**Project Details**

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<th><strong>PROJECT TITLE</strong></th>
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**THE COPro PROJECT**

The goal of CoPro is to develop and to demonstrate methods and tools for process monitoring and optimal dynamic planning, scheduling and control of plants, industrial sites and clusters under dynamic market conditions. CoPro pays special attention to the role of operators and managers in plant-wide control solutions and to the deployment of advanced solutions in industrial sites with a heterogeneous IT environment. As the effort required for the development and maintenance of accurate plant models is the bottleneck for the development and long-term operation of advanced control and scheduling solutions, CoPro will develop methods for efficient modelling and for model quality monitoring and model adaption.

**The CoPro Consortium**

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<th>Participant No</th>
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Abstract
The goal of task 5.1 is to develop new Human Machine Interface (HMI) concepts that can be used for plant coordination and decision support. This report presents some of these concepts. Particular attention is paid to the use of interactive visualisation elements to form part of the user interface, and the use of multi-modal HMIs mainly driven through mobile device usage.

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Table of contents

1 Executive summary ................................................................. 5
2 The Human Machine Interface .................................................. 6
3 Multi Modal Human Machine Interfaces .................................... 6
   3.1 Example Usage – Plant Walk-Around .................................... 6
   3.2 Unambiguous Input and Output .......................................... 6
4 Current Industrial HMIs and Visualisations ............................... 7
   4.1 Process Data Visualisation and Monitoring ............................. 7
   4.2 Scheduling HMIs ............................................................ 8
   4.3 Integration and Collaboration ............................................. 8
5 Multi Modal HMIs in CoPro ....................................................... 8
   5.1 Dynamic Data Source Specification ..................................... 8
   5.2 Dynamic Visualisations ................................................... 9
   5.3 Reporting at Different Levels ............................................ 9
   5.4 Context Aware HMIs ....................................................... 10
6 Scheduling HMI ................................................................. 10
   6.1 Visualising Schedule Data ................................................. 10
   6.2 Interacting with Scheduling Algorithms ................................. 11
   6.3 Comparing Schedules ..................................................... 11
   6.4 Reviewing Schedules ..................................................... 12
7 Linking Data to Business Processes ......................................... 14
   7.1 Notes ........................................................................ 15
   7.2 Actions ....................................................................... 15
8 Mobile Devices ......................................................................... 16
   8.1 Tablets ....................................................................... 16
      8.1.1 On-Plant Use .......................................................... 16
      8.1.2 In-Office Use ......................................................... 17
   8.2 Mobile Phones ............................................................... 17
9 Summary ........................................................................... 17
1 Executive summary

The goal of task 5.1 is to develop new Human Machine Interface (HMI) concepts that can be used for site-wide plant coordination and decision support. These concepts will be produced in template form to allow them to be used in the CoPro use-cases.

All of these HMIs will be multi modal, meaning that they will provide multiple methods for users to input data into the system, and multiple ways for that information to be displayed by the system. This allows users to utilise the formats that best suit the data, rather than being forced to use a mechanism that is poorly suited.

A variety of multi modal concepts are proposed to ensure data consistency, ease of use, and the flexibility to allow users at any level of an organisation to benefit from the data.

Many of the CoPro use-cases involve scheduling, so the interaction with scheduling data and algorithms, and interfaces to allow users to interrogate and compare these schedules are key in ensuring that users can maximise the benefits seen from this work. In this report novel scheduling interfaces and visualisations are presented, as well as methods to link findings from data exploration to the suitable business processes.

In a modern HMI the data visualisation should not be separate from the user interface, instead it should be the way that users interact with, and navigate through, the data. This provides a more intuitive experience as the system follows the natural flow of the user’s investigation, which in-turn reduces the time taken to interrogate data, and the amount of training needed. The visualisation elements presented here all have interactive aspects to provide intuitive feedback and ensure that detailed information is available without it needing to be permanently onscreen.

Mobile devices such as tablets and mobile phones are the main driver for multi-modal HMIs, with their use becoming more widespread in industrial settings. It is therefore important that any HMI developed in the CoPro project supports mobile platforms wherever possible, either in its entirety or through the presentation of condensed information and functionality.
2 The Human Machine Interface

The keystone to any industrial software solution is the human machine interface (HMI). It is vital that the information being presented is clear, unambiguous, and up-to-date. This ensures that users are able to use the information quickly and effectively, and in turn makes it far more likely that they will continue to use the system. Conversely, if the HMI makes it difficult for the user to interpret the results then regardless of how sophisticated the underlying software may be, the user is unlikely to use the system. If they do use it, they may make sub-optimal choices due to poor data representation, which can lead to reduced productivity and in some cases serious issues with safety.

3 Multi Modal Human Machine Interfaces

Multi modal interfaces provide users with several methods of interacting with a system. The advantage of multi modal HMI is the ability for users to use the input and output format that best suits the information, rather than being forced to use a tool that may be poorly suited to the job. For example, take the case of a plant engineer performing a daily “walk-around”.

3.1 Example Usage – Plant Walk-Around

The task at hand is to take readings from field sensors and ensure the plant is in a safe condition. The engineer is using a handheld tablet device to enter this information. When given a simple single mode HMI the engineer must enter everything as text. This is suitable for the field readings, as they can be accurately entered in a format that can be automatically uploaded to a database system when the tablet is within the company Wi-Fi network range.

However, when encountering a blocked fire exit the text input is no longer ideal. This safety violation must be logged in the system so that it can be addressed, but the level of detail provided will vary depending on which engineer is performing the walk-around. One user may simply enter “blocked fire exit”, which does not specify the size of the blockage or how easy it would be to clear. Will several people be needed to rectify the problem? Will any special equipment be required? A user that does enter this level of detail will take a long time typing, making the process more difficult and time-consuming.

With a multi modal HMI the engineers could be presented with several ways of entering information. One could still be text input as this is a good way to take meter readings, but the other could be using the tablet’s inbuilt camera to attach pictures to the report. In the case of the fire exit blockage it is now extremely quick to register the problem, with the picture providing all the required detail of the safety violation without the user needing to enter any extra information.

3.2 Unambiguous Input and Output

In the process industry it is important that there is no ambiguity in the data entered into a system, or in the outputs it produces. It is for this reason that some input modes are generally considered unsafe for industrial use. Gesture control has been popularised by modern gaming consoles such as Microsoft’s Xbox 360 and the Nintendo Wii. Although it provides a convenient way to interact with a computer game, there is an unacceptable level of unreliability in its ability to discern background movements and small motions. This, combined with the limitations on camera placement make it
difficult to use effectively in a setting such as a control room. Speech recognition also has severe limitations in an industrial setting due to the need for internationalisation and the ability to cope with varying levels of background noise.

However, there are a multitude of input and output modes that are advantageous in an industrial setting, such as the use of touchscreens, digital pens, dynamic visualisations, and cameras in conjunction with more traditional modes such as plain text. If used correctly, these input and output modes will ensure precise recording and reporting of information with a level of flexibility that will allow application to a wide range of industrial scenarios.

4 Current Industrial HMI\s and Visualisations

There are a wide range of HMIs in use in the industrial sector. Some are developed by suppliers, but many are constructed by engineers using interface building tools provided by data historians or other software systems.

4.1 Process Data Visualisation and Monitoring

Figure 2 shows a visualisation used in the monitoring of an ethylene cracker built using a data visualisation tool. It is extremely difficult to see the data, and almost impossible to extract useful information unless you are familiar with the chart.

This visualisation could be improved within the software tool by splitting it into several charts. However, with multidimensional analysis such as this, it would be more effective to use a different visualisation technique that shows only the important derived information. Although such techniques may be available in external libraries, the engineers cannot use them as they do not have a way to link these to the live plant data. They therefore must choose between concise visualisations looking at out-of-date exported data, or obfuscated visualisations that are automatically kept up-to-date. This is an important issue that will be addressed with the CoPro HMI work, providing a range of clean, concise, and clear visualisations that can be dynamically connected to live data sources.

![Figure 2: A data visualisation used in the monitoring of an ethylene cracker built by a site process engineer.](image-url)
4.2 Scheduling HMIs

Within the CoPro project a range of industrial scheduling problems are being addressed. Outside of specific scheduling software a limited set of visualisations are available to engineers, with the most common being a Gantt chart. Although Gantt charts are an efficient method of visualising a set of tasks they are not well suited to represent changes in asset operation over time, which is the scheduling challenge being addressed by many of the CoPro industrial partners.

If scheduling software is being utilised then more specific visualisations are available, but these systems typically do not provide the functionality to build HMIs that link to the source process data. This introduces a separation between the plant process data and the schedule, when in fact the two should be intimately linked as the results of schedule optimisations are used to set the process variables.

4.3 Integration and Collaboration

Many HMIs used on industrial sites do not provide mechanisms for collaboration. This makes it difficult for users to interact with one another, for example, asking or answering questions about data behaviour when not in the same location. It also means that there is either no auditable trail of the discussion, or that this trail is in a separate system such as email that is not linked to the data.

5 Multi Modal HMIs in CoPro

5.1 Dynamic Data Source Specification

In a modern industrial plant there are several sources of data that can feed into visualisations and reports. These include data historians, databases containing field readings, financial systems, and basic manual input. To ensure a good level of flexibility the HMI templates created for CoPro must make it easy for users to change the data sources being used “on the fly”. This would allow users to quickly see the effect of applying a manual override by switching from a data historian source to manual text input, or allow them to feed in the results of a simulation run into the visualisations to see the results of some derived optimisation.

![Figure 3: Data configuration for a visualisation template. Each area of the template can be connected to a data source, or have a value entered as free text by the user.](image-url)
5.2 Dynamic Visualisations

Dynamic visualisations provide an interactive way for users to visualise results, drill-down to get more information, and enter new information. If the visualisation elements are bound to an updating data source, they also provide an always up-to-date view that can be crucial in ensuring the right decisions are made. Dynamic visualisations could be based on traditional charts with an interactive element embedded, such as the ability to hover over a bar to get specific values, or the ability to click on a bar to see a breakdown of the data that makes up that aggregated total. They can also be more complex displays, such as a directed graph that can be “dragged” around the screen and repositioned to make the relationship between data clear.

Interactive elements can also contain data input fields to allow users to update the data on which the visualisations are reporting. This means that users do not have to use different systems for data input and reporting, instead everything is seamlessly presented in one place for ease of use.

![Dynamic visualisation example](image)

Figure 4: An example of a dynamic visualisation. This force directed graph has draggable nodes, labelling information on hover, and clicking on a node draws a new graph with that node at the centre.

5.3 Reporting at Different Levels

The specific way that data is presented should depend on the intended audience. Within a large organisation the same data will be digested at different levels, with each level requiring a different type of aggregation and emphasis. For example, a plant operator may only be interested in a specific part of the process, so only wants to see the information that relates to this subset of equipment with no aggregation so that they can effectively control the operation.

The next level up could be a shift manager who wants to see the average performance of each of their shifts over the last month compared to the average performance of the other shifts for the same period.

At the next level could be a site director who is not concerned with the performance of individual shifts, simply the performance of the plant as a whole over the last month compared to the projected performance.
New Multi Modal HMI Concepts
Visualisations and Interfaces

It should be simple to display data in these different ways, most importantly from the same data source without needing to mirror the data for different levels. This ensures that each level of reporting is consistent, with each data consumer simply seeing a different view of the same underlying information.

5.4 Context Aware HMIs

As outlined above, multi modal HMIs provide multiple methods for users to input data to a system and view its outputs. Just as important as these modalities are the way in which they are presented. It may not be beneficial to show each different input or output method at the same time. Instead the application can automatically choose the most relevant mode depending on factors such as the device type, the job role of the person consuming the data, the current GPS location, or the past behaviour of the user. This ability to make decisions based on the current context make these software systems easier to use, and helps users to process the data quickly and effectively without losing any flexibility.

6 Scheduling HMI

6.1 Visualising Schedule Data

Access to optimised schedules are important for every business level, from plant operators to site directors. The visualisations for schedules should be clear and concise, easily interpreted (at least at the basic level) without training.

![Figure 5: A sketch of a possible scheduling visualisation. There is a row for each piece of equipment. When the equipment is online the process data is shown (solid line) along with the current schedule (dashed line). The other possible states are STARTING UP (green), SHUTTING DOWN (orange), and SHUT DOWN (red). Supporting data can be included even if it isn’t a scheduled variable. In this example water temperature is shown.](image)

In the above diagram you can see several bars containing time series data. Each of these bars represents a piece of equipment showing the recent history, and the future scheduled activity. Where the equipment is not running there are coloured sections to indicate whether it is starting up, shutting down, or offline. The majority of the visualisation is in the future, so an indicator is required
to mark the current time position. This visualisation has interactive elements, allowing users to drag and drop shutdown activities onto the chart to mark periods of required downtime. This would trigger a re-run of the scheduling algorithms.

### 6.2 Interacting with Scheduling Algorithms

Plant engineers need the ability to change constraints in the schedule, re-run the algorithms, and see the results in a sandboxed environment. This would allow them to try different scheduling options and assess the impact through visual feedback.

![Figure 6: In a sandboxed environment engineers and planners can change parameters in the model and compare the outputs of the scheduling algorithms in both cases. In this case the capacity of Tank A has been reduced to '0' for a set period-of-time. The effect this has had on the schedule can be seen in the block chart at the bottom where the current schedule is shown alongside the revised schedule.](image)

In the above diagram there is a top panel that is showing the value of the constraints relating to the capacity of two tanks. The capacity of Tank A has been set to zero to allow some maintenance activity to be carried out for a specific time-period. Once simulated, the new schedule is superimposed on the scheduling block diagram so that differences can be highlighted.

This exploratory work is carried out in an isolated sandbox environment, which means that it has no impact on the plant and is not seen by other users of the system. If the engineer wants this to be used as the schedule for the plant they can publish it ‘live’ provided they have sufficient access rights to do so. If not, they must share it with an engineer who has this level of control to check and publish.

### 6.3 Comparing Schedules

Although schedules can be compared by plotting the planned outputs, it can be more useful to compare the effects of the different schedules on quantitative measures that are directly related to the plant goals.

To achieve this RADAR charts can be used to compare two schedules, for example an edited schedule against the unconstrained optimum.
The axis of the RADAR chart would be user-configurable and reflect the goals of the plant. For example, these could be cost per ton, CO₂ per ton, energy usage per ton, and material yield. The number of axis is not fixed, providing a high level of flexibility.

The data for each axis should act in the same direction otherwise the visual interpretation is overly complex. For example, energy usage per ton is considered more optimal for lower numbers, but material yield is considered optimal for higher numbers. They are therefore not suitable to be used on the same RADAR chart without some manipulation. However, if instead of considering the proportion of raw material converted to final product, the proportion of raw material that is not converted to final product is used in place of material yield these measurements become compatible.

### 6.4 Reviewing Schedules

It is important that engineers can review either past schedules, or the current schedule suggested by the algorithms. An intuitive interface for this is a collapsible weighted tree, which visualizes the schedule in a tree structure for which the tree branch thickness is proportional to the amount of time spent in that node. The nodes of the tree can be defined at different levels to allow tasks to be grouped. The tree shown in Figure 8 splits all of the tasks in schedule into two main groups, In-Production and Maintenance. These nodes can then be expanded to explore the specific tasks carried out in each section, Figure 9 shows the tree with some of the Maintenance nodes expanded, Figure 10 shows the tree with all nodes expanded.

It can be seen from the figures that it is possible to colour the tree branches by category. In the example here, this is used to visually split the maintenance and production activities, however, it would be possible to use different colours for each tree section if desired.

The leaf nodes represent tasks specified in the schedule, these could be made clickable, linking the user to data relating to the specific task. This could be maintenance logs, production reports, or shift logs.
New Multi Modal HMI Concepts
Visualisations and Interfaces

Figure 8: Collapsible weighted tree. At the base level the tasks are split into two categories: In-Production and Maintenance.

Figure 9: Collapsible weighted tree with expanded Maintenance nodes. In this view the tasks of interest are visible in detail without losing the context of the whole schedule.
7 Linking Data to Business Processes

An effective HMI should not simply visualise data but should also provide intuitive methods for users to annotate this data and act on the derived insights. To achieve this, mechanisms will be provided to allow users to annotate data in-place, providing an auditable trail of commentary, and raise actions for wither themselves or other users.

To aid in the mapping of elements such as Actions and Notes to business processes a hierarchical structure of user-groups which we term ‘Communities’ is useful. Communities are groups of users with similar roles or functions. HMI components and pages can be made available to specific Communities, ensuring that only the relevant people have access to each section of a system.
7.1 Notes

Notes provide a way for users to leave comments directly on data. These could be individual data points, or ranges of data between certain times. This provides a way for metadata to be collected along with measurement readings, allowing insight to be attached to points of interest in a visualisation.

Users can reply to notes that have been raised by either themselves or other users, allowing for collaborative interaction such as the asking and answering of questions. All of this taking place in the context of the data.

![Figure 11: A Note attached to a range of data on a chart (highlighted section). This mechanism can be used to annotate data, such as providing information relating to abnormal behaviour. The Note can appear in a side panel, or when the user interacts with the highlighted data portion.](image)

7.2 Actions

Actions can either be raised as a standalone item or attached to a Note. The image in Figure 12 shows an Action being raised from the Note left in Figure 11.

Actions provide a mechanism for users to set tasks for themselves or other people. This ensures that issues or events identified are addressed by the appropriate people, providing an auditable trail of the action taken. Actions are assigned a due-date and a priority to help people prioritise the work they must complete. Actions are raised for individual users, but it is possible to make them visible to a specified Community.
New Multi Modal HMI Concepts
Visualisations and Interfaces

Figure 12: An Action being raised from an existing Note. The Action is assigned to an individual, but a Community can be specified to which the Action will be visible.

8 Mobile Devices

A key functional advantage of multi-modal interfaces is the ability to use a variety of platforms and devices. A device set that can be extremely advantageous in plant operations are mobile phones and tablets.

8.1 Tablets

Mobile tablets can be used to reduce the amount of paper reports and forms that are used on site and ensure that people have the information they need to hand at all times. Intrinsically safe tablets are available, these devices are safe to use in hazardous environments such as a petrochemical plant. Tablets would be used in different ways depending on the role of the user, this can generally be separated into two categories.

8.1.1 On-Plant Use

Toughened safe devices would be used on plant to provide engineers and operators with key information and an easy way to flag issues. An example use-case for this is plant walkarounds described above in Section 3.1. In these cases, the interfaces must be clean and easy to operate with a low tolerance for error, utilising large buttons operable by users wearing gloves. A major advantage of tablets on-site is the availability of a camera. Users should be able to attach images to elements such as Actions, with the option to add annotations to these images.
8.1.2 In-Office Use
Users who are not on-plant do not require special devices, and so have more flexibility in the platforms they can use. They are also more likely to need the full suite of visualisations and functionality as the devices can be used to provide dynamic reports in meetings, raise actions and post notes, and view and edit process data and schedule information.

8.2 Mobile Phones
Where possible, a modern HMI should make key functionality available to mobile phones. Although complex visualisations are generally not needed, access to the Actions system and summary information could be extremely useful.

As intrinsically safe mobile phones are available their use should be considered when constructing mobile device HMIs. The use-cases are similar to those of the tablet, with care taken to consider the reduced screen size when designing the element layouts. As for the on-site tablet, the camera is a key tool for inspections so the ability to attach images should still be available.

9 Summary
In this report examples of HMIs that can be used for plant coordination and decision support have been presented. These HMIs represent templates that can be dynamically connected to data sources and updated in real-time to ensure an always up-to-date view of the current plant state.

Multi-modal interaction is considered through the use of mobile devices both on and off site. All of the HMIs presented are compatible with mobile platforms either in their entirety, or through the presentation of condensed information. This ensures that users have all of the information they need wherever they are.

An important driver in the adoption and usage of HMIs is their integration with existing systems, and their compatibility with business processes. The ability to trigger Actions for users in the context of data ensures that maximum value is achieved, and important findings are interrogated by the appropriate people.

A metadata capture mechanism is shown through the ability to annotate data using Notes. This allows users to label important events descriptively or ask questions of other users in the context of the relevant information.

All of the HMI concepts presented aim to maximise the impact of enhanced analytics such as schedule optimisation by providing intuitive feature-rich interfaces that remain clean and clear for all users.