An Adaptable Process Planning Tool

A Tool for Information, Comunication, and Interaction in a Robot Cell

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Abstract—**This study presents work in progress on how to develop a process-planning tool to handle interaction between human operators and robots within a robot cell. First, we introduce how to include human activities in the process flow; then, we turn to our ideas for communication and feedback systems inside a robot cell. A small example of how to design interactive and re-programmable screens is presented.**

Keywords-Process planning tool; robot cells; automation; interaction; human operators and interface design.

I. INTRODUCTION

When producing automotive vehicles, a large part of the manufacturing process is automated. The vehicle parts go through different stations or cells to be adjusted and assembled and robots and humans have different, usually isolated, assignments. A typical robot cell might consist of a couple of robots up to as many as 20 robots. The entire cell is controlled and coordinated by a PLC (Programmable Logic Controller) or an industrial computer. A robot might be assigned a specific manufacturing process or to transport the product through the cell.

A problem with this type of automated production is the time it takes to make changes. An update in the vehicle model or the introduction of a new vehicle in the manufacturing line could take up to a year or more from planning to implementation [9]. The goal with our work is therefore a quicker process with fewer steps involved and production cells with robots easy to reconfigure and adapt so the time for changeover can be reduced. As a first step to try to achieve this goal, a process planning tool, P-SOP (Product oriented Sequence of Operation), was introduced in our earlier work [5] where the operators could create a new flow of activities for a robot cell through dragging and dropping icons in the tool. The tool then generated code from the graphical flow chart, which could be uploaded to the robots and PLCs. The next step to achieve more flexible production was to include the operator in the process; create possibilities for humans and robots to interact. The human operators should be able to go in to the cell and help the robot or interact with the robot to make the assembly more efficient. This required new functionality in our tool and a new way of thinking in the robot cell, involving safety, interaction, and efficiency issues.

This study will focus on how to reconfigure the software tool to be adaptable for human-machine interaction during the production. We will present our work in progress for how to 1) communicate to the robot that a part of an assignment is performed by a human operator, 2) give the human operator feedback on what to do and where and when to step in, 3) visualize the work flow, and 4) in real-time analyze the consequences of a human operator stepping in and performing a task. In this paper we will discuss how to change the software tool and how to create an adapting solution. The work is planned to be performed in two steps; firstly, create an adaptable tool, where the human interaction can be predetermined, and secondly, a fully adapting system where the human, on the fly, can go into the production line and assist the robot.

Next, we will introduce a brief background followed by our suggested solution and a small discussion of our work in progress.

II. BACKGROUND

This project started a few years back when the industry of Europe required quicker changeover times for changing automated production cells. Through a better and quicker process for how to give the robots instructions and reconfigure a cell a first step towards reduced changeover times could be achieved. A team was put together and worked within the FLEXA project [5, 7] to develop a tool and work with process development.

In the original process (also the process still used in most companies), a process planer creates a sketch or workflow for the activities a part should go through in a specific production cell. Information about the part, the material and different constraints are added to the sketch and the document is then sent to a subcontractor. They turn the sketch into instructions and code that is uploaded to the robots and PLC. They configure the cell to be "turn-key" ready for production. While this is done the process planer have sent work instructions to the operators of the cell for what to do and how. To speed up this process the idea is to exclude the subcontractor and create a tool where the process planner and operator can make the robots and PLC ready by themselves. Eventually the idea is to also exclude the process planer and only have an operator to perform the whole chain of activities.

A software tool was invented [5], where an operator could create new sequences or flows of instructions by combining graphical icons representing different tasks in the

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cell. The sequence is translated into code and downloaded to the robots and PLC. This made it possible to put together different tasks for the robot to perform with rather short notice; creating a more flexible production.

Parallel to this project a second project called Flex Lean was initiated [6] where safety issues were addressed; due to safety regulations (HSG43 and EN ISO 13849-1) the humans are not allowed to be in the robot cell when active. If a human enters the robot cell during operation, sensors will activate the safety system. This will initiate the safety control system to cut power to the robots. Such a response will slow down production and halt the entire cell. In Flex Lean, these safety regulations have been further investigated and different ways for robots and humans to interact have been introduced within the safety regulations.

These two projects create the foundation for our work in this study. Where we add more functionality to the tool and assume that the safety issues of the cell can be solved through cooperative solutions for robots such as SafeMove from ABB [2, 12].

A. Related work

A more advanced process simulation tool and theories for how to best describe, model and simulate process planning activities are produced within the framework of FLEXA but by another research group [3, 19]. They have studied how to create and simulate the sequences in which tasks should be carried out but also how to include different constraints and organizational parameters when trying to optimize the process flow.

Comparing the more advanced tool to the current one in this study; the current tool tries to focus more on how to quickly re-program a robot cell and the actual interaction and communication language between operators and robots while the other tool focus more on a understanding of the process it self and the work model. Their tool is used as a guide earlier in the process when the actual steps of the process are being determined; they also try to visualize the workflow. In current work we assume that the process steps have been already determined by a tool like theirs or similar. We start with a process plan that has been simulated in earlier steps and then try to look at how to handle rapid changes in that sequence and how to, eventually, include the operator in the process sequence. We will however, in later work, try to merge the ideas from booth tools.

III. WORK IN PROGRESS - INTEGRATING HUMAN TASKS IN PROCESS FLOW

To create a situation where the human operator and the robots or machines can cooperate we need to adapt 1) the configuration tool, 2) the interface of communication, 3) the feedback system, and 4) the physical environment. In the current study we have initiated work on no. 1, 2 and 3 while 4 is considered in a parallel project and related studies. In our work we are very aware of the safety issues but also confident that results from related projects [2, 3, 6, 12, 19, 21] will solve the physical challenges in the robot cell. To a get better understanding of the requirements for how to include the operator in the process, we are closely cooperating with a number of industrial partners [14].

The work of further developing the configuration tool has been divided into two sub-steps. In the first step we create an adaptable tool where the human activity can be pre-configured and planned, analyzed and implemented during setup of the cell. In the second step this should be possible to do in real-time from the cell while in action, resulting in changed activities for the robot during production. We are currently working on the first step of introducing human activities into the workflow.

A. Adapting the configuration tool

In **Figure 1**, an example of a process flow is illustrated, taken from one of our industrial partners. The flow could be described as a regular UML activity diagram [1], but we want to show both the physical robots and their activities, which is why we use this type of flowchart. The product, illustrated by a triangle, comes into the flow from the left and is then moved from station to station until it has passed through the sequence. Each rectangle in this example represents a machine or robot that performs a specific task. In the example in **Figure 1**, no human activities are included.

If we now introduce activities performed by a human operator, it could look like the flow presented in **Figure 2**. The activity is marked as *"human activity"* during process planning and translated into information to the cell. A formal way to describe the details of the human activity and the interaction could be to use BPEL4People [11] or any other standardized modeling language. By clicking the rectangle marked as a "human activity" a new UML chart or flow chart should be visible showing each step of the task performed by the human. A tree view according to GOMS model (Goals, Operators, Methods, and Selection rules) [4] could be added to the chart to further expand the details. The goal would be the purpose of the human activity – what is the human expected to do. The Operators then describe the particular actions the human must perform to reach the goal. The order of the operators creates a sequence or a Method. There might be more than one viable sequence of actions available and if so the selection rules are used to establish when to use which method. In **Figure 2** the human is expected to perform an inspection and the GOMS documentation should then provide information about how to perform the inspection, what type of inspection it is and if there are alternative ways depending on the product.

From a software-tool perspective, this looks just like a small change but in reality this will have major consequences. The outcome of the human activity has to be communicated to the robots so that the next robot in the flow knows how to act. The communication could be through a broadcast signal or a message sent from the PLC system. The messages also have to be visualized to the operators in the screen. This can be done in several ways and is a matter for future testing.

The overall PLC control system will be responsible for coordinating the work and keep track of the parts. By using a unified process description, the system can keep track of the parts in a sequence of activities.

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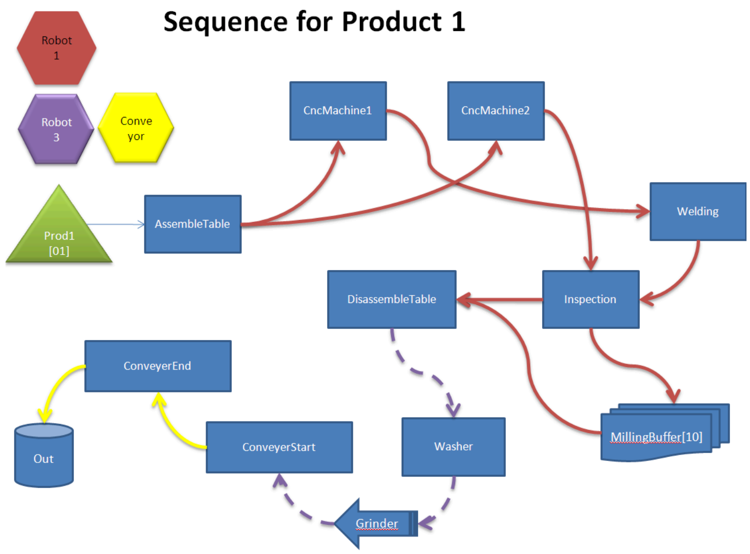

Figure 1. An example of a sequence of activities in a production line, created in our process planning tool.

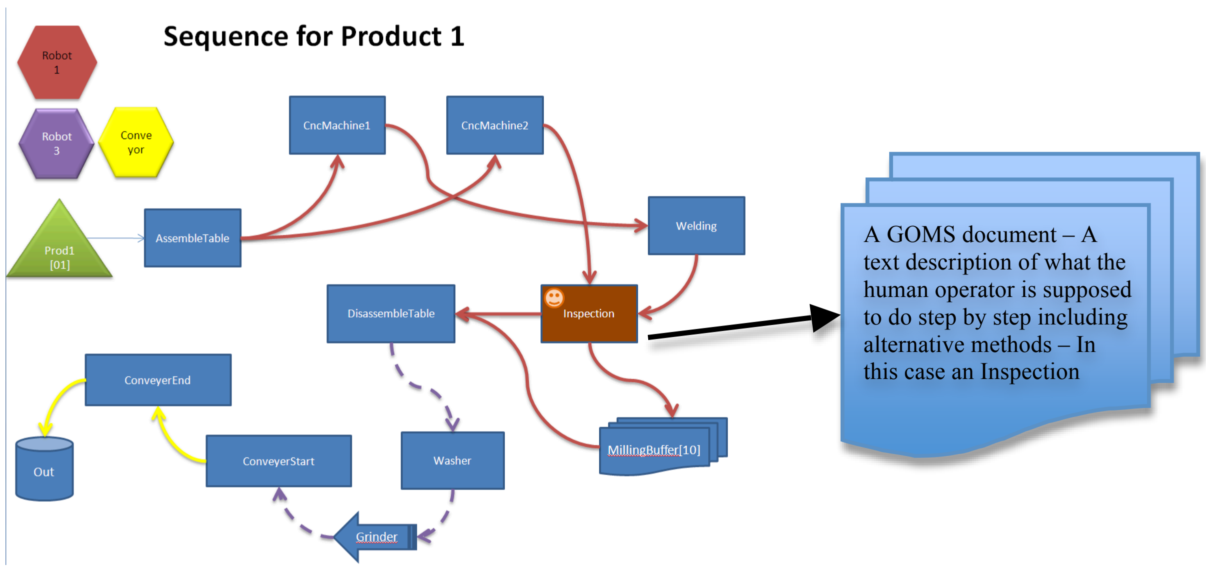

Figure 2. An example of how a human have taken over one activity in the process flow.

B. An interface for comunication between actors

To solve parts of the communication problem we have to turn to the actual robot cell. It is here the interaction is being performed and also here the signals have to be sent from. In **Figure 3** below we see a typical robot cell and a human operator waiting outside for an activity (left side). Next we see how the operator goes into the cell (right side) to perform the tasks. To communicate with the operator it has been concluded that we need a screen of some sort in the cell.

According to our industrial partners the screen should have multiple purposes and communicate different types of information to the operator. The screen should provide the operator with support for the task at hand but also show the overall flow so the operator knows where in the flow they are involved and why.

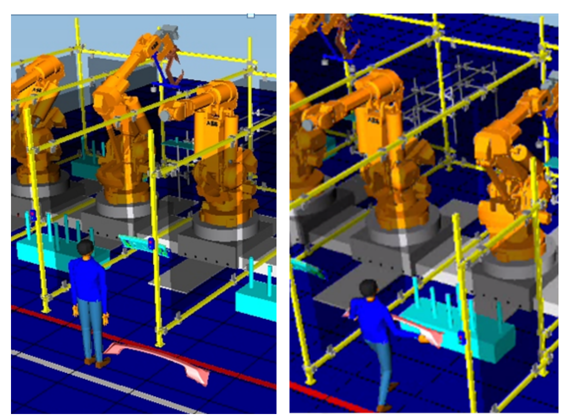

Figure 3. A robot cell where an operator is first waiting for the command to go in (to the left) and then goes into the cell (to the right) to solve a set of tasks.

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It is beneficial to use symbols and icons the operators are used to as well as interaction styles that are adapted to the industrial environment [20]. By using an interface with different levels of information the operator can get access to information of the process from a meta level down to detailed information on materials and assemble instructions. The interface should show the process flow so that the operator can see what is going on in the cell in front of him or her. In **Figure 4**, an example of our current design suggestion is illustrated. When an activity in the flowchart is clicked a set of icons in a menu appear and the operator can select what to do by clicking one of the icons. In **Figure 4** the operator has selected the document mode and a group of documents, attached to the activity selected, have appeared in the lower part of the screen. It should then be possible to open up available documentation for that activity and detailed descriptions on the different steps.

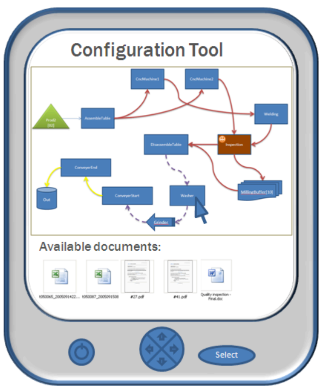

Figure 4. An example of what a screen for cell interaction and process information could look like.

According to our background research, the screen should provide process completion information; time status of the activity. It should also signal to the operator that it is time for human activity within the cell and when to go in (see **Figure 5**). When the operator has entered the cell, the screen should provide information about the tasks at hand, and be able to guide the operator through the tasks by providing text and image descriptions.

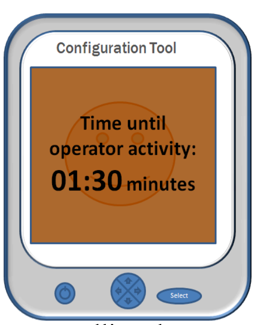

Figure 5. An alert message telling the operator that it is time for him or her to enter the cell in a minute and a half.

In **Figure 5** an example of an alert message is displayed showing that an operator is needed within a minute and a half of time. In this screen we have also concluded that it could be helpful to show instruction for pre-conditions. A pre-condition could be material or a tool needed for the assembly, which the operator must fetch and bring with him or her into the cell before the task can be performed.

C. Creating a feedback system for interacting actors

When the robots have performed a task they signal to the PLC that the part can be picked up and moved to the next station. The screens described in previous section should not only function as information displays they should also adapt and provide possibilities for the actors to interact. The screen should be able to signal different scenarios to the operator but also be used to signal feedback to the robot and to the PLC. When an action has been performed or a problem has been solved the human must be able to signal back to the system. **Figure 6** illustrates an example of our current design for what such a screen could look like. In the figure the action Inspection is selected and its work tasks are shown as a list. The list is clickable to provide details for each task. By clicking a task the operator also gets access to forms for measurements, error reports and feedback notes. The operator can use the checkboxes to signal when a task is completed. When all tasks in an action are performed and checked the "completed" button will light up and get available. The operator can then click it and through that signal to the control system that the action is complete and that the part can be moved to the next cell. Depending on the outcome of the activity the PLC will order different actions for the next step in the flow. If for example the part is discovered to be defect during inspection the part should be discard and the PLC will order the moving robots to do this instead of moving it to the next station in the flow.

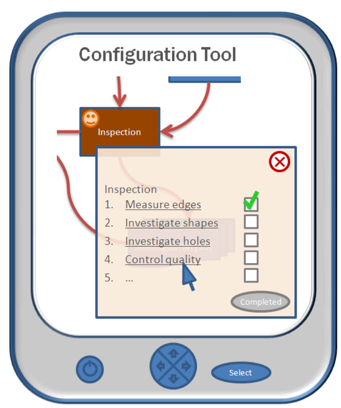

Figure 6. The process flow and instructions for the operator.

IV. DISCUSSION AND CONTINUING WORK

The next step of our work is to gather more information of how to design the interfaces. We will look at icons, click patterns, interactions styles, and colors, as well as contents and information presentation; using established research in the field [20]. The operators will then be involved in usability analyzes [16]. Later on, the human operator should be able to change the process flow during operation by accessing the tool from the cell; changing a *"machine made"*

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activity into *"performed by operator"*. According to industry, it would be beneficial if a sensor grid could identify what the operator is doing and by automation change the activities in the process flow and tell the robot how to interact. It should be possible to signal to the system and the robot by hand signals or camera identification when a part for example has been assembled correctly and then update the status of that task in the tool. Research has been done [8, 10, 13, 17-18] on this type of Human-Robot inter-action and should be possible to incorporate in our solution. We have also concluded that the process planning tool has to be able to in real-time analyze a change of procedure and estimate different consequences and produce a risk assessment for the operator. The idea is that the tool should be able to look at the process flow and estimate the consequences of different scenarios. It should be able to tell the operator if it is beneficial to enter the robot cell at that time or if he or she should wait a bit depending on how that interruption affects the robot at that time. The tool should also be able to signal for help when a robot gets overloaded and falls behind the work flow, so that an operator can go in and if possible assist that robot or reassign another robot in the line to help out.

Similar problems have been tackled in research on holonic manufacturing systems [9, 15, 22, 23]. Here each robot, machine or operator is assigned with autonomous and cooperative properties and their activities are determined through cooperation instead of a centralized system. A large proportion of the work done within holonic systems is focused on the technical sides however and our work on including the operator could perhaps add knowledge to that domain. Current work in related projects on artificial intelligence could also render guidance in this matter.

However, this is highly non-trivial and it will require solutions both from our project and parallel projects within FLEXA [18, 19] and Flex Lean [6, 7] as well as related work within the research community. The work from several projects will eventually be turned into one or two applications that will be used within our partner industries.

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