Rossini

RObot enhanced SenSing, INtelligence and actuation to Improve productivity and job quality in manufacturing

Deliverable

D6.2 Design tool for industrial human-robot collaboration

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Disclaimer

Abstract

The Rossini project aims to reach unforeseen levels of efficiency and quality in industrial robot applications by exploiting the maximum level of collaboration between the robot and the human operator.

The focus of this deliverable and its underlying task (T6.2) is incorporating job quality in the design stage of a process where humans and robots collaborate. This resulted in a software tool that models the work process and makes it possible to compare different scenarios for human-robot collaboration with each other. For example, with the tool it would be possible to compare the use of a collaborative robot in a process with the traditional way of working. The tool focusses on a qualitative comparison of scenarios on multiple aspects of job quality.

The main activities within the task were:

- Development of a generic process model that allows the comparison of different scenarios
- Development of a step-by-step method to analyse multiple scenarios for human robot collaboration
- Selection of job-quality measures and ranking methods
- Development of (visual) comparison tools to compare different scenarios on job quality aspects

A process model was developed that contains the necessary information to calculate the job quality outcome measures. One model can contain multiple scenarios and has a hierarchical structure. This facilitates the re-use of information and usability of the tool.

A step-by-step method was developed that provides the model with required information. Each step has a specific focus, such that people with different expertise can contribute to specific steps within the tool. The tool is set up to be used iteratively, such that after an initial analysis, scenarios can be improved and refined.

Primarily, the tool focuses on the following four aspects of job quality: physical load, cognitive load, psychosocial load, and environmental load. For each primary aspect the tool allows to evaluate several sub aspects (such as pushing and pulling within physical load). Each aspect is scored qualitatively on a 1-5-point scale. The set of job quality aspects to evaluate can be selected based on the use case characteristics.

In the final step the results from the analysis can be visualized. Visualizations include a radar plot that gives an overview of the critical steps in one view and a timeline plot that shows how work is divided between the different actors (human or robot) within a scenario.

The first version of the design tool was successfully finished. This tool has been used to compare example scenarios. Future use of the tool will include modelling the three use cases within the Rossini project. Along the project the tool will be improved and refined.

Scope

Assessment of job quality in early stages of development

List of Acronyms

European Commission	EC
Job quality	JQ

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1 Introduction

This deliverable describes the design tool that has been developed in order to be able to evaluate work processes and more specifically, human-robot task allocation scenarios with respect to job quality. For instance, one could evaluate the use of a collaborative robot in a specific process and compare that with the traditional way of working.

This deliverable is the outcome of Task 6.2. For this deliverable, we have used the outcome of previous tasks and deliverables. These include T2.3/D2.3, which provides information about and requirements for the aimed human-robot collaboration set-ups in each use-case, and T6.1/D6.1 on the state of the art regarding job quality, the relevance of job quality in relation to human-robot collaboration and evaluation methods on job quality. The outcome of Task 6.2 feeds into Task 6.3.

This report provides: The goal of the tool and the target group (Section 2), the underlying model (Section 3), job quality factors (Section 4), design approach for the tool (Section 5), an in-depth description on the working of the tool and the user interface (Section 6), and details on the technical implementation of the tool (Section 7).

2 Goal

The goal of task 6.2 was to develop a tool that evaluate work processes and more specifically different human-robot task allocation scenarios with respect to job quality. Job quality describes 'the goodness of a job' or in other words 'how well the job is experienced by the worker'. In the preceding task 6.1, multiple factors have been identified that contribute to job quality. In this deliverable the following primary aspects of job quality will be considered: physical load, cognitive load, psychosocial load, and environmental load

2.1 Job quality and human-robot collaboration

The adoption of a collaborative robot in a work place implies that tasks and responsibilities of workers change. Therefore, the adoption of a collaborative robot may well affect underlying factors of job quality. This holds for all the main categories of job quality: physical, cognitive, psycho-social, and environmental. The effects on these factors can be positive or negative.

The effect of the adoption of a collaborative robot on job quality are often unclear before implementation on the work floor is completed.

By considering job quality in an early design stage:

- one ends up with better conditions for the worker (more attractive job)
- one prevents to arrive at sub-optimal which are not attractive to workers and hampering productivity
- one saves the costs that would be required to repair sub-optimal working conditions

2.2 Goal of ROSSINI design tool

The design tool helps the user to:

- account for job quality aspects in the early stage of designing human-robot collaboration.
- evaluate specific human-robot task allocation scenarios with respect to job quality.
- compare multiple different task allocation scenarios, including for instance comparing with vs. without collaborative robot conditions.

2.3 Target users group

The tool can be used by manager/engineers of a manufacturing company that are interested in how the adoption of a robot might affect the working conditions. The tool does not require in-depth knowledge on ergonomics or human-factors.

This section describes the process model that was developed to contain the information that is required to calculate the job quality outcome measures. Furthermore, it was set up in such a way that it facilitates the design principles that will be discussed in Section 5.

Figure 1 shows how the process is hierarchically divided into smaller tasks, sub-tasks, and actions. Figure 2 shows how the smallest part (an action) is modeled.

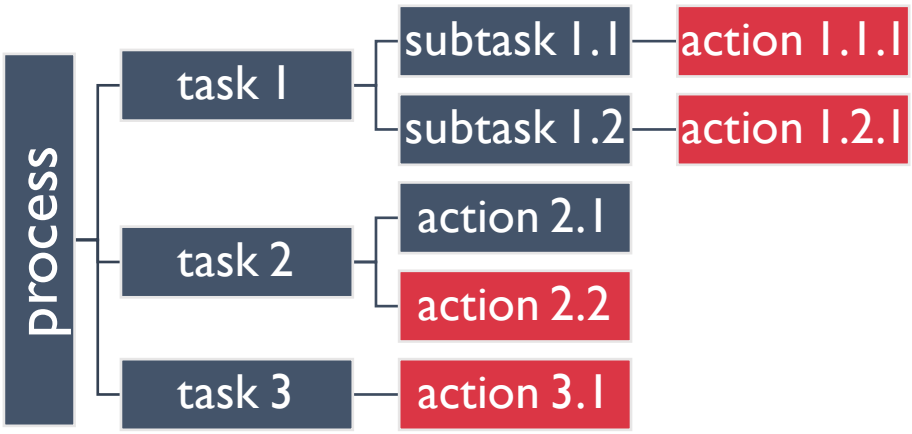


Figure 1: HTA model

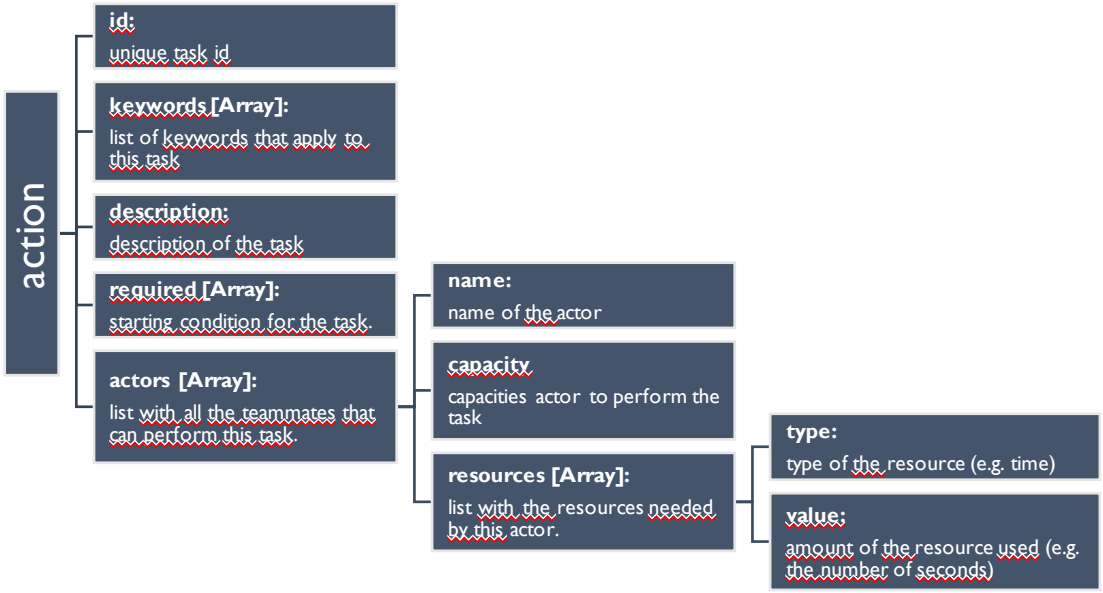


Figure 2: Task definition model

4 Job quality factors

This section discusses the job quality factors that are included be default in the design tool. Deliverable D6.1 lists the main aspects of job quality and relevant evaluation methods.

It must be noted that evaluation methods that require a (physical) realization of the process are not feasible for the software tool. Since the intention is to use this tool in the design phase, it was decided to use a uniform qualitative scoring for each aspect of job quality. Each job quality item in the tool is scored on a 1-5-point scale ranging from very good to very bad. This allows an easy first assessment of job quality and facilitates a side by side comparison of two or more scenarios.

Furthermore, not every aspect might be relevant for each use case. Therefore, the tool allows the evaluation of the following four primary aspects of job quality:

- Physical loads
- Cognitive loads
- Psychosocial loads
- Environmental loads

It is also possible to assess job quality on a more detailed level, because for each primary aspect several secondary aspects are defined. The user can select the relevant job quality aspects (primary and secondary) depending on the use case. Details on the primary and secondary aspects of job quality can be found in Appendix A-D.

5 Design

This section describes the key design principles that were used to achieve the goal of the tool. The following key design principles were used:

Step-by-step approach: The user is guided step-by-step through the evaluation process. Each step has a specific goal and specific requirements. This makes it easier to fill in the tool and request expertise from different team members when completing the steps one-by-one.

Coarse to fine: Job-quality can be evaluated on different levels. Both the process model and the job-quality metrics are hierarchical. This makes it possible to assess items on a more global level where possible and make refinements where needed. This limits the required effort when filling in the tool

Re-use of information: If information applies to multiple tasks, actions or scenarios, the interface is designed such that the user only has to provide this information once.

Flexible: The user only evaluates the job-quality metrics that are relevant. As described in deliverable D6.1 there are many factors that are associated with job quality. However, not all these factors might apply significantly to all use cases and scenarios. This can be the case when the factor is constant over the different scenarios (e.g. they are performed in the same environment, and therefore factors such as lighting and noise are constant) or they do not appear at all (e.g. the scenario does involve handling heavy loads).

Iterative design: After completion of a specific step the user can go back to previous steps in order to update or refine the information filled in earlier.

6 Tool usage

This section describes the interface of the tool and how to use the tool to make a job-quality assessment for one or more scenarios. The user will complete the job quality assessment in six steps, from a description of the process and the tasks to a visualization of the results.

First the general lay-out of the tool will be described. Secondly all the steps that need to be completed by the user will be reviewed.

6.1 Overview of the user interface

Figure 3 shows the general outline of the tool. The interface is divided into four sections:

Task panel: The task panel contains the process tree that will be defined in step 1 (see section 6.2.1). The process tree is made up from tasks, subtasks, and actions. The process tree is searchable through the search window (at the top of the task panel).

Step tabs: The step tabs guide the user through the design tool. Each tab can be selected to bring forward the relevant interface for that step. By completing the consecutive steps, the user is able to assess the job quality for one or more scenarios.

Information panel (steps 1-4): The information panel displays the information that is needed to complete a specific step.

Parameter panel (steps 1-4): This panel shows the parameters that are relevant for the currently selected step and allows the user to change these parameters.

Note! The screenshots in this report might differ slightly from the actual implementation to improve readability.

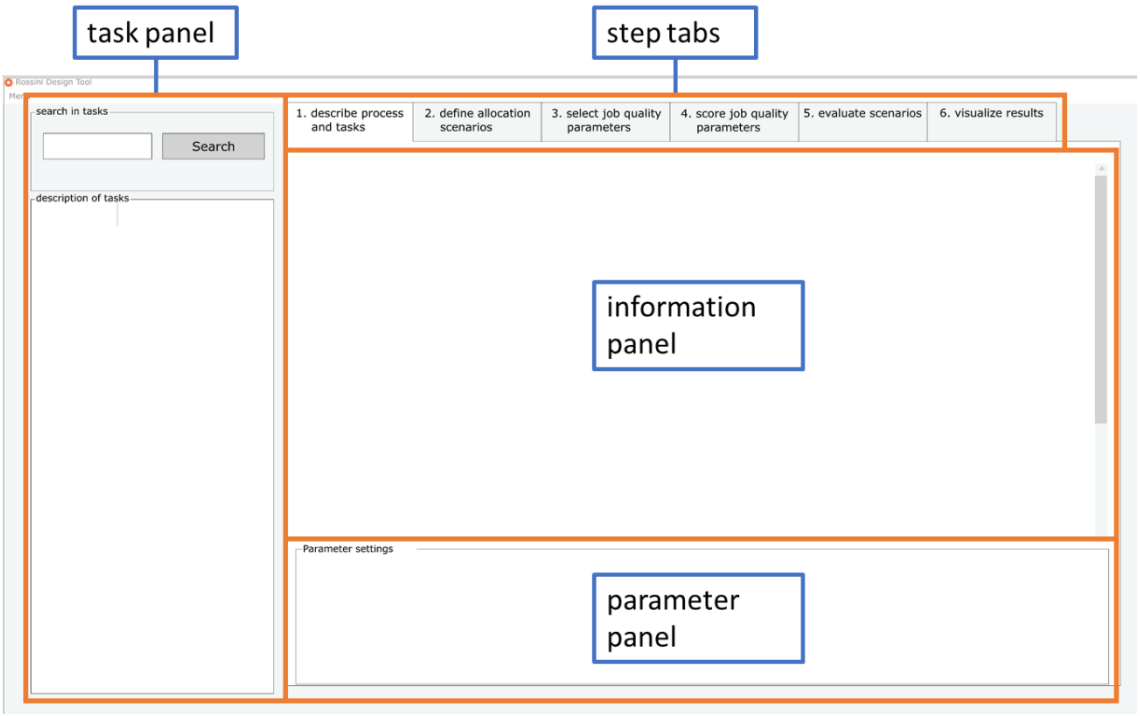


Figure 3: General outline of the tool.

6.2 Steps

This section reviews the steps the user must complete to assess job quality. In the screenshots of the user interface the task pane is omitted for better readability.

6.2.1 Step 1: Describe process and tasks

In step 1 (Figure 4) the user is guided through three stages to define the processes and tasks. This definition is made top down. First, the scope of the project/process is defined, then the tasks within the process are defined, and then the actions are defined.

The user can keep track of their progress by using the tick boxes. To access the stages, the user selects the corresponding buttons shown in the lower part of the screen.

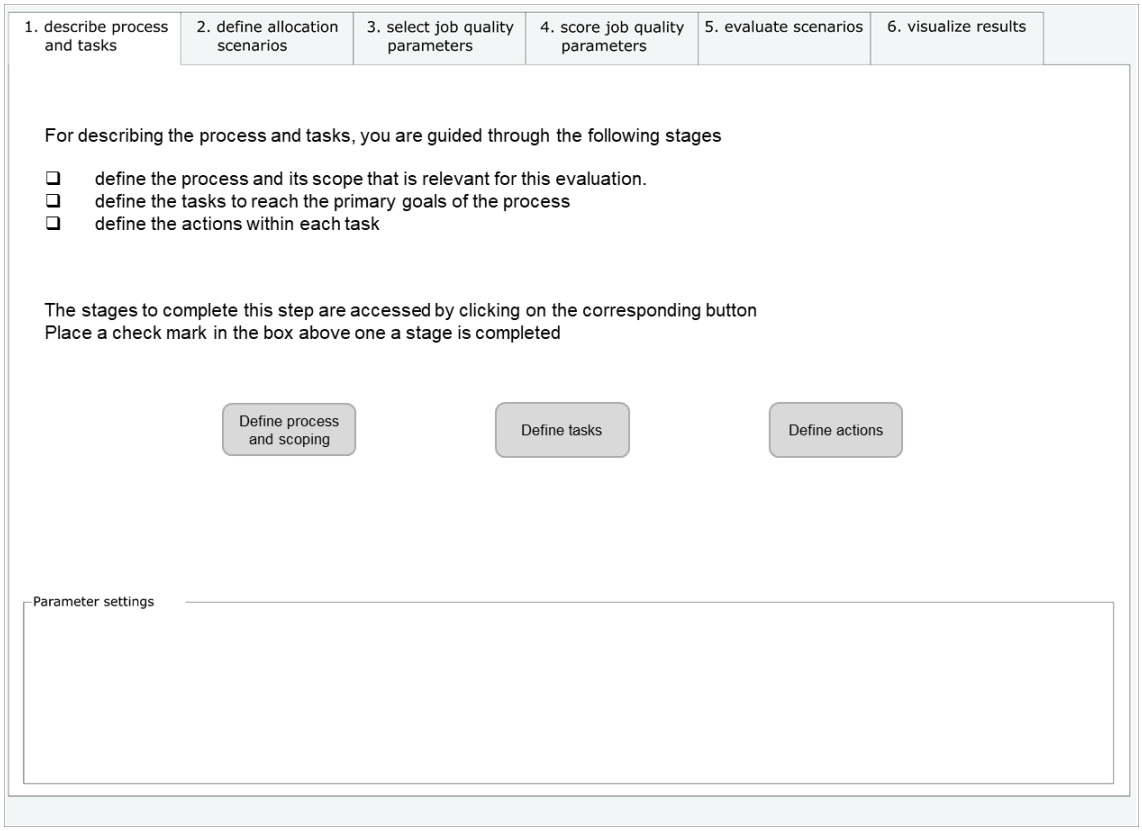


Figure 4: Overview window of step 1.

6.2.1.1 step 1, stage 1: define process and scoping

The user provides an overview of the process and its scope (Figure 5). The required information can be inserted in the Parameter setting panel.

The process description outlines the process on a high level, this could be seen as the summary of the process. The lists of parts, tools, resources and actions are used in later steps to describe the tasks and actions with consistent semantics.

After completing this stage, one may use the *back to overview* or *continue to define tasks* buttons at the bottom of the info panel.

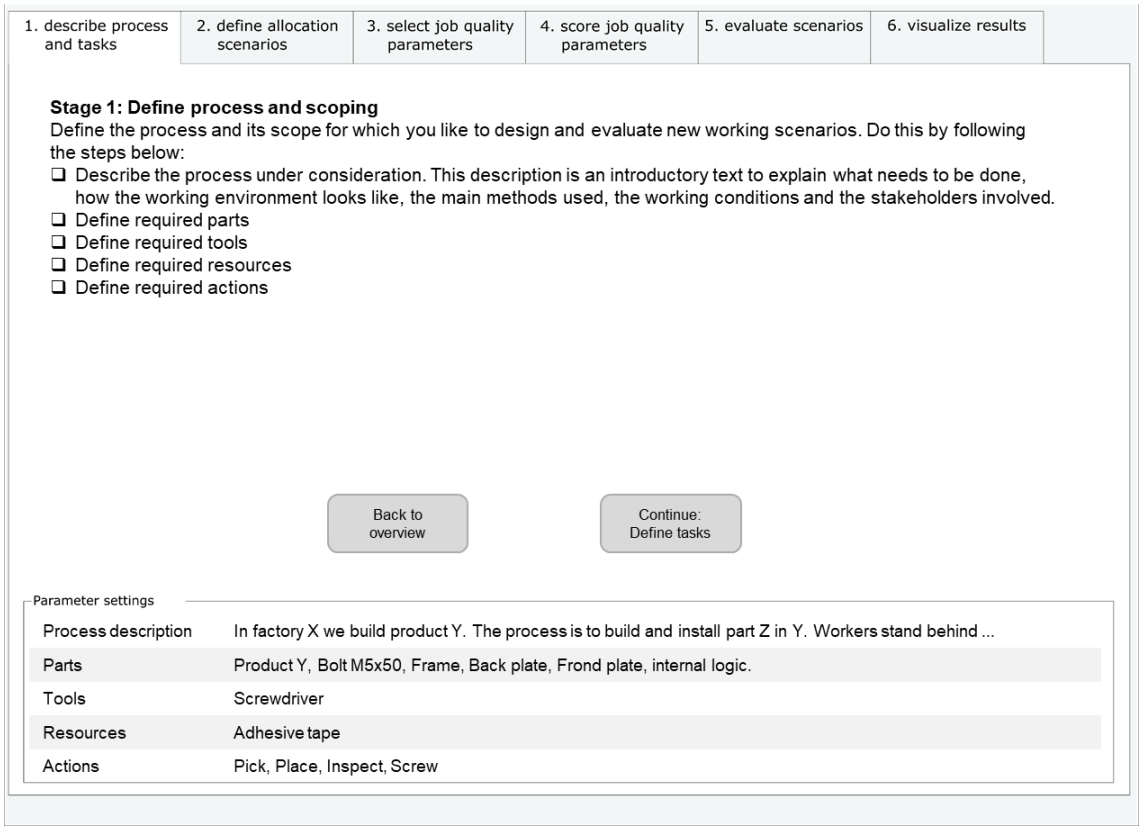


Figure 5: Process and scoping

6.2.1.2 step 1, stage 2: define tasks

The work process is divided in tasks with underlying actions. In this stage we define the tasks, which can be added via the *task panel*.

In later steps tasks are attributed to human or robot and will be evaluated for job quality.

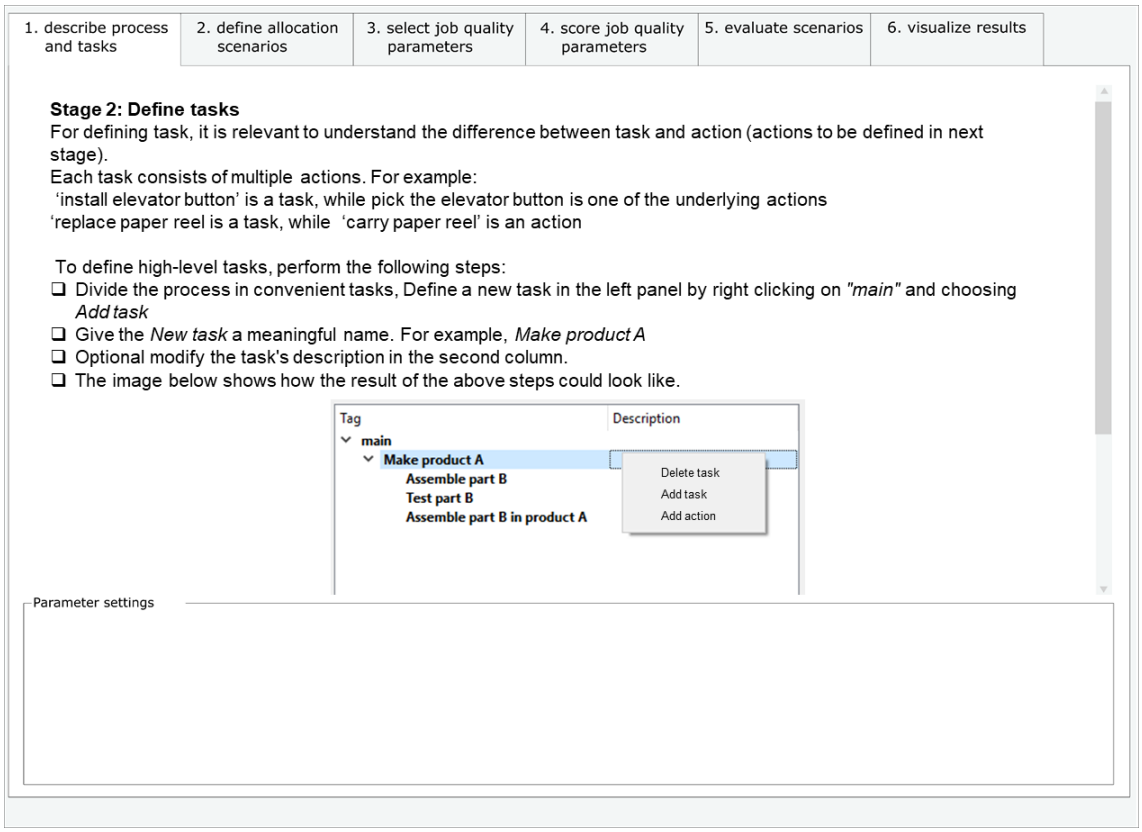


Figure 6: Define tasks

step 1, stage 3: define actions

In this stage we define the actions, which can be added via the *task pane*

Tasks and actions can later be attributed to either the human or robot teammates and when attributed to human scored on JQ evaluation parameters.

Once all stages are completed, the user clicks on the corresponding tab to continue to *step 2: Define task allocation scenario*

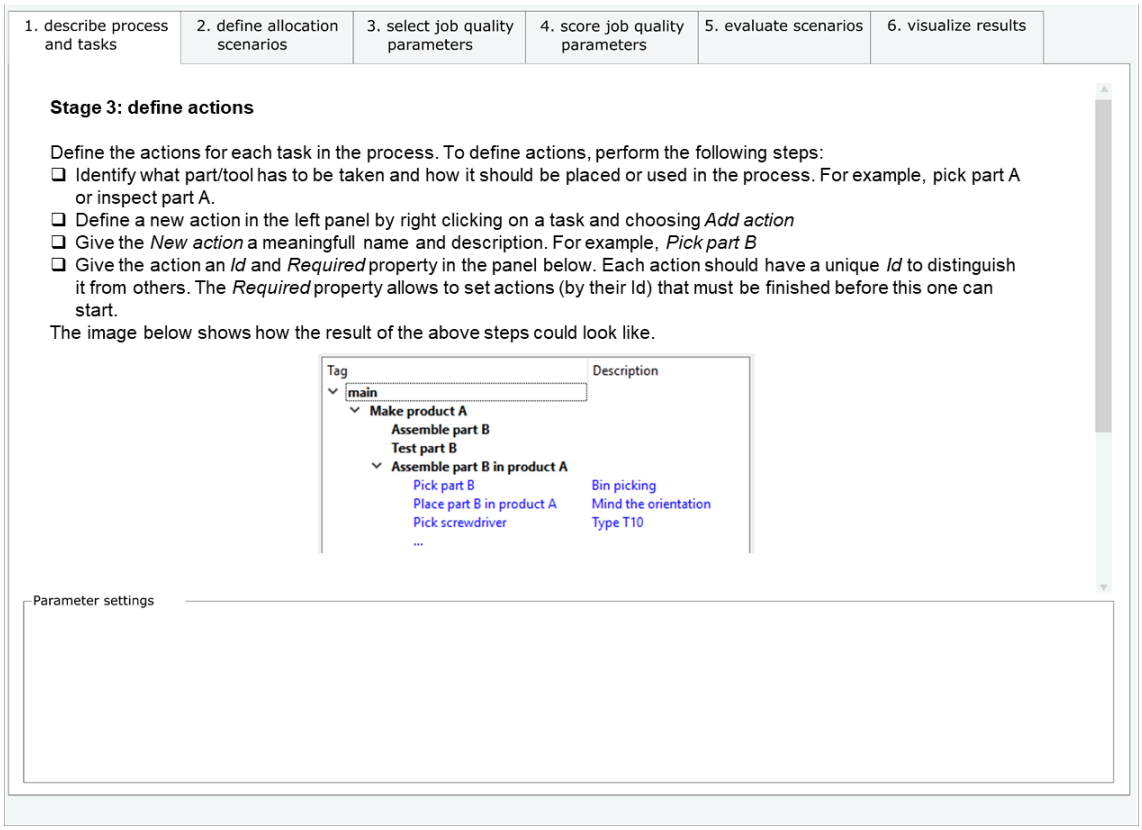


Figure 7: Define actions

6.2.1.3 Example

Process tree
• Task 1 ○ Action 1 ▪ *Actor: Human*
• Task 2 ○ Action 2a ▪ *Actor: Human* ○ Action 2b ▪ *Actor: Human*
• Task 3 ○ Action 3 ▪ *Actor: Human* ▪ *Actor: Robot*
• Task 4 ○ Action 4 ▪ *Actor: Human*

Table 1: Step 1 results in a filled in process tree with tasks, actions, and actors

6.2.2 Step 2: define allocation scenarios

Scenarios are alternative approaches to reach the primary goal of the process. A scenario is defined as a selection of the tasks and actions that were defined in the previous steps. Furthermore, actions can be assigned to actors, which can also be selected to belong to a specific scenario. An actor can be a human or a robot or another entity that is able to perform the task. Once a scenario is populated with tasks and actions, the user clicks on tab *Select job quality parameters* to continue.

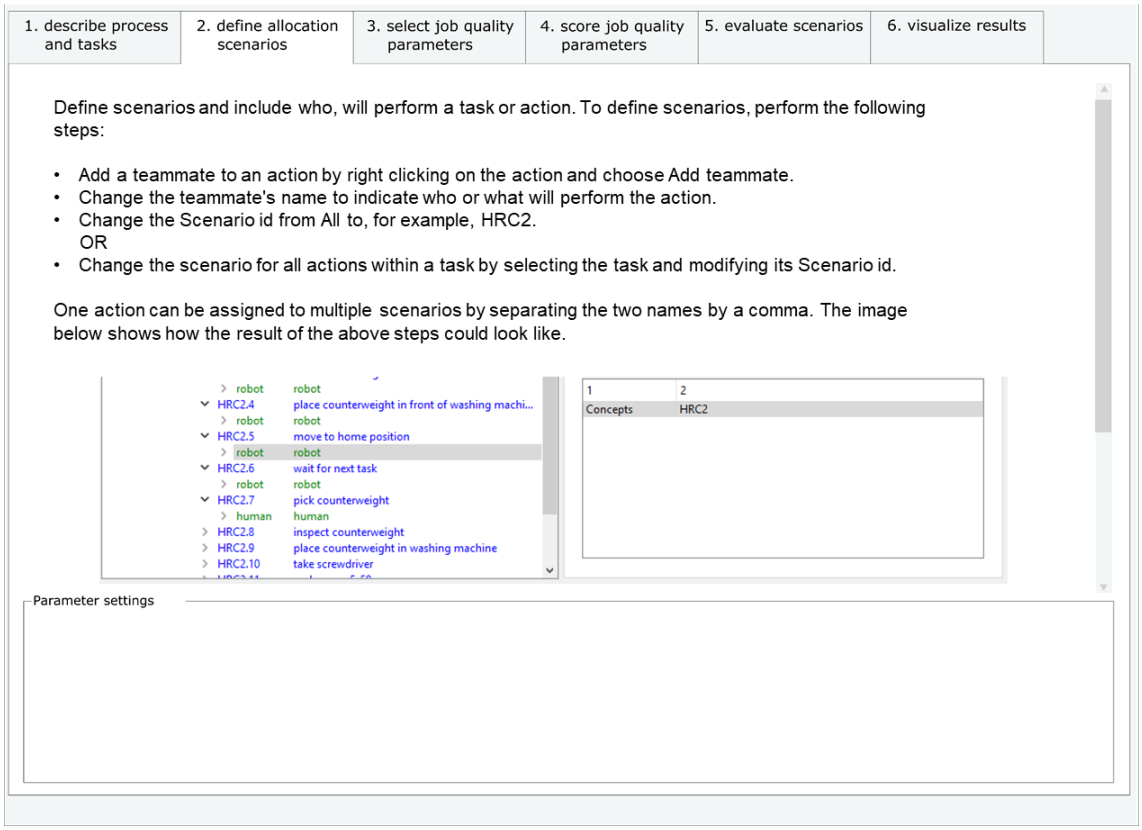


Figure 8: define allocation scenarios

6.2.2.1 Example

Table 2 shows the result from step 2, the process tree with the assigned scenarios.

Process tree	Scenario 1 (s1)	Scenario 2 (s2)
• Task 1 ○ Action 1 ▪ *Actor: Human (All)*	• Task 1 ○ Action 1 ▪ *Actor: Human*	• Task 1 ○ Action 1 ▪ *Actor: Human*
• Task 2 ○ Action 2a ▪ *Actor: Human (s1)* ○ Action 2b ▪ *Actor: Human (s2)*	• Task 2 ○ Action 2a ▪ *Actor: Human*	• Task 2 ○ Action 2b ▪ *Actor: Human*
• Task 3 ○ Action 3 ▪ *Actor: Human (s1)* ▪ *Actor: Robot (s2)*	• Task 3 ○ Action 3 ▪ *Actor: Human*	• Task 3 ○ Action 3 ▪ *Actor: Robot*
• Task 4 ○ Action 4 ▪ *Actor: Human*	• Task 4 ○ Action 4 ▪ *Actor: Human*	○

Table 2: Step 2 results in the assignment of parts of the task tree to specific scenarios. Values between brackets in the process tree indicate the scenario assignment. Tasks can be selected in all scenarios (Task 1), Different actions alternatives can be selected (Task 2), different actors can be selected (Task 3), task can be left out from one scenario (Task 4)

6.2.3 Step 3: select JQ parameters

In the parameter settings panel, the user can tick the boxes of the job quality parameter that they wish to evaluate.

Background information about each job quality parameter can be accessed by clicking on the corresponding button.

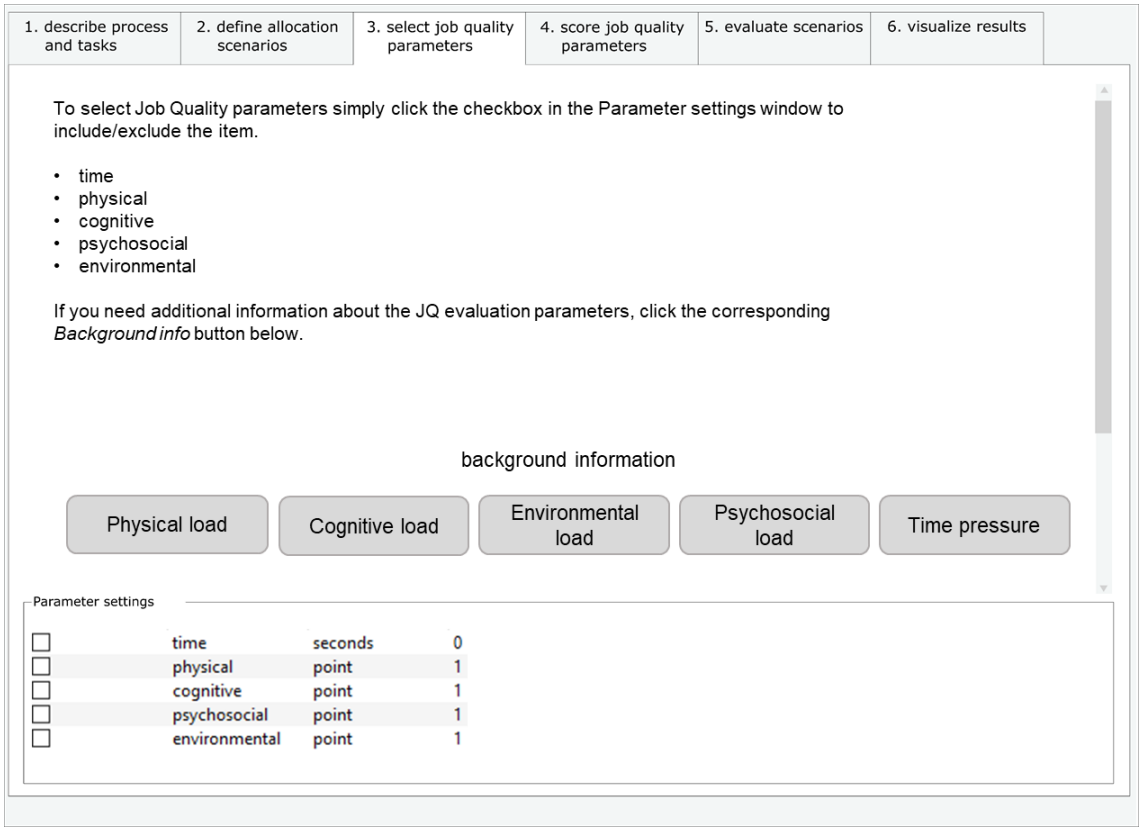


Figure 9: Select JQ parameters

6.2.3.1 Example

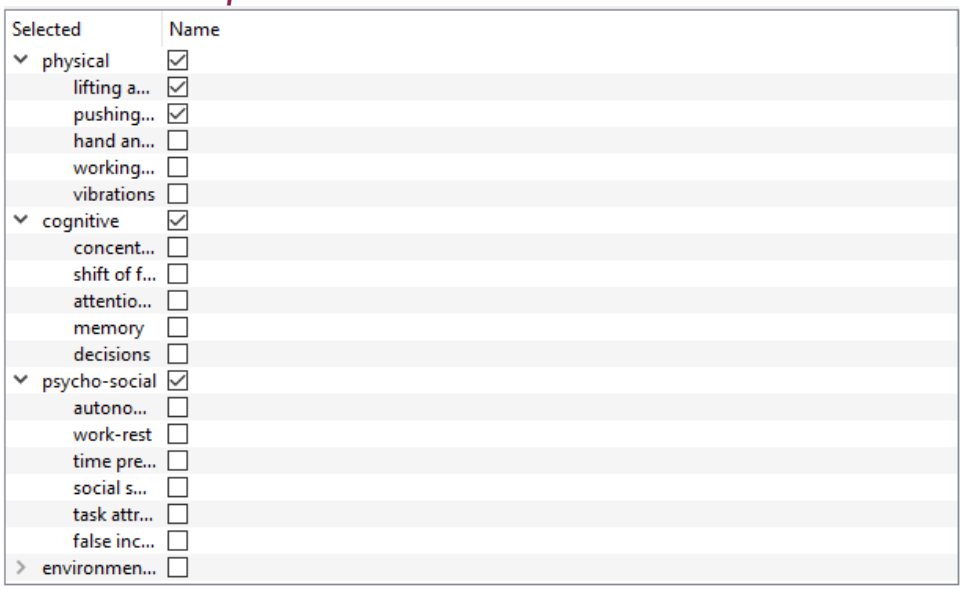
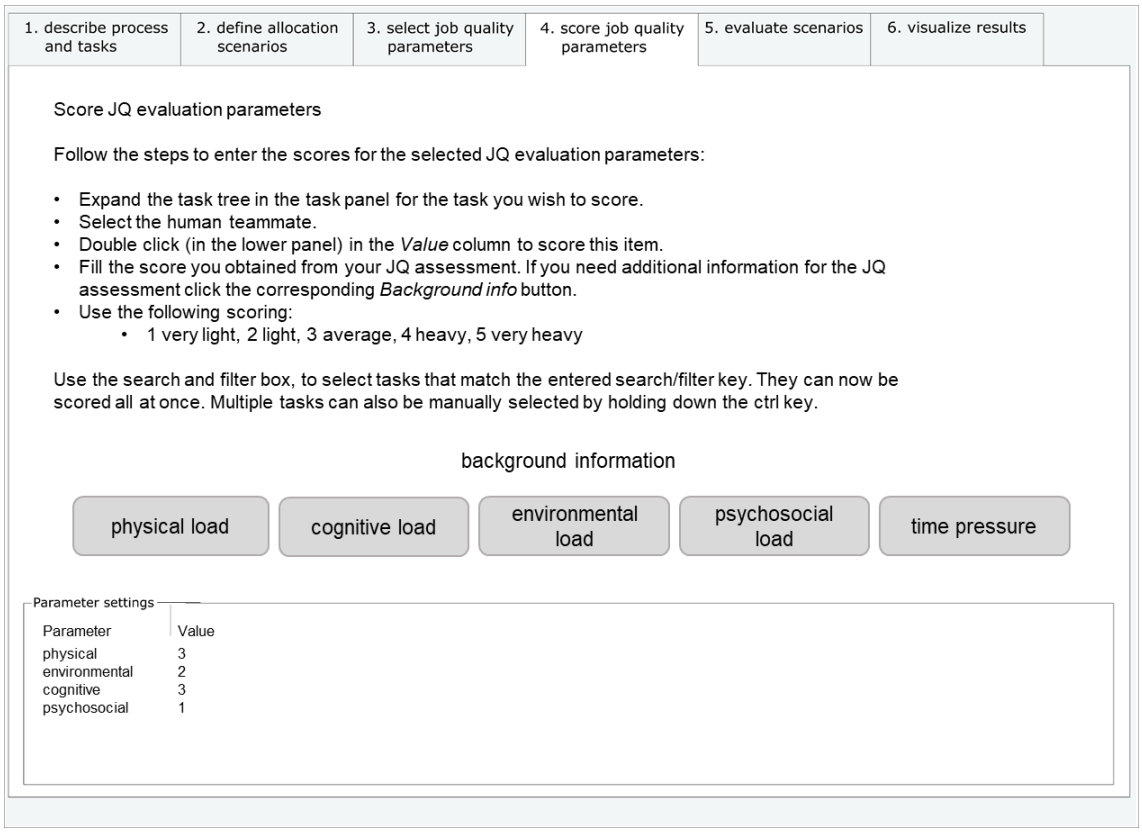


Figure 10: Selection of job quality parameters in the design tool. Three out of four primary aspects are selected (physical, cognitive, and psychosocial). For physical load 2 secondary aspects are selected (lifting and carrying, and pushing and pulling)

6.2.4 Step 4: score JQ parameters

The user scores parts of the process on the JQ evaluation parameters that were selected in the previous step. The scoring is ultimately performed on the actor level. However, it is possible to perform the scoring on a higher level in the task tree which results in all the descendent items receiving the same value.

Rough estimations of the scores can be entered. However, if a more detailed approach is desired the background info button opens a window with additional information on how to score certain JQ evaluation parameters. Appendix A through D give the background information that is available on the job quality measures that are available in the tool.



6.2.4.1 Example

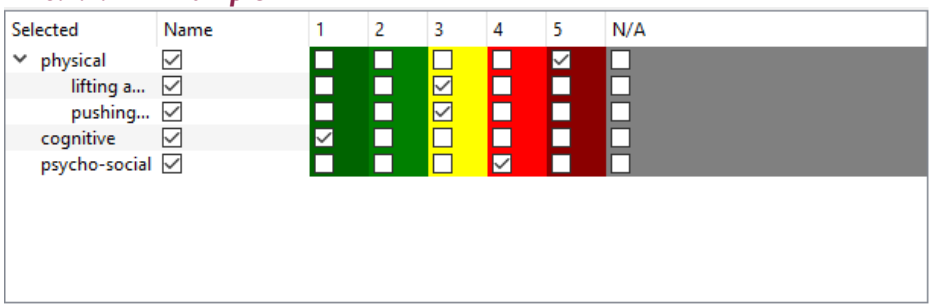


Figure 11:Scoring of job quality parameters on a 1-5-point scale. Note that only the parameters that were selected in the previous step (Figure 10) are available for scoring.

6.2.5 Step 5: visualize results

In the final step, the results are calculated and presented. For each scenario it is calculated which tasks are executed, in which order, when the tasks start and when they and. Based on the results of these calculation visual representations of the scenarios can be made. Currently, two visualization options can be chosen by clicking on the corresponding tab (JQ radar or Timeline).

1: JQ radar

the JQ radar is a visualization of the load of each task for all selected JQ evaluation parameters. Tasks are represented by circles; larger circles represent tasks with longer durations

The user can hoover the mouse over a circle to get a description of the task and trigger a connection between all the circles that represent this task in different JQ categories.

2: Timeline

the timeline is helps to visualize the task allocation and dependency of the different actors on each other

for example, it can be seen that the human operator can only start his task after the robot has finished his task at around t = 40s

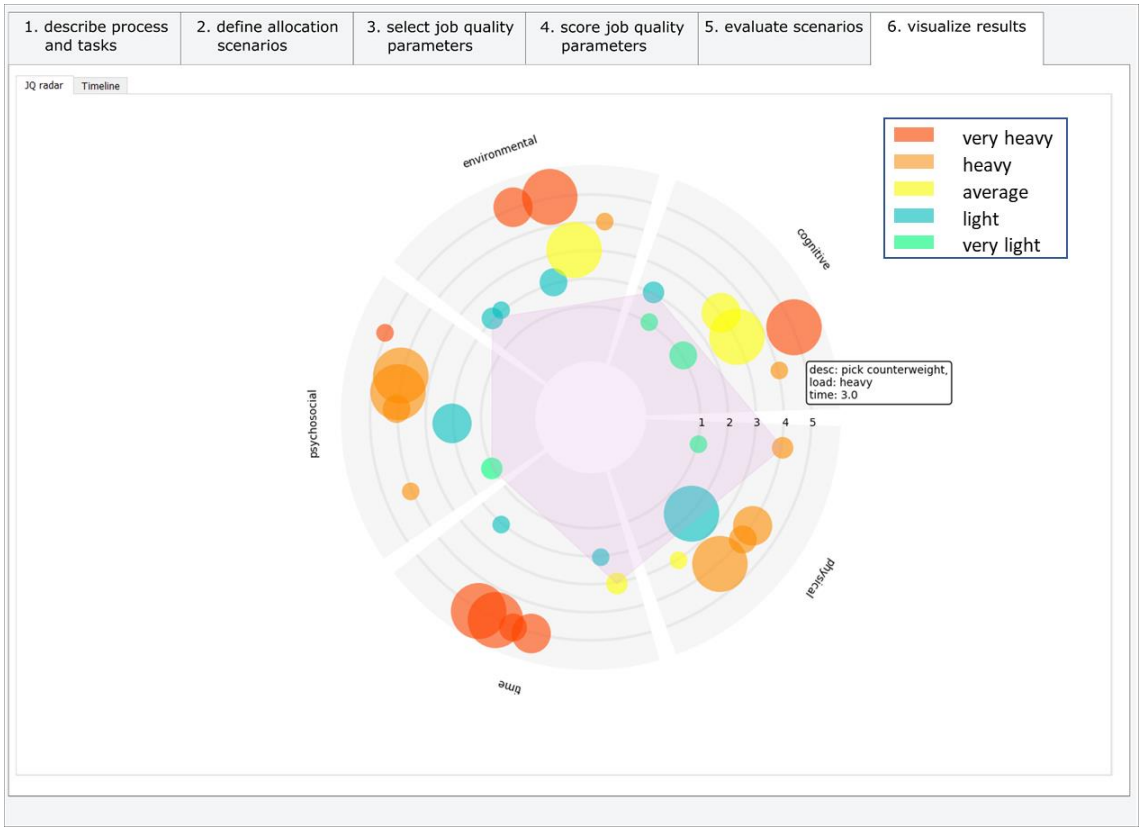


Figure 12: Radar plot

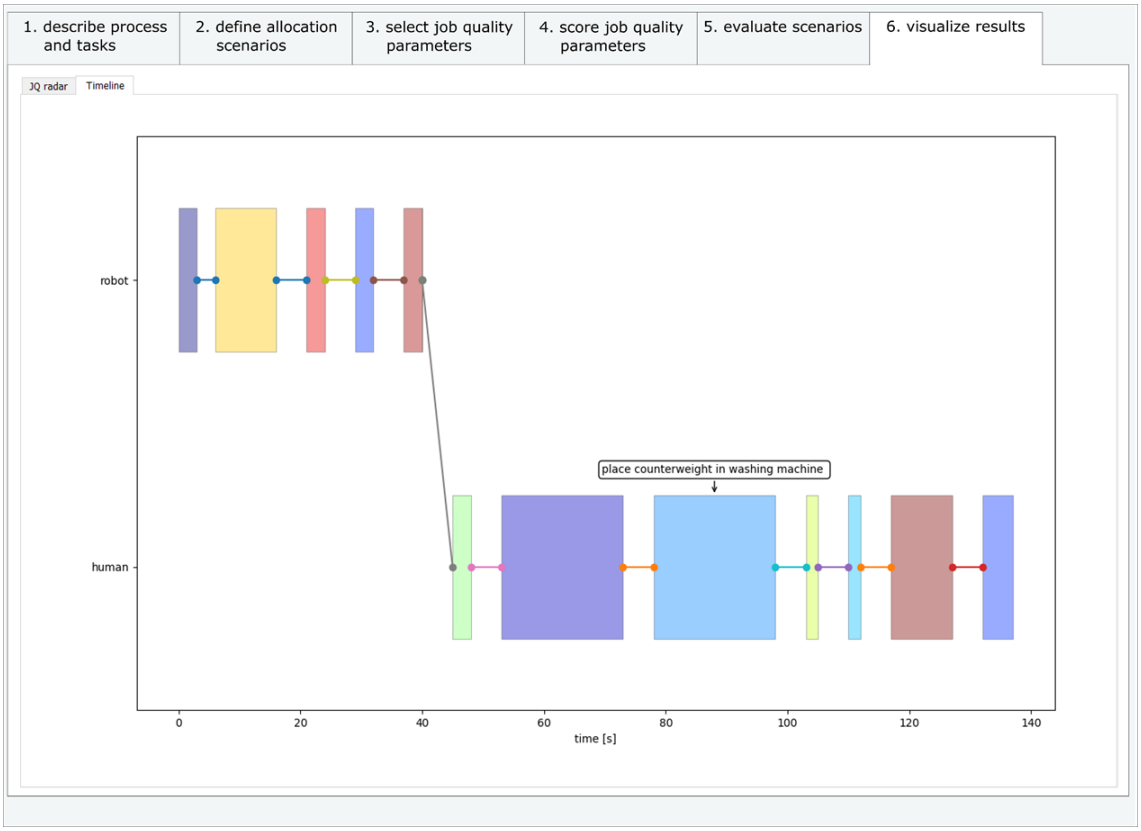


Figure 13: Timeline

7 Technical implementation

The tool is implemented in Python using multiple additional libraries. An overview is found in Table 3.

Software/Package	Version	License	Link
Python	3.6.9	GPL compatible	www.python.org/
pyqt5	5.13.0	GPL	www.riverbankcomputing.com
NumPy	1.11.3	https://numpy.org/license.html	numpy.org
Matplotlib	2.2.2	only uses BSD compatible code	matplotlib.org/

Table 3: used software

8 Conclusion

Task 6.2 resulted in a software tool that allows to model different scenarios. These scenarios can be subjectively scored on different job quality aspects. Scenarios can be visualized and compared. The tool has been tested with an example process.

Future use of the tool will include the modelling and scoring the three use cases within the Rossini project. Along the project the tool will be improved and refined.

Appendix A: Background information physical load

Physical loads are 'bad' ('5') if one or more of the following occurs:

- heavy (+25kg) and/or frequent lifting, especially in bad postures
- pushing and pulling of carts heavier than 400 kg
- high hand / arm loads (high repetition and/or large joint angles and/or high forces)
- strenuous working postures; postures that are difficult to maintain for longer periods of time.
- strong vibrations to the arms or the body

If a general assessment is not possible, individual items under physical loads can be assessed separately.

Lifting: There is a health risk when one or more of the following aspects apply: weights over 20kg, frequent lifting below knee level and above chest level, lifting in otherwise awkward postures, cumulative weights exceed 600 kg per hour and 1200 kg / day. https://www.cdc.gov/niosh/docs/94-110/default.html

Pushing and pulling: There is a health risk if one or more of the following applies: load on cart is more than 400 kg, push / pull forces exceed 200N, pushing/pulling is in awkward postures, floor conditions are not optimal (slopes, rough surface, thresholds) http://www.hse.gov.uk/msd/pushpull/assessment.htm

Hands and arms: There is a health risk if one or more of the following loads apply: arms/hands need to apply large forces (>100N), forces are applied with large to extreme joint angles, finger forces are high (> 10N), large pinch and /or grip forces are required. https://www.fysiekebelasting.tno.nl/en/

Static posture: Prolonged static postures are not good for the body and may lead to fatigue. Either support (like back or arm support) or changes of posture should be made possible. Frequent and prolonged joint positions that are close to extreme, are potentially harmful and should be avoided as much as possible. https://www.fysiekebelasting.tno.nl/en/

Vibrations: Riskful whole body vibrations generally are associated with driving a vehicle in uneven terrain leading to shocks and vibrations. Hand arm vibrations are generally associated with using mechanical hand tools such as for grinding, sanding and drilling. Riskful exposures due to vibrations emerge in a situation with high levels of vibration for longer periods of time.

Appendix B: Background information cognitive load

Cognitive load can be scored as 'bad' when cognitive load is too high or too low[1].

- Cognitive load is **too high** (and thus bad) if:
- a lot of information needs to be processed in short time
- fast decision making is required
- a lot of information needs to be remembered
- particularly under distracting circumstances
- Cognitive load is **too low**, if work is leading to boredom

If a general assessment is not possible, individual items under cognitive loads can be assessed separately.

Concentration: Assess the level of concentration required by the task(s). This aspect is scored 'bad' if the required concentration to perform the task(s) (within time and without mistakes) is high in relation to the worker's capacities and the environment is highly distracting

Shift of focus: Assess to what extent the task allows to remain focused or requires shifts of focus. This aspect is scored 'bad' if the workers needs to shift his focus of attention frequently.

Attention division: Assess to what extent the worker must divide attention over more than one task. This aspect is scored 'bad' if the worker must divide his attention across multiple tasks which may lead to mistakes and/or safety risks

Memory: Assess to what extent the task relies on the worker's memory. This aspect is scored 'bad' if the worker needs to remember a lot of information and not remembering leads to mistakes and/or safety risks

Decisions: Assess to what extent the task requires decision making. This aspect is scored 'bad' if many decisions of high complexity and/or large consequences must be made in short periods of time.

[1] https://oshwiki.eu/wiki/Cognitive_ergonomics

Appendix C: Background information psychosocial load

Assess whether the task(s) and its setting are positive or negative to the operator's psycho-social well-being[2].

Psycho-social issues are scored 'bad' if one or more of the following apply:

- task autonomy is absent, level of control is low
- time factors (duration, work-rest cycle, time pressure) may lead to overload
- social contact opportunities are limited
- incentives are present that may lead to unwanted behavior.

If a general assessment is not possible, individual items under psychosocial load can be assessed separately.

If task psycho social issues remain unclear, more information can be obtained from local occupational health and safety specialists and under the hyperlink

Autonomy: Assess the worker's level of autonomy and control over task execution This aspect is scored 'bad' when the worker:

- would like to control work speed but cannot
- has no control over the output of his task (quality)
- has no control over how the task needs to be performed

Work-rest: Assess whether work-rest cycles are in sync with the task load. If tasks are difficult or heavy, there should be enough opportunities to recover from these tasks during the working day. E.g. periods of very high concentration or very monotonous work should be alternated with tasks with a different cognitive load.

Time pressure: Assess the time pressure in the tasks / scenario. This aspect is scored 'bad' if the time frame for finishing the task(s) is not or hardly enough (while opportunities to control this are lacking)

Social support: Assess the opportunity for interaction with colleagues. This aspect is scored 'bad' when work stations are isolated and workers do not have the opportunity to communicate with or find support from each other during work

Task attractiveness: Assess the attractiveness of the task(s) for the worker. This aspect is scored 'bad' if the task(s) is not liked by the worker, because the task content is too small, is monotonous and does not include any challenge

False incentives: Assess whether the tasks hold false incentives**.** This aspect is scored 'bad' if certain behavior or outcomes with negative consequences are (indirectly) rewarded and thereby stimulated.

[2] https://oshwiki.eu/wiki/Psychosocial_issues

Appendix D: Background information environmental load

Assess in what way the working environment in the scenario is good or bad with respect to lighting, noise and climate[3].

The working environment is scored 'bad' if one or more of the following applies:

- lighting levels not adjusted to the task that needs to be performed
- presence of glare: strong light sources visible in the operator's field of view
- noise levels above 80 dB (requires speaking with elevated voice to understand each other)
- irritating sounds
- indoor climate not adjusted to the task that needs to be performed (considering adjustment to local conditions)

If a general assessment is not possible, individual items under environmental loads can be assessed separately.

See directive 89/654/EEC - workplace requirements[4]

Lighting: Assess lighting factors in the working environment for the scenario/task

Lighting is 'bad' if one or more of the following applies:

- light conditions are not fit for the tasks that needs to be accomplished, e.g. reading, seeing details, recognizing color differences.
- presence of glare: strong light sources visible in the operator's field of view
- presence of visible flicker in light sources

For more information on lighting in the working environment, read the information in a booklet from UK's government organization HSE[5].

Noise: Assess the exposure to noise for the scenario/task. Noise conditions are 'bad' if one or more of the following applies:

- noise levels require talking with raised levels at 1m distance to understand each other (noise levels likely > 80 dB)
- noise levels / sounds that are annoying such as high pitch tones
- frequent sound bursts such as pneumatic systems discharging
- noises and sounds disturb the operator at concentrating for the task

Assess the sound environment in which the tasks need to be performed. Are they potentially damaging, and could they lead to concentration loss or annoyance?

Noise can be both risk ful as annoying. Sound levels more than 80 dB are damaging to the ear; exposure should be avoided or limited to short periods of time. High sound levels require measurements by experts.

There can also be a risk from sound levels that are safe to the ears. Noise from machines, music and/or colleagues can lead to annoyance, concentration loss, mistakes, lower productivity, irritability and high blood pressure. This depends on many factors such as sound level, composition and emotional factors. Expert knowledge is required to perform a good assessment of all noise aspects.

Climate: Assess (indoor) climate for the scenario / task

Climate conditions are 'bad' if one or more of the following applies[6]:

- working temperature and clothing is not adjusted to the task that needs to be performed (considering adjustment to local geographical conditions)

[3] https://oshwiki.eu/wiki/Physical_agents

[4] https://osha.europa.eu/en/legislation/directives/2

[5] https://www.hse.gov.uk/pubnS/priced/hsg38.pdf

[6] https://oshwiki.eu/wiki/Thermal_risks

- strong temperature gradients at the workstation
- strong airflow with big temperature difference to ambient temperature
- hot radiating surfaces