respect to fish escapes. Based on the Norwegian reports of escape incidents for salmon farming, more than two thirds of the registered escape incidents are related to holes in the net, [13]. One important measure established to reduce escapees is a mandatory net inspection after all operations involving manipulations of the net and weighting system. Examples of net damages can be seen in Figure 4.

A. Context description

Through a preliminary discussion, it was clear that the use conventional tethered ROVs is the most relevant alternative, as these are already in use in the farming industry today. They are remotely operated, but to reduce ROV-pilot fatigue, increase precision and inspection quality, more autonomous functionalities needs to be developed, [9]. The final design of the ROV system should be postponed until after the AJA is completed. For instance, the designed operation may show that some other physical variables needs to be measured which requires other sensors than the ones available on ROVs of today.

Figure 4: Examples of holes in net.

The cage as a system consists of a floating collar with weighting/spreading gear, the net and the mooring. There are different varieties of all these components in use and they occur in different combinations. We consider the most common used construction in Norwegian salmon aquaculture, which consists of a circular floating collar, an upper part of the net structure that is cylindrical and a lower part that is conical.

The main operation is to inspect a specific area of the net area. This operation may be divided into the following sub-operations:

1. Find the predefined start-position.
2. Perform calibration.
3. Inspect specified area.
    a. Find start-point
    b. Follow intersection line vertically.
    c. Find end-point.
4. Get position fix.
5. Find predefined end-position.

B. *Application of the AJA canvas*

A description of the complete operation is beyond the scope of this paper. The purpose is rather to illustrate a first iteration of the AJA method by applying the canvas. We will in the following focus on the sub-operation "Follow intersection line". Notice that under some categories several alternatives might be suggested. Typically, final decisions on the design of the operation would be postponed to a later stage in the process, based on additional knowledge from the application of other methods, see [2]. It also depends on the chosen LOA for each sub-operation, which in turn often boils down to a question of cost versus benefit.

In the following, each canvas category is discussed based on the questions given in Figure 2. The discussion is very much based on what is considered realistic alternatives for development of an autonomous net inspection operation in Norway. Legislation, cost of human labour, environmental conditions, etc. means that other solutions could be more beneficial in other countries.

Sub-Operation Description:

•The goal is to follow the intersection lines in order to have a systematic coverage of the full net cage area.

• A conservative approach is to follow the same intersection line both up and down. This approach leads to a high degree of redundancy in terms of area coverage. Obviously, this come at the cost of a longer total time spent for the inspection.

Relation to other operations: After sub-operation "Calibration", but before sub-operation "Stop following intersection line".

Success Criteria:

• Must be able to move follow intersection line vertically. Have sufficient image quality, either to be judged by operator or machine vision algorithm. Must be able to reference images in relation to a known point on the cage. Detect that correct end-point is reached.

Operational Safe State:

• If the ROV is tangled in the ropes inside the cage: Go to "station keeping". Turn to "manual mode" to untangle.

• If the ROV is tangled in the net. Turn off thrusters. Divers must probably investigate the situation to decide how to proceed.

• Failed to follow intersection line. Return to surface and find start-point.

What can go wrong?

• Bad image quality. This can for instance be due to a school of fish in front of the camera. A possible remedy is to wait until the fish has moved, or to go closer to the net and pass the school. If the ROV is moved closer to the net a re-planning of the route might be necessary, as the camera field-of-view capture a smaller portion of the net.

•The net is not stretched out properly. This may be due to specific currents or poor quality of the net itself. This in turn might make it harder to detect if net is damaged.

• Sensor faults. An example can be that the ROV is unable to measure the distance to the net, or give wrong sensor readings, which endangers the cage or the ROV.

•The operator has defined the starting point wrong or inaccurately.

•Equipment or ropes inside the fish cage are not accurately known in advance.

•Communication errors which causes the operator to lose overview of the situation and therefore also the ability to make good decisions.

Communication:

• The operator must receive information about the position and quality of the navigation estimates.

• The operator must receive camera images.

• The operator must receive status of technical condition of the ROV.

• The operator must send the ROV which part of the fish cage which should be inspected. The operator should be able to take control of the ROV when he/she wants to.

• There is basically no constraints in the communication capacity as the ROV is assumed to be tethered.

Human Machine Interaction:

• The evaluation of the image quality could be done either by computer vision, or by operator.

• If the images or the position referencing of images is not according to the specifications, the operator should be informed in order to take the appropriate action. The operator could be provided with suggested actions.

• The operator should be presented with a 3D map with planned and actual trajectory of the ROV, and what part of the net that has been inspected. Uncertainty in the localization system, and the image referencing system could for instance be presented with colour codes.

Perception:

- Camera system for detecting holes in the net.
- The shape of the cage. The cage itself is a flexible structure, and its shape will depend on sea currents. Under steady conditions, the shape will not change much over the course of the operation.
- Knowledge about ropes and other equipment inside the fish cage.
- Localization of the ROV relative to the net.

C. The autonomous system

A complete description of the autonomous system performing the inspection operation is outside the scope of the paper. We will however briefly discuss how some of the AJA findings can be related to how the ROV should be equipped, and what the operator interface should be like. As mentioned in [2] AJA provide valuable information for designing the autonomous system realizing the operation.

For instance, the ROV must be equipped with an electro-optical HD camera. The operator can use video feed to judge whether there are holes in the net. Alternatively, computer vision algorithms can automatically detect holes. Computer vision can also be used for net relative localization. A Doppler Velocity Log may be able to measure net relative distances, as well as net-relative angles and velocities, see [14]. Depth is typically measured using a pressure sensor. An ROV is typically also equipped with a magnetic compass and gyro, to provide yaw angles, and angle rates. Absolute or relative position can be provided by hydro acoustic positioning system. Absolute position can also be measured using a global navigation satellite system when surfacing.

The operator interface may in many cases be defined by what equipment that is already available. The AJA revealed however, that the interface should consist of a joystick for remote control of the ROV and one or more screens displaying ROV status information and video stream to the operator. The operator should also have a keyboard to be able to send commands to the ROV in real time.

VI. CONCLUSIONS

We have in this paper presented the Autonomous Job Analysis (AJA) *canvas*. AJA is a method for designing and evaluating autonomous operations, and the canvas is a one-pager with the most relevant information of AJA. It contains several categories, and corresponding questions to be asked for each of the sub-operations. The canvas also provides example answers. We believe that the canvas can be a tool both to ease the application of AJA, but also to increase the likelihood of the method actually being used as a part of the design process of an autonomous operation. It is inspired by the business model canvas which is used in to develop new or document existing business models (infrastructure, resources, customers, finances, etc).

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