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Høgskolen i Molde
Vitenskapelig høgskole i logistikk

MØREFORSKING
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Predictive Offshore Crane Maintenance Manager (PCM)

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1. Abstract

This paper reports on the project "From time-based to condition-based maintenance – offshore cranes." (In Norwegian: Fra tids- til belastningsstyrt vedlikehold – offshore kraner) conducted by Molde Engineering AS from January 13th until May 8th 2017. The project was supported by VRI, the Norwegian Research Council's support mechanism for research and innovation in Norway's regions. We describe the background for the project, the goals, and the results.

Keywords: Offshore crane; predictive maintenance; relational database; user interface tool

2. Background

The Norwegian offshore industry face falling oil and gas (O&G) prices and increasing operation and exploration costs. New fields at larger depths, further from the cost, with rising security and documentation requirements implies rising costs. Thus there is a need in the sector to reduce cost and improve efficiency. Offshore cranes are central components in offshore operations. Traditionally, operation and maintenance of offshore cranes follows a time-based strategy where maintenance are done on a regular basis at fixed intervals. However, since it is a goal to keep the crane in service, a considerable amount of redundancy is built into time-based maintenance schemes. In addition, the time-based maintenance does not consider the actual usage of the crane including its exposure to load conditions and weather conditions.

Cranes are increasingly equipped with digital sensors provide a stream of data on crane usage, the type of loads it has been exposed to, and environmental conditions. The load and motion pattern of individual components are mapped, as well as the combined load and motion for central components. Based on this knowledge, operators can shift from the costly time-based maintenance strategy, to a condition-based maintenance strategy based on a combination of diagnostic and performance data, maintenance histories, operator logs and design data (Starr 2010). Unnecessary maintenance is avoided; correct maintenance is done at the right time and at the right components according to the crane manufacturer's requirements and safety regulations. The result is reduced costs and reduced downtime for the crane, which is of particular importance for offshore cranes. Summary of advantages:

- Environment: avoid unnecessary substitution of components
- Improved safety: More accurate point in time for maintenance and substitution of components
- Improved utilization: Components are utilized better resulting in lower maintenance costs
- Reduced risk for downtime: Since components are not used more than they are designed for
- Servicification: Predictive maintenance opens for new business models based on metering-per-usage to move from capital expenditures to operational expenditures.
- The failure rate is reduced, thus improving plant availability and reliability.
- A reduced inventory of spares is required.

The goal of this project is develop a demonstrator of a Predictive Offshore Crane Maintenance Manager (PCM). The demonstrator illustrate the functionality and the user interface of the

software. The project is done by Molde University College of behalf of Molde Engineering AS. The initial document describing predictive maintenance based on condition and load-based maintenance is included in Appendix C. Molde Engineering AS was established in 2016. One of their projects is the R&D project for developing a new regime for predictive maintenance of offshore cranes, including the Predictive Offshore Crane Maintenance Manager (PCM) demonstrator described in this report.

3. Introduction

The PCM demonstrator is a prototype of the new Predictive Offshore Crane Maintenance Manager (PCM). Predictive maintenance initiates maintenance upon deterioration of crane condition or detection of symptomatic conditions when a predetermined level is exceeded. A component is usually maintained as soon as the level value differs from the normal level. We present a new method to predict when to carry out maintenance in order to avoid failures and to improve crane performance. The PCM demonstrator user interface visualize the load experienced by the crane, and the demonstrator use the load values together with the manufacturer's specifications to predict when to do maintenance and what type of maintenance. Maintenance activities are broadly classified into *preventive maintenance* and *corrective maintenance*. Preventive maintenance is further subdivided into *calendar-based maintenance* and *conditions-based maintenance*. The second category is *corrective maintenance*, which is divided into *planned maintenance* and *unplanned maintenance. Planned maintenance also includes the condition based maintenance* as shown in Figure 1.

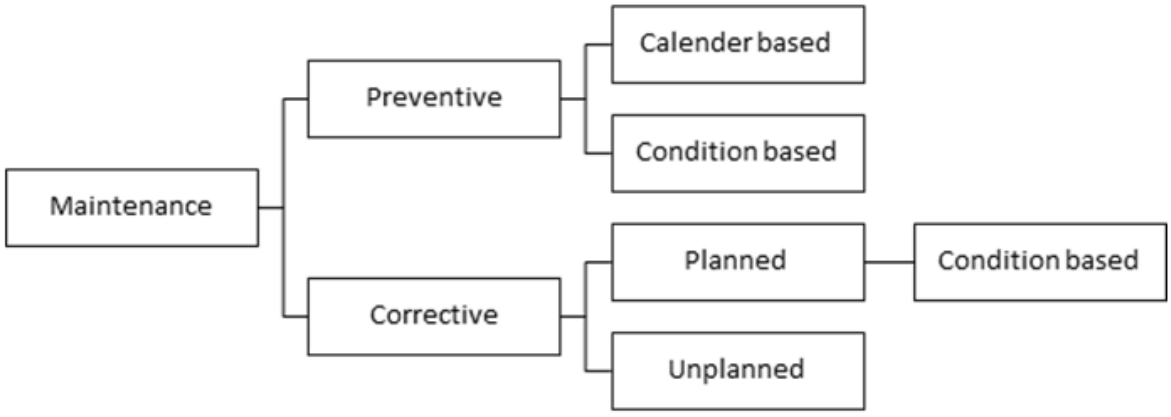

Figure 1: Schematic overview of the different types of maintenance (adopted from Wiggelinkhuizen 2008)

Calendar-based maintenance is done at regular time intervals or after a fixed number of operating hours. With the advancement of sensor technologies, condition based maintenance is used to decide the maintenance activity. The conditions of the machines are captured without hindrance of the day-to-day activities. Unplanned maintenance is performed due to unexpected failure. When maintenance activities are being carried out, the cranes can not be used. For reducing the number of times the maintenance activities are performed, we need to increase the quality of prediction on when to execute the maintenance activities and to avoid performing any unwanted maintenance activities. One of the key machinery used in offshore fields are the cranes. A downtime of crane or when a maintenance activity is carried out, it affects the day–to–day activity and increases the cost for the company.

The reminder of the report is as follows. In Chapter 4, the Database Design is presented, followed by the User Interface and the Predictive Maintenance Logic in Chapter 5. Chapter 6

provides further possible developments, and finally, the conclusion of the report is presented in Chapter 7. We have attached the requirements document in Appendix A, a snapshot of the menus in Appendix B, and an introduction to Condition and Load Based Maintenance by Molde Engineering in Appendix C.

4. Database Design

46 companies are currently active oil and gas producers on the Norwegian shelf, 27 companies as operators and 19 as partners in production licences (Norwegian Petroleum 2017). The PCM-system is a stand-alone application with a user interface specifically designed for predictive maintenance. PCM is connected to a Crane Database containing data describing each crane, as well as a logged performance data. The database is a standard relational database accessed via structured query language (SQL). The software architecture is illustrated in Figure 2.

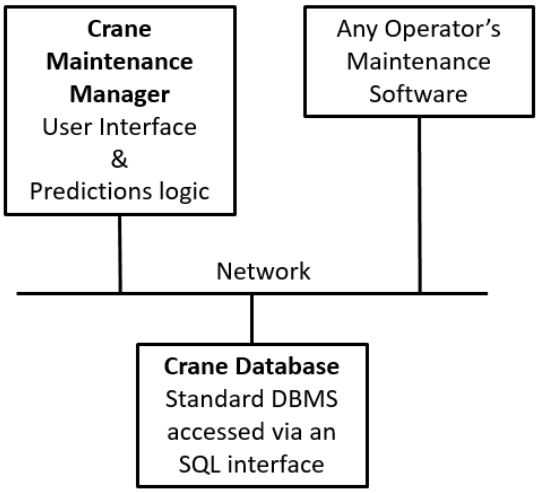

Figure 2: Software Architecture of the Predictive Offshore Crane Maintenance Manager (PCM)

This design allows any operator to connect to the Crane Database to use the data in their own system.

Crane Database Modelling

The Crane Database provides data to the User Interface upon request. Figure 3 shows the Entity-Relationship Diagram of the database.

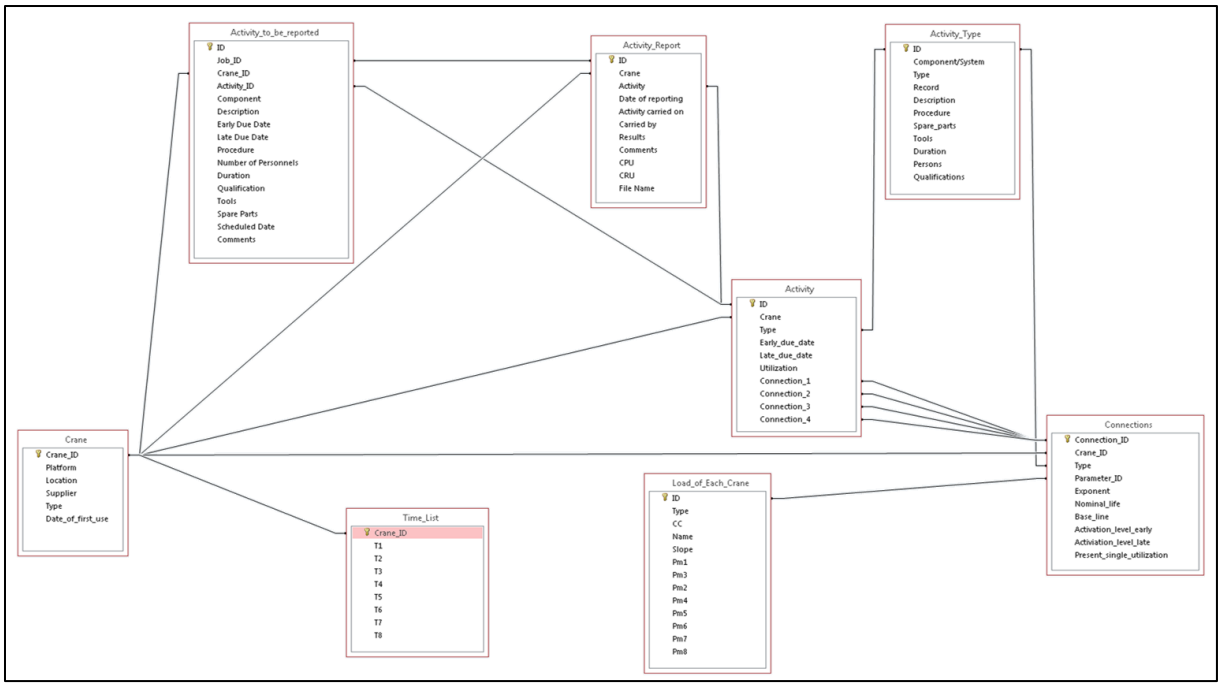

Figure 3. Entity-Relationship diagram for the Crane Database

Each of the 8 entities in Figure 3, i.e. the Activity, Activity-to-be-Reported, Activity-Report, Activity-Type, Crane, Time-List, Load-of-each-Crane, and Connections entities are described by a separate table below.

Table 1: The Activity Entity

Attribute	***Data Type***	***Description***
Activity ID	Number (Primary Key)	ID of the maintenance activity assigned by the organization
Crane ID	Short text	ID of the crane
Activity Type ID	Number	ID of the type of activity
Early Due Date	Date/Time	Early date for starting the maintenance activity
Late Due Date	Date/Time	Last date of stating the maintenance activity
Utilization	Number	Combined utilization of the components that undergoes the maintenance by this activity. The value is between 0 – 100%
Connection 1	Number	ID of the first part / sub – assembly to undergo maintenance by this activity
Connection 2	Number	ID of the second part / sub – assembly to undergo maintenance by this activity
Connection 3	Number	ID of the third part / sub – assembly to undergo maintenance by this activity
Connection 4	Number	ID of the fourth part / sub – assembly to undergo maintenance by this activity

Each Activity is carried out for a certain the sub-assembly of the crane. A crane might use the same sub-assembly type in different locations. For example, a roller bearing could be used in multiple locations, but the maintenance activity follows the same procedure. Therefore, the Activity Entity is defined. It contains attributes describing the sub-assembly for which the activity takes place, the tools required, the duration of the activity, etc.

Table 2: Activity-to-be-Reported

Attribute	***Data Type***	***Description***

Auto ID	Number	Auto ID generated for internal use in the database
Job ID	Number	ID of the job
Crane ID	Short text	ID of the crane
Activity ID	Number	ID of the activity
Component / System	Short text	Name of the component / system involved with the activity
Description	Short text	Description of the activity
Early Due Date	Date/Time	Early date for starting the maintenance activity
Late Due Date	Date/Time	Last date of stating the maintenance activity
Procedure	Short text	Code of the procedure of the activity
Number of Persons	Number	Number of persons required to do this maintenance activity
Duration	Number	Duration for the completion of the maintenance activity
Qualification	Short text	Qualifications of the personnel's doing the maintenance activity
Tools	Short text	Tools to be used in the activity
Spare Parts	Short text	Spare parts used in the activity
Scheduled Date	Date/Time	Scheduled date for the maintenance activity manually assigned
Comments	Long text	Comments provided by the person assigning the job

When the due dates are reached, the maintenance activities job build is to happen, and upon completion, these activities is to be reported. Therefore, two entities with similar fields are created.

Table 3: Activity-Report

Attribute	*Data Type*	*Description*
Auto ID	Number	Auto ID generated for internal use in the database
Crane ID	Short text	ID of the crane
Activity ID	Number	ID of the activity
Date of Reporting	Date/Time	Date of reporting the maintenance activity
Activity Carried On	Date/Time	Date of carrying the maintenance activity
Activity Carried By	Short text	Person carrying the maintenance activity
Results	Ok / Not Ok	Is the overall results ok / not ok?
Comments	Long text	Comments for the maintenance activity
Condition Parameter Update	Yes / No	Is the condition parameter to be updated?
Connection Reset/Update	Yes / No	Is the connection to be updated?
Reference File	Short text	File to be uploaded into the system

After undertaking the maintenance activities, they are to be reported. There are also, several parameters or values to be stored for further analysis of condition of these parts. Therefore, the file has to be stored. In this entity the details of results, comments, reference file, etc. are to be stored.

Table 4: Activity-Type

Attribute	*Data Type*	*Description*
Activity Type ID	Number (Primary Key)	ID of the type of the activity
Component / System	Short text	Name of the component / system involved with the activity
Type	Short text	Type of the activity (ex: repair / measurement)
Record	Short text	Whether to record any details during the performance of the activity
Description	Short text	Description of the activity
Procedure	Short text	Code of the procedure of the activity
Spare Parts	Short text	Spare parts used in the activity
Tools	Short text	Tools to be used in the activity
Duration	Number	Duration for the completing the maintenance activity
Persons	Number	Number of persons required to do this maintenance activity
Qualification	Short text	Qualifications of the personnel's doing the maintenance activity

Each activity is carried out for a certain the sub-assembly of the crane. A crane might use the same sub-assembly type in different locations. For example, a roller bearing could be used in

multiple locations, but the maintenance activity follows the same procedure. Therefore, an Activity Type is defined by this entity. This entity contains attributes describing the sub-assembly for which the activity takes place, the tools required, the duration of the activity, etc.

Table 5: Crane

Attribute	*Data Type*	*Description*
Crane ID	Short text (Primary key)	ID of the crane given by the organization operating the crane
Platform	Short text	Name of the platform where the crane is installed and used
Location	Short text	Location of the crane at the platform
Supplier	Short text	Name of the supplier of the crane
Type	Short text	Type of the crane
Date of first use	Date/Time	Date of first use of the crane

The crane entity attributes describe the characteristics of each crane. An offshore operator typically has several cranes. In the database, is will be represented by a separate row with data for each column.

Table 6: Time-List

Attribute	*Data Type*	*Description*
Crane ID	Short text	ID of the crane
Day 1	Date/Time	Date – 1 of the load parameters recorded into the system
Day 2	Date/Time	Date – 2 of the load parameters recorded into the system
⋮	⋮	⋮
Day n	Date/Time	Date – N of the load parameters recorded into the system

The date and time the crane has been operated is an important detail for making the prediction for when to do maintenance. In this Time-List entity, the Date and Time of crane usage are stored. In this entity, there are two details stored, one is the Crane ID and the other is the date in which the cranes were used.

Table 7: Load-of-each-Crane

Attribute	*Data Type*	*Description*
Parameter ID	Number	ID of the parameter for the crane
Type	Number	Type of the parameter
CC	Number	ID of the component
Name	Short text	Name of the component / system
Slope	Scientific Number	Slope of the load
Load 1	Scientific Number	Load recorded in day – 1
Load 2	Scientific Number	Load recorded in day – 2
⋮	⋮	⋮
Load n	Scientific Number	Load recorded in day – N

A new Entity is defined for each crane for storing load values. The Entity name is a variation of the Crane ID. These values are important data required for predicting the due dates. The load values added are based on crane usage. Both the *Load-of-each-Crane Entity* and *Time-List Entity* are updated simultaneously

Table 8: Connections

Attribute	*Data Type*	*Description*
Connection ID	Number (Primary Key)	ID of the connection / system for a particular crane
Crane ID	Short text	ID of the crane

Type	Short text	Type of the connection
Parameter ID	Number	ID of the parameter of the crane
Exponent	Number	Exponent of the connection
Nominal Life	Scientific Number	Nominal life of the connection
Baseline	Scientific Number	Baseline of the connection
Early Activation Level	Number	Early level of the activation (value required for calculating the early due date)
Late Activation Level	Number	Late level of the activation (value required for calculating the late due date)
Present Single Utilization	Number	Present utilization of the connection (value is between 0 – 100%)

Each maintenance activity is connected to certain parts (connection points). The key factor for predicting the due date for a maintenance activity is the load experienced by a connection point. The information provided includes the load parameter, the nominal life of the component, and the activation level for the maintenance activity. Several other data are also provided.

5. User Interface and Predictive Maintenance Logic

We present the user interface and the basic operations. The PCM starts with two options for the user: *Maintenance planning* and *Adding of a new crane to the database*. In this demo version, adding of the crane is inactive. Figure 4 shows a snapshot of the start menu.

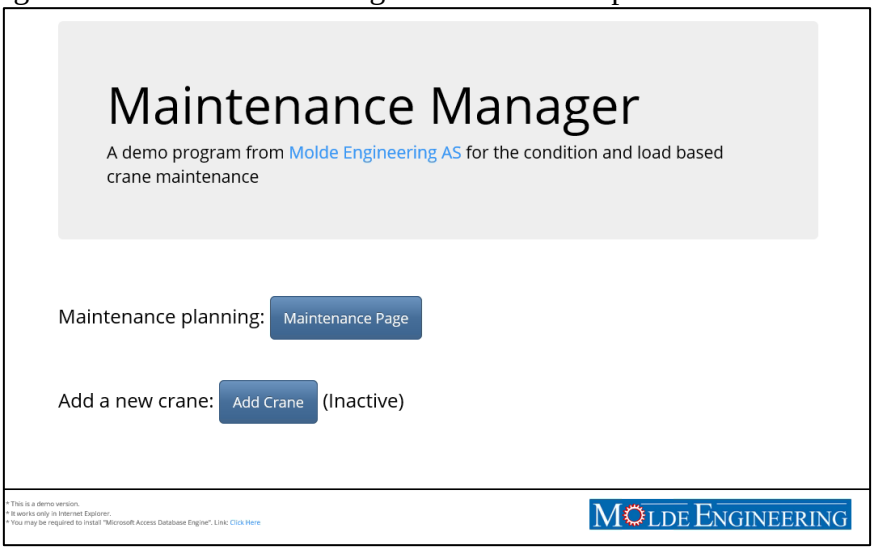

Figure 4: PCM start menu

There are many functions available via several windows. We discuss the functions for each window. The overall interactions for these pages is shown in Figure 5.

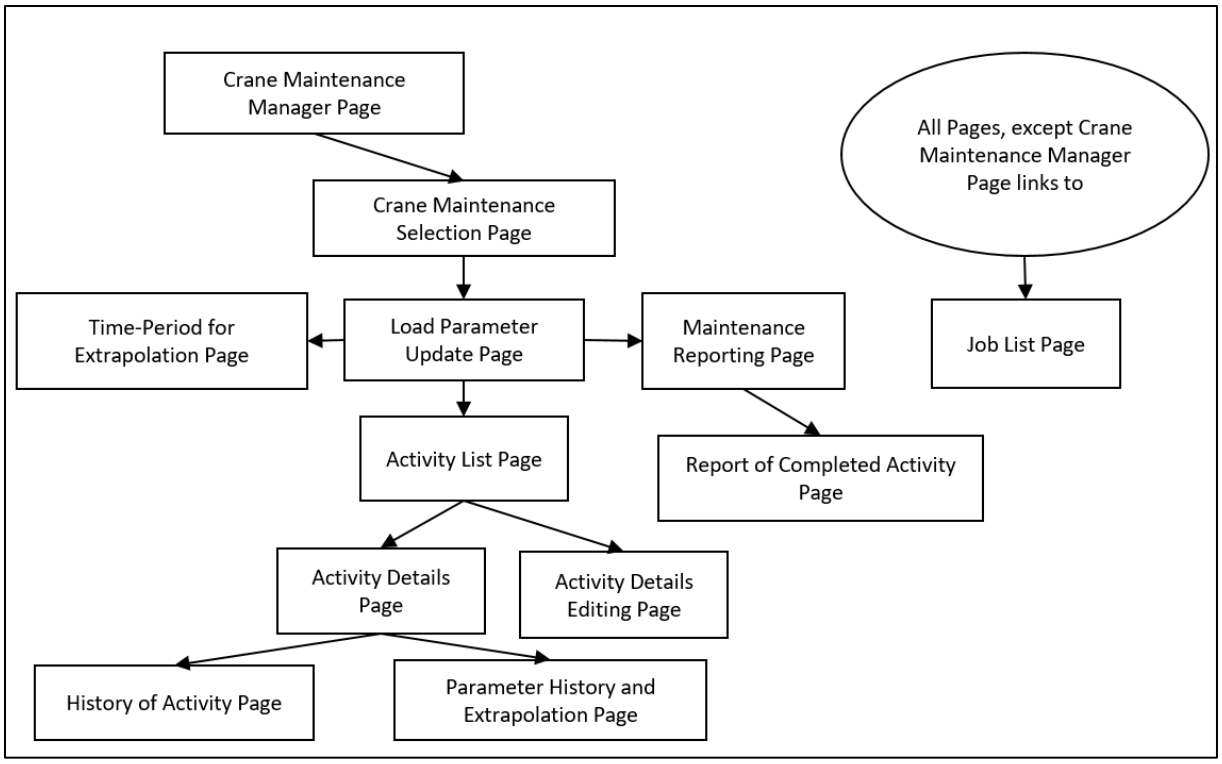

Figure 5: PCM start menu

Here all these pages have a back button to go the previous page. To make it simple, only one-sided interaction is shown in the figure. In all the pages with an exception to the Maintenance Manager page, we can navigate to the job list page. This is similar to the cart function used in online stores web pages. Now we will see the details and functions of each of these pages and their snapshots are attached in Appendix B.

Crane Initialization

Currently, master data for 10 cranes are manually inserted into the database using the MS Access interface. In future versions, data for new cranes can be inserted either via new user interface menus, or by new import-functions to load data from various external systems.

Crane Maintenance Selection Page

The first step for maintenance planning is to select a crane. Upon selecting a crane id, details of the crane selected are shown in the same window, i.e. the *Crane Maintenance Selection Page*. Here, we can proceed to either the *Load Parameter Update Page*, or we can go back to the *Crane Maintenance Manager Page*.

Load Parameter Update Page

In this page, we can select:

1. Update the load values for the crane and the date at which these loads occurred. This value is obtained from the text file created from OCAAD (FORTRAN crane analysis/calculation program that performs technical crane calculations).
2. The second function is to start the calculation of the due dates by extrapolation. For this, the Maintenance Manager navigates to Time-Period for Extrapolation Page.
3. The third function is to go forward with activity selection. For this, the Maintenance Manager navigates to Activity List Page.

4. The fourth function is to go forward with maintenance reporting for the crane. For this, the Maintenance Manager navigates to Maintenance Reporting Page.

Time-Period for Extrapolation Page

With the current utilization levels, it is possible to extrapolate when will it reach the activation level for doing the maintenance activity. Here, there is option for selecting the period that represents the usual work load patterns. By default, the program provides the first and last date available in the database. The calculation is run in the background and then automatically navigates to the load parameter update page.

Activity List Page

In this page, we have the option for presenting the all maintenance activities list for the cranes. The program offers to set a cut-off date and then present the maintenance activities which fall on or before this date. This helps the companies to plan and perform the maintenance activities. Here there is option to add the available maintenance activity in the job cart or delete the already added maintenance activity from the job cart. Apart from this, there are two options of which one is to display the detail of the maintenance activity and the other is to edit this maintenance activity.

Activity Details Page

In this page, the details of the activity and the information about the connections are presented. There are two options available in the page one for providing the history of the activity and load parameter history and the extrapolated information for this activity.

Parameter History and Extrapolation Page

In this page, the details of the parameter and the extrapolated information is provided. The graph for each parameter connected to an activity with the current load experienced and the extrapolated information on the due date is provided. Apart from this, a special graph for single and double parameter activities is displayed.

Activity Details Editing Page

In this page, the details of the selected activity are displayed. Including this, the option for editing certain details of the activity is available. The changes made here are updated in the crane database.

Job List Page

In this page, the list of jobs added in the job cart are displayed. Along with this, the planned date for undertaking the maintenance activity and any additional information required for it is provided and updated in the database. Along with this, the print option is also provided.

Maintenance Reporting Page

In this page, the maintenance activity list which are to be reported are displayed. In this list, the maintenance activity for the selected crane is only displayed. Here, the option for selecting the maintenance activity and navigates to report of completed activity page.

Report of Completed Activity Page

In this page, the form for reporting the selected activity is provided. In this form, certain activities are mandatory and an option for uploading a report file for the maintenance activity is available.

History of Activity Page

In this page, the history of the maintenance activity is provided. This helps to understand the performance of the component/system and improve the prediction of the maintenance activity. These options are only part of the demo version and in the subsequent section, we have discussed the possible developments of the Maintenance Manager.

6. Further Development

Below of the list of possible further developments, that are to be made for the Maintenance Manager.

- In the present version, adding of new crane is done manually in the database. Instead of this, in the upcoming versions, this feature will be automated.
- The Maintenance Manager is not connected to the any main database of any company. This could be developed in accordance with companies.
- The cranes are located offshore, so connecting to the weather data will help in figuring the right time planning for the maintenance activity.

Currently, the focus is given only to cranes. The future research possibility is to develop the system for the other machineries

7. Conclusion

We have presented the Predictive Offshore Crane Maintenance Manager (PCM) for improving the offshore crane maintenance. Information of the demonstrator and the database were presented as well as possible further developments.

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Appendix A: Requirements Document from Molde Engineering AS

CONDITION AND LOAD BASED MAINTENANCE

MAINTENANCE PROGRAM

MAINTENANCE MANAGER

1 GENERAL PROCEDURE FOR LOAD BASED MAINTENANCE

The following procedure is carried out periodically. The period should depend on how much the crane is used but may be 2-12 months.

1) Download logged crane movement data from the crane control system.

2) Convert the downloaded data to a standard format readable by OCAAD.

3) Generate a complete crane movement history by using the logged data and supplement with probable data if data is missing.

4) Calculate the resulting accumulated load increment for all load parameters.

5) Calculate/update the due date for all maintenance activities based on the latest load parameter values.

6) Maintenance planning by aggregating activities into maintenance jobs based on the calculated due dates.

7) Report results of maintenance activities carried out.

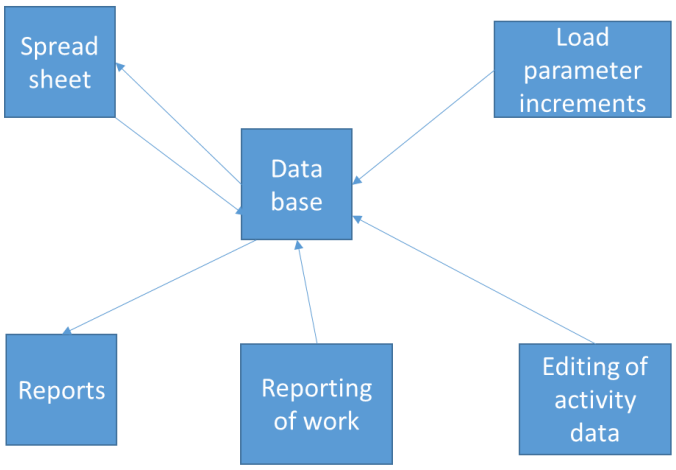
Two main software programs will be involved, *OCCAD* and *Maintenance Manager*.

OCAAD is a Fortran crane analysis/calculation program that performs technical crane calculations. Item 3) and 4) will be performed by this system. The resulting load parameter increments for the last period will be written to a standard file in text format.

Maintenance Manager will take care of item 5), 6) and 7).

In addition, a small ad hoc program will be needed for item 2). The data logging system will in principle be different for each crane and the conversion program has to be tailormade in each case.

2 *MAINTENANCE MANAGER* PROGRAM



Spreadsheets are used for setting up information on cranes, maintenance activities etc. to the data base.

Load parameter increments is a text file created by OCAAD with a list of the load increments for all load parameters for the last period.

Reports are lists and other information required by the user.

3 *MAINTENANCE MANAGER* DATA STRUCTURE

The following description is not necessarily correct in all details but may serve as a first approximation.

The program will handle maintenance of a number of cranes. A crane will be an entity with a number of attributes (items of information).

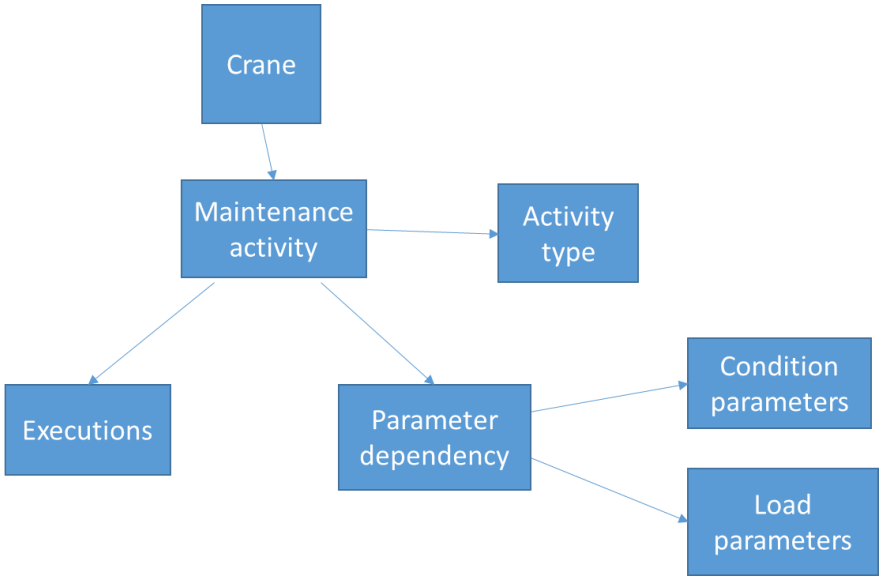
For each crane there will be a maintenance program, consisting of a number of maintenance activities. Each activity will be of a certain activity type. An activity is always connected to a specific crane. Activity type may be common to many activities and many cranes.

Activity type is an entity with a set of attributes. Activity is a different entity with a set of attributes.

For each crane there will be a set of load parameters. These are parameters that are calculated periodically from recorded information on the use of the crane. This calculation is not part of this program and is assumed to be made available by a different system. A load parameter is an entity with a set of attributes, consisting of a series of dates and parameter values.

For each crane there will be a set of condition parameters. These are parameters that can be measured or observed periodically. A condition parameter is an entity with a set of attributes, consisting of a series of dates and parameter values.

Each maintenance activity will be connected to one or several load parameters or condition parameters. The due date for the activity will be calculated from the parameter values in a certain way. A connection is an entity with a set of parameters.



Crane.
A number of cranes are included in the maintenance portfolio, typically 5-10.

Maintenance activity.
A single maintenance activity on one specific crane. Each crane will have a number of activities. Each activity is always associated with one crane only.

Activity type.
A maintenance activity is always of a specific type. Many activities will have the same type.

Load parameters.
Accumulated loads that causes the component to deteriorate and eventually fail.

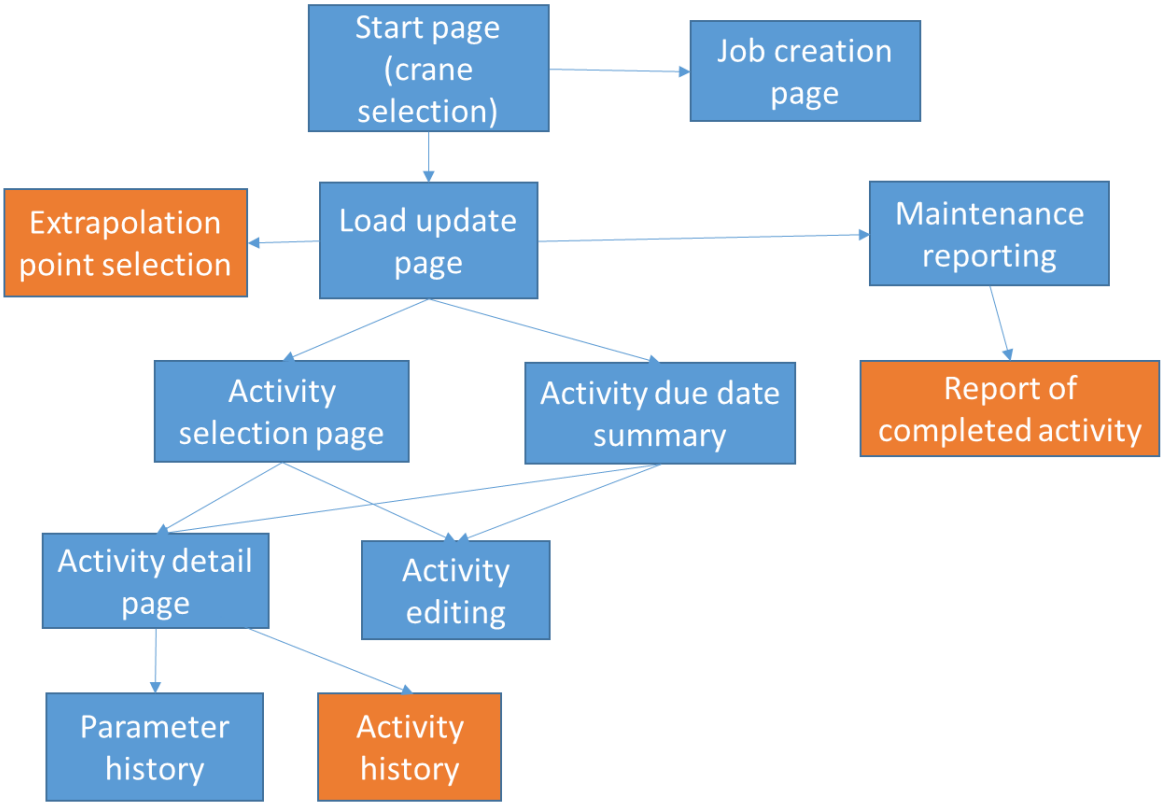
Condition parameters.
A quantification of the degree of deterioration of a component.

Parameter dependencies (connections.)
A maintenance activity is dependent of (connected to) one or more load parameters or condition parameters. The load parameters quantify the loads that may cause deterioration of the component and the condition parameters indicate the degree of deterioration. The parameter dependency contain information on how the expected life of the component depends on loads and conditions.

4 ESSENTIAL FUNCTIONALITY OF *MAINTENANCE MANAGER*

1) Upload data in spreadsheet Maintenance Manager input data to the data base.
2) Download data from the data base to the spreadsheet Maintenance Manager input data.
3) Read a set of load parameter increments from text file Loadupdate.txt.
4) Calculate new due dates for all maintenance activities based on the latest load parameter values.
5) List all maintenance activities with due date in a specified time window, sorted on due date.
6) Create a maintenance job by selecting a set of activities from the activity list.
7) Display information on a single maintenance activity.
8) Edit/modify a maintenance activity.
9) Report results from an executed maintenance activity into the data base.

5 USER INTERFACE STRUCTURE



6 USER INTERFACE, MENUS

START PAGE / CRANE SELECTION PAGE

- ☐ GFA-1 North
- ☐ GFA-2 South
- ☐ GFA-3 East
- ☐ GFA-4 West
- ☐ GFB-1 West

- ☐ Go to the job creation page
- ☐ Proceed with selected crane
- ☐ Termination

LOAD UPDATE PAGE

- ☐ Import maintenance program from spreadsheet
- ☐ Import load parameter increments
- ☐ Go to extrapolation point selection page
- ☐ Go to due date summary page
- ☐ Go to activity selection page
- ☐ Start a new maintenance job
- ☐ Go to maintenance reporting page

- Execute
- Back to start page

EXTRAPOLATION POINT SELECTION

Present list of all previous periods/updates.

Select two updates (points in time) that will used for calculation of the slope of the parameter curves.

- Calculate slopes and update all due dates

MAINTENANCE DUE DATE SUMMARY PAGE

Select time window: 01.11.2018

- Select and present list

Select	ID	Component/system	Description	Early due date	Late due date
	1	Slew bearing	Lubrication of roller bearing	20.02.2018	03.11.2018
	2	Slew bearing	Grease sampling from roller bearing	20.02.2018	03.11.2018
	3	Slew bearing	Rocking test	20.02.2018	03.11.2018
	4	Slew bearing	US examination of retaining ring	20.02.2018	03.11.2018
	5	Slew bearing bolts	Bolt knocking test	20.02.2018	03.11.2018
	6	Slew bearing bolts	Bolt prestress measurements	20.02.2018	03.11.2018
	7	Slew bearing bolts	Bolt re-tensioning	20.02.2018	03.11.2018
	8	Slew bearing gear	Lubrication of gear race	20.02.2018	03.11.2018
	9	Slew bearing gear	Measurement of backlash	20.02.2018	03.11.2018

- Add the selected activities to the maintenance job
- Delete the selected activities from the maintenance job
- Show details of the selected activity
- Edit the selected activity
- Report completed maintenance for the selected activity

- Execute
- Back to update page

ACTIVITY SELECTION PAGE

Select time window: 01.11.2018

- Select and present list

Select	ID	Component/system	Description	Early due date	Late due date
	1	Slew bearing	Lubrication of roller bearing	20.02.2018	03.11.2018
	2	Slew bearing	Grease sampling from roller bearing	20.02.2018	03.11.2018
	3	Slew bearing	Rocking test	20.02.2018	03.11.2018
	4	Slew bearing	US examination of retaining ring	20.02.2018	03.11.2018
	5	Slew bearing bolts	Bolt knocking test	20.02.2018	03.11.2018
	6	Slew bearing bolts	Bolt prestress measurements	20.02.2018	03.11.2018
	7	Slew bearing bolts	Bolt re-tensioning	20.02.2018	03.11.2018
	8	Slew bearing gear	Lubrication of gear race	20.02.2018	03.11.2018
	9	Slew bearing gear	Measurement of backlash	20.02.2018	03.11.2018

- Add the selected activities to the maintenance job
- Delete the selected activities from the maintenance job
- Show details of the selected activity
- Edit the selected activity
- Report completed maintenance for the selected activity

- Execute
- Back to update page

MAINTENANCE ACTIVITY DETAIL PAGE

Activity ID: 12
Crane: GFB-4
Component/system: Slew bearing
Description: Grease sampling
Procedure: 12.2
Spare parts: None
Tools: Grease sampling tool set
Duration: 0,5

Personnel: 1
Qualification: M2
Early due date: 12.05.18
Late due date: 24.08.18

Connections:

Connection ID	4	5	
Parameter ID	L3	L5	
Name	Boom chords, lower	Boom chords, lower	
CC	3	5	
Exponent	1.00	1.00	
Nominal life	1.234E5	1.234E5	
Early activation	0.20	0.20	
Late activation	0.25	0.25	
Single utilization	0.002	0.007	
Combined utilization	0.023	0.023	

- Show parameter history data
- Back to activity selection page

PARAMETER HISTORY DATA

Graphical presentation of parameter history.

- Back to maintenance activity detail page

ACTIVITY HISTORY PAGE

A list of all completed executions of the selected activity is presented, including results, comments etc.

MAINTENANCE REPORTING

Present list of all activities in the present job for the selected crane.

Select an activity on the list and go to the report of completed activity page.

REPORT OF COMPLETED ACTIVITY

Date	20.12.2016
Carried out by	Nils
Results	OK
Comments	Looks good
Condition parameter update	Yes
Connection reset/update	Yes

Reference to spreadsheet containing the condition parameter values.

- ☐ Execute
- ☐ Back to maintenance reporting page

Comment on condition parameters:

There will be condition parameters, that in principle should be treated in exactly the same way as load parameters. However different parameters will be of different nature. Some will be a single value and some will consist of a large set of different values. In the cases with many values these should be translated into a single or a few values for entry into the data base table of conditions. The details of this are not clear at the moment. The temporary solution is to assume that condition parameters are stored on spreadsheets, one file for each crane, one page for each condition.

ACTIVITY EDIT PAGE

Activity ID:	12
Crane:	GFB-4
Component/system:	Slew bearing
Description:	Grease sampling
Procedure:	12.2
Spare parts:	None
Tools:	Grease sampling tool set
Duration:	0,5
Personnel:	1
Qualification:	M2
Early due date:	12.05.18
Late due date:	24.08.18

Connections:

Connection ID	4	5	
Parameter ID	L3	L5	
Name	Boom chords, lower	Boom chords, lower	
CC	3	5	
Exponent	1.00	1.00	
Nominal life	1.234E5	1.234E5	

Early activation	0.20	0.20	
Late activation	0.25	0.25	
Single utilization	0.002	0.007	
Combined utilization	0.023	0.023	

- Change the activity data as indicated
- Back to activity selection page

JOB CREATION PAGE

Selected activities in the maintenance job

ID	Component/system	Description	Early due date	Late due date
1	Slew bearing	Lubrication of roller bearing	20.02.2018	03.11.2018
2	Slew bearing	Grease sampling from roller bearing	20.02.2018	03.11.2018
3	Slew bearing	Rocking test	20.02.2018	03.11.2018
4	Slew bearing	US examination of retaining ring	20.02.2018	03.11.2018
5	Slew bearing bolts	Bolt knocking test	20.02.2018	03.11.2018
6	Slew bearing bolts	Bolt prestress measurements	20.02.2018	03.11.2018
7	Slew bearing bolts	Bolt re-tensioning	20.02.2018	03.11.2018
8	Slew bearing gear	Lubrication of gear race	20.02.2018	03.11.2018
9	Slew bearing gear	Measurement of backlash	20.02.2018	03.11.2018

Summary of number of persons, time consumption, necessary qualifications, tools and spare parts necessary for the job. This information is taken from the data base.

Add scheduled date and other information.

- Print complete job information
- Back to start

7 TERMS AND DEFINITIONS

OCAAD
A program (Fortran) that calculates geometry, loads, stresses etc. for an offshore crane.

Maintenance Manager
A program for managing and planning maintenance activities on offshore cranes.

Maintenance activity (or just activity)
An activity carried out on the crane offshore in order to ensure that the crane is safe and reliable.

Activity due date
The point in time when a maintenance activity should be carried out, based on the usage of the crane and the condition of the crane. A certain tolerance is applied, resulting in an early due date and a late due date.

Activation level
The amount of accumulated load on a component or amount of deterioration of a component that is allowed before a compensating maintenance activity should be carried out.

Maintenance job
A set of maintenance activities that are carried out at the same time and by the same personnel, due to practical reasons considering type work and due dates.

Condition
Quantifiable state of deterioration. Wear is one type of deterioration.

Condition parameter
A measurable or observable parameter that indicates the state of deterioration of a component.

Load parameter (check point)
Accumulated loads that causes the deterioration of a component. The load parameter is in many cases a composite of several factors involved. Load parameters are equivalent to **check points** used in load chart calculations.

Load parameter increment
Accumulated loads are calculated periodically. Load parameter increments are the accumulated loads for each or the latest period.

Parameter dependency
The connection (dependency) between a maintenance activity for a component and the load parameters or condition parameters that are involved in the deterioration of the component.

8 CALCULATION OF UTILIZATION AND DUE DATES

NOTATIONS

P = Load parameter value at any time T, the total accumulated value of the parameter from the crane was new until the time T.

T = Time in number of days since the crane was taken into use. T can be converted into a date or vice versa.

P(m,n) = Accumulated load parameter values for each time period (sum for all periods)
m = parameter number
n=time period number
A set of load increment for the last period is imported from the text file created by OCAAD for each period. These are added to the P-values for the previous period to get the P-values for the last period.

T(n) = Time at the end of each time period, in days from the crane was taken into use. The date at the end of each period is imported from the text file created by OCAAD for each period and converted into days.

P_b = Base line value (the P-value when the component was new). When the crane is taken into use all base line values are set to zero. If a component is replaced by a new component the base line value is reset to zero. The base line value is specific for each dependency (connection) and is specified in the connections table.

P_n = Nominal component life, in terms of loads defined by a load parameter. The nominal life is specific for each connection and is specified in the connections table.

CALCULATION OF PARAMETER VALUES BY EXTRAPOLATION

Parameter value P at a time T in the future can be calculated by extrapolation from the last recorded P value:

$P = P(m,n) + S(m)\,(T - T(n))$
P(m,n) = Parameter value at the last updating
S(m) = Slope of the linear curve
T(n) = Time at the last updating

The slope should be calculated for each parameter after each updating and listed in the parameter tables.

There should be two ways of calculating the slope, selectable by the user. The selected method should be used for all parameters.

First method (default method):
The slope is determined by linear regression taking into account all data points (all update values for the parameter).

Second method:
The slope is calculated as the slope between two selectable data points. The points may be selected by clicking on the points on the page with the parameter value history graph.

$$S(m) = (P(m,n2) - P(m,n1)) \ / \ (T(n2) – T(n1))$$

UTILIZATION

Utilization U is a measure of how much of the nominal life is used at a point in time. For a single connection, or for each of multiple connections, utilization is defined as:

$$U = (P-P_b) / P_n$$

Total (combined) utilization at multiple connections is defined as:

$$U_{comb} = [(U_3/U_{3early})^{e3} + ((P_2-P_{b2}) / P_{n2})^{e2} + \ ...]^{(k/(e1+e2+ ...))}$$

k=number of connections

ACTIVATION LEVEL

A maintenance activity is activated (assigned a due date) when the utilization reaches a specified level, which is called activation level. For practical reasons two levels are defined, for an early and a late activation.

U_{early} = Early activation level for a maintenance activity, in terms of utilization.
U_{late} = Late activation level for a maintenance activity, in terms of utilization.

Each maintenance activity is activated when the utilization has reached the activation level. Activation level is specific for each connection and is specified in the connection table. Early and late activation results in an early and a late due date and a time window in which the maintenance activity has to be carried out.

DUE DATES

Single connection:

In the case the maintenance activity is connected to a single parameter (load parameter or condition parameter). The early and late due dates are the dates when the following conditions are fulfilled:

$$U / U_{early} = 1.0$$
$$U / U_{late} = 1.0$$

The due dates can be calculated directly as:

$$T_{early} = T(n) + (U_{early}\, P_n + P_b) / (P(m,n)\, S(m))$$
$$T_{late} = T(n) + (U_{late}\, P_n + P_b) / (P(m,n)\, S(m))$$

Multiple connections:

In this case the maintenance activity is connected to more than one parameter. Due dates for each parameter can be calculated as in the single connection case, but these will not be the real due dates. The real early and late due dates, taking all connections into account, are the dates when the following conditions are fulfilled:

$$(U_1/U_{1early})^{e1}+(U_2/U_{2early})^{e2}+ (U_3/U_{3early})^{e3}+ \ldots = 1.0$$
$$(U_1/U_{1late})^{e1}+(U_2/U_{2late})^{e2}+ (U_3/U_{3late})^{e3}+ \ldots = 1.0$$

e = Exponent, connection specific, specified in the connection table
1 denotes the first connection, 2 denotes the second etc.

In this case the due date cannot be calculated directly but has to be determined by iteration by the following procedure:

- Assume a date.
- Calculate the parameter values for the assumed date.
- Calculate the utilization for these parameter values.
- Calculate the value of the expression above.
- Assume a new date, earlier if the expression value is more than 1.0, later if the value is less than 1.0.

The bisection method can be used (safe and simple), starting with the present date as the lower limit and the latest single connection due date as the upper limit.

Appendix B: Snapshot of the Maintenance Manager Pages

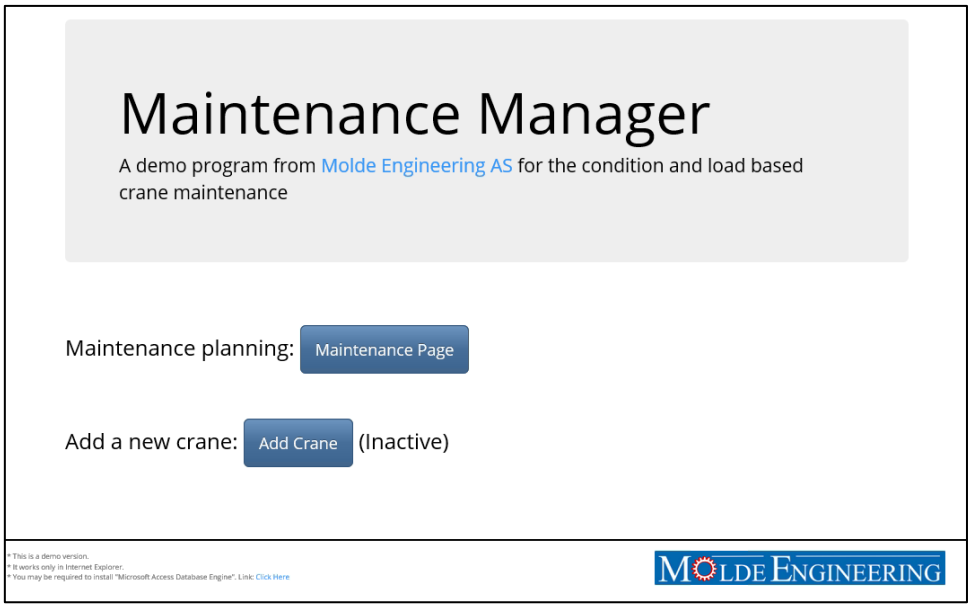


Figure 2: Maintenance Manager Page

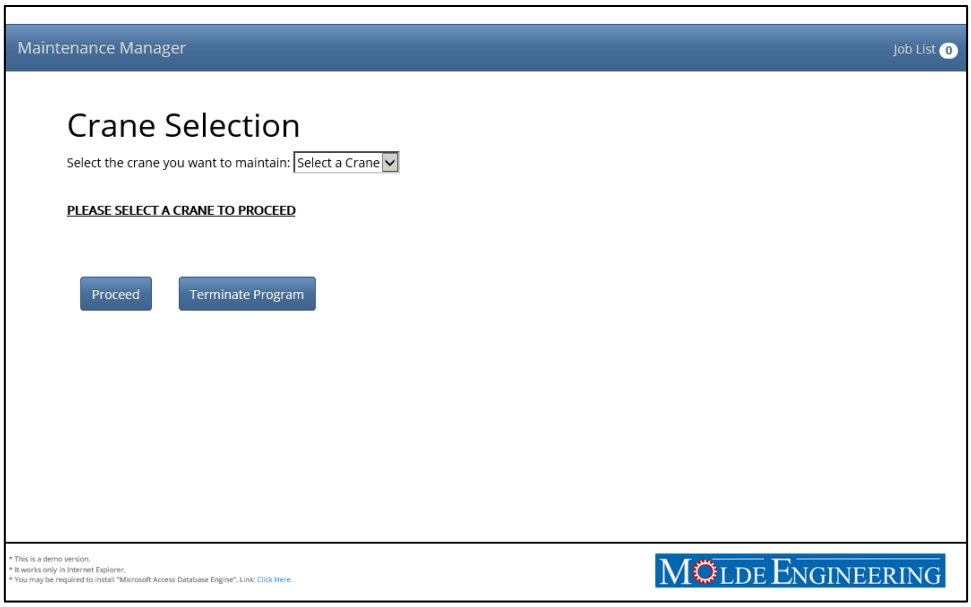


Figure 3: Snapshot of Crane Selection page

Figure 4: Snapshot of Crane Selection page with a selected crane

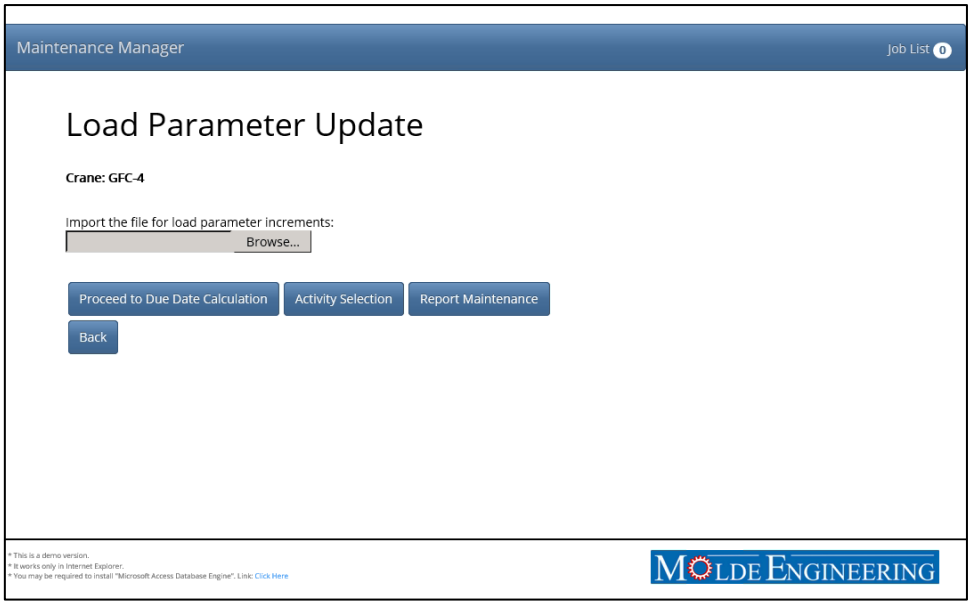


Figure 5: Snapshot of Load Parameter Update Page

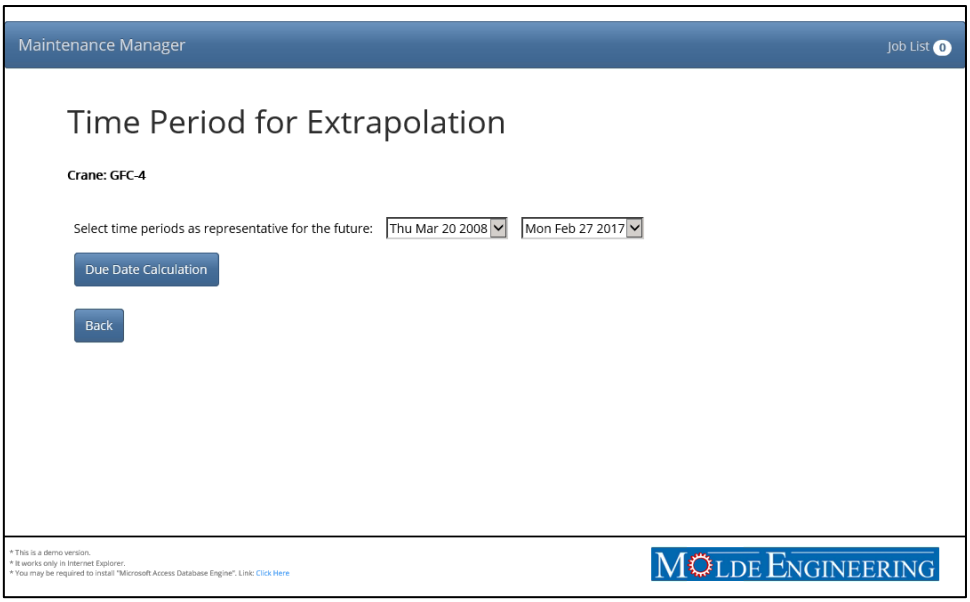


Figure 6: Snapshot of Time-Period for Extrapolation Page

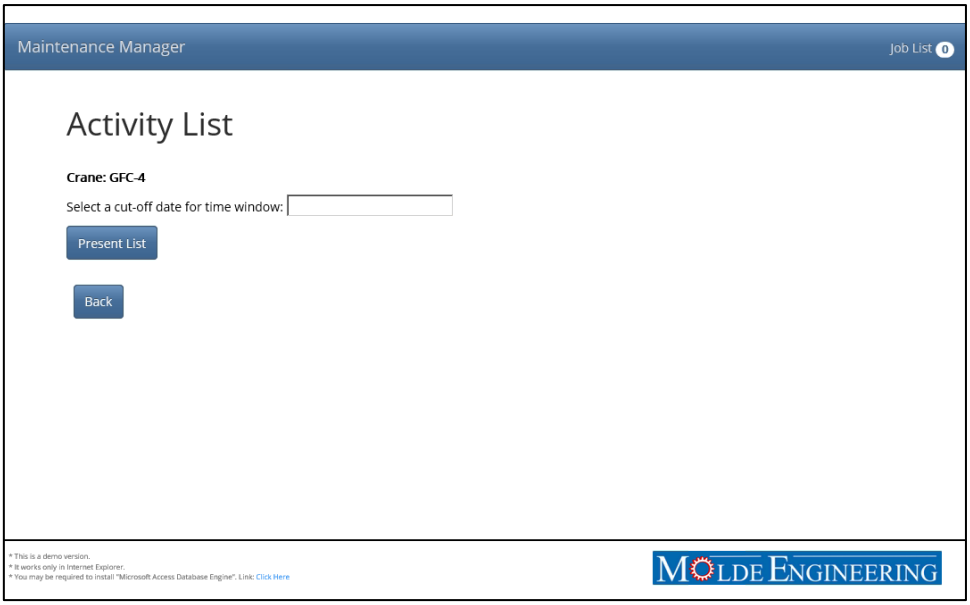


Figure 7: Snapshot of Activity List Page

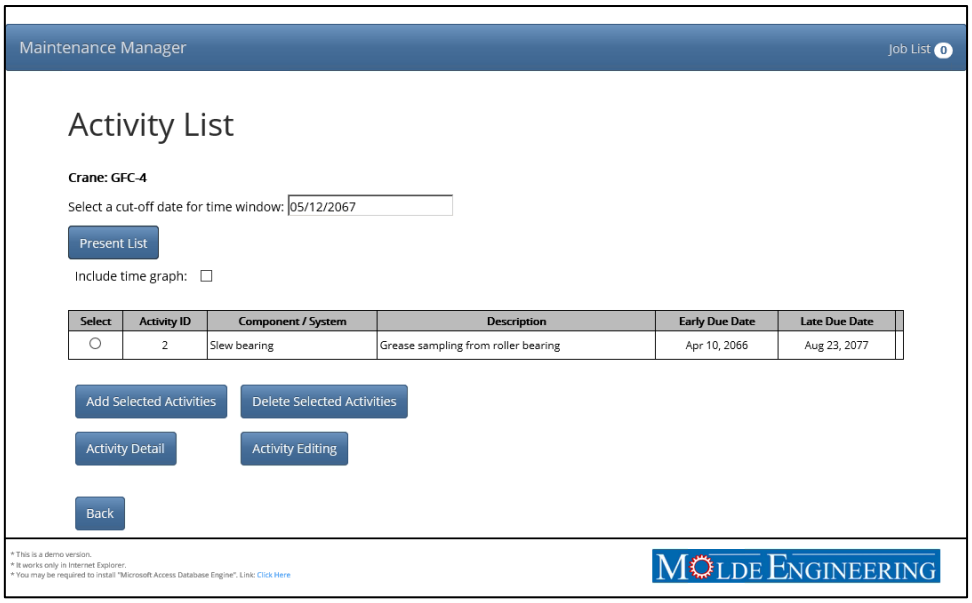


Figure 8: Snapshot of Activity List Page with the one activity

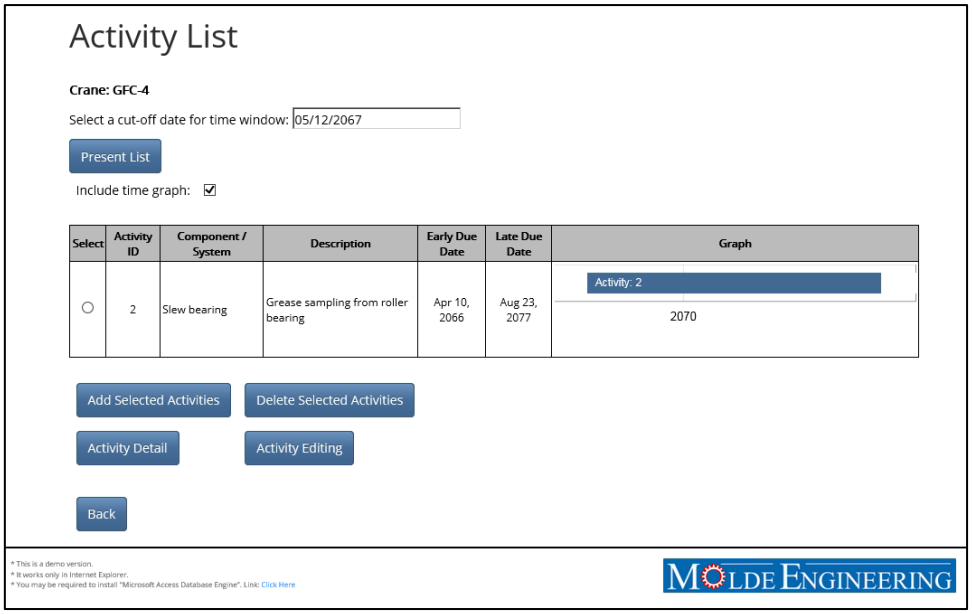


Figure 9: Snapshot of Activity List Page with the activity and time graph

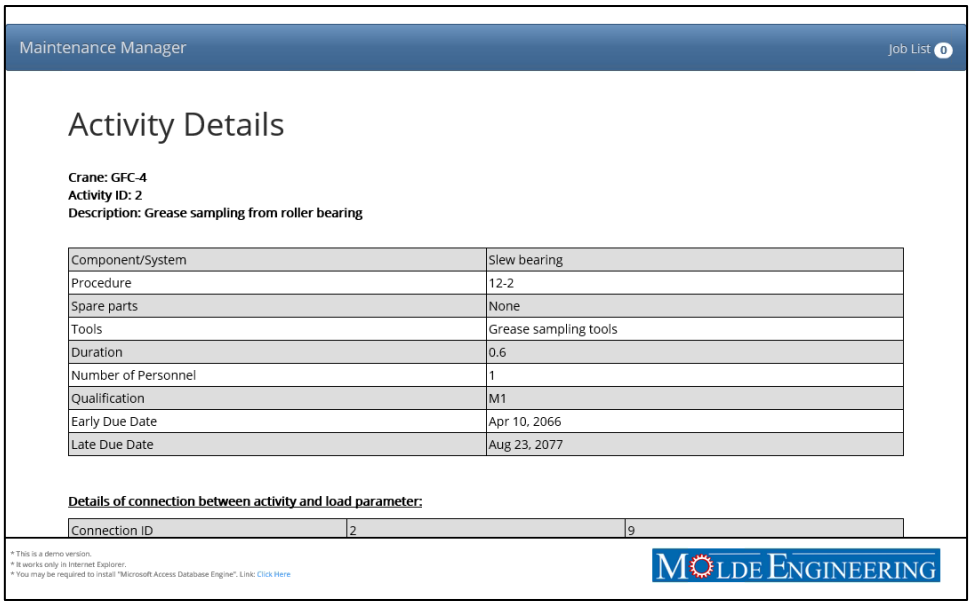


Figure 10: Snapshot of Activity Details Page – 1

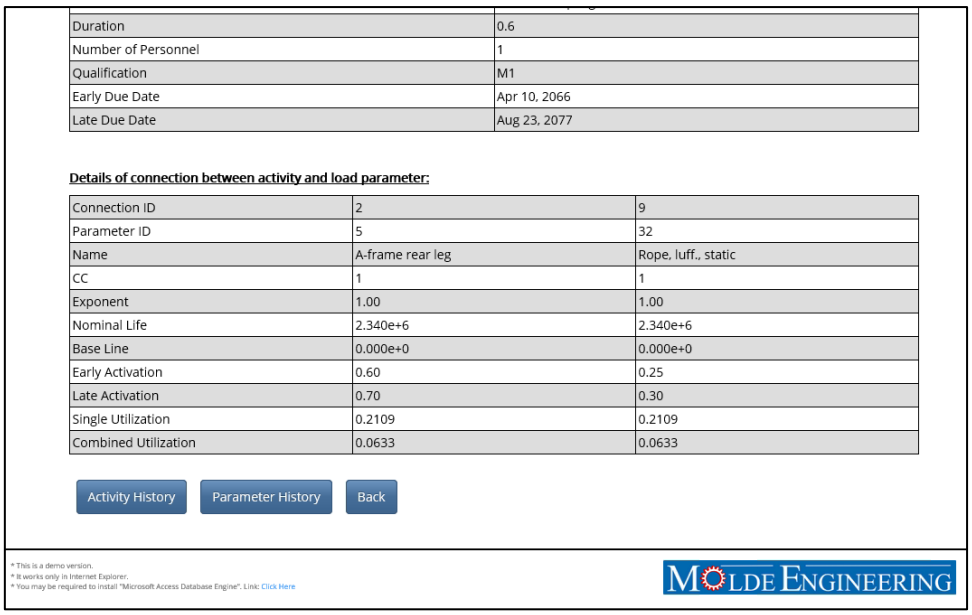


Figure 11: Snapshot of Activity Details Page – 2

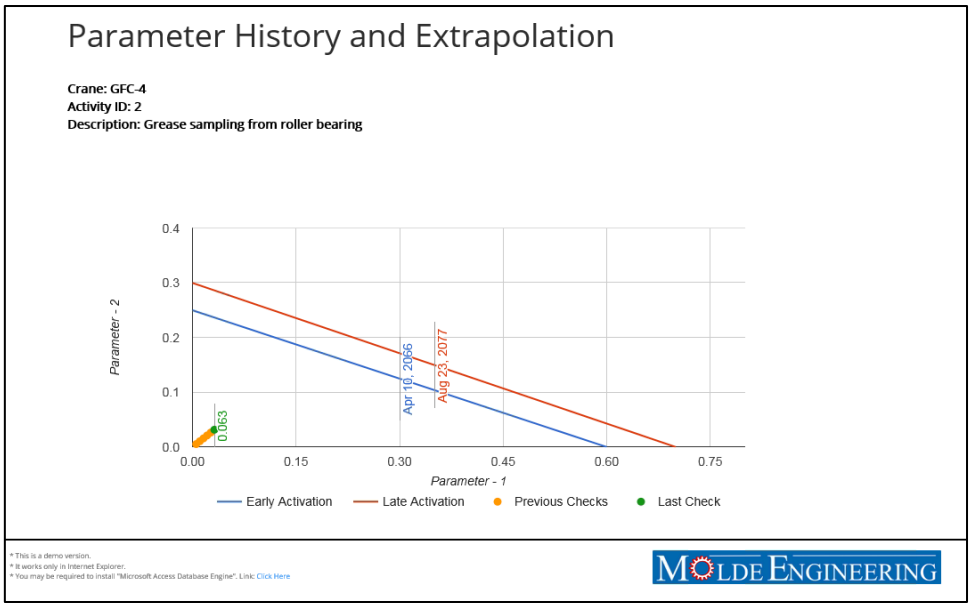


Figure 12: Snapshot of Parameter History and Extrapolation Page – 1

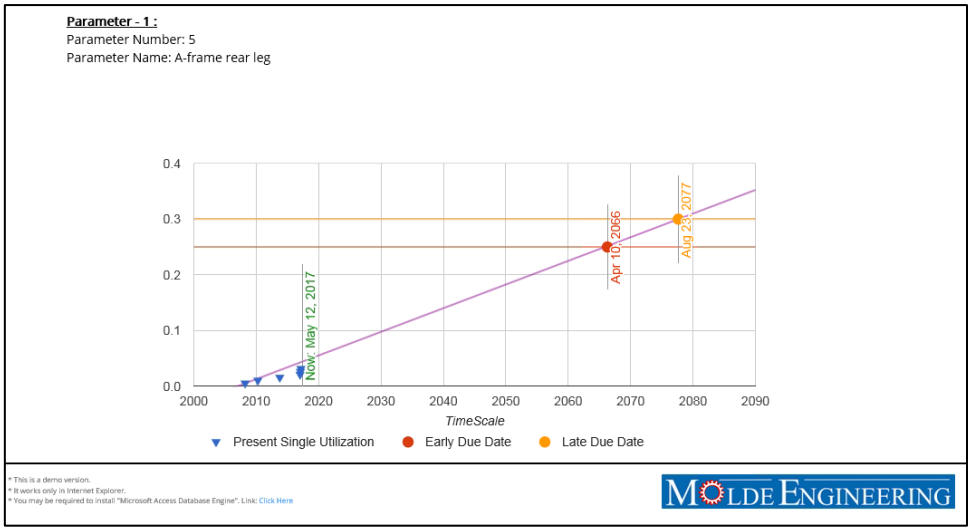


Figure 13: Snapshot of Parameter History and Extrapolation Page – 2

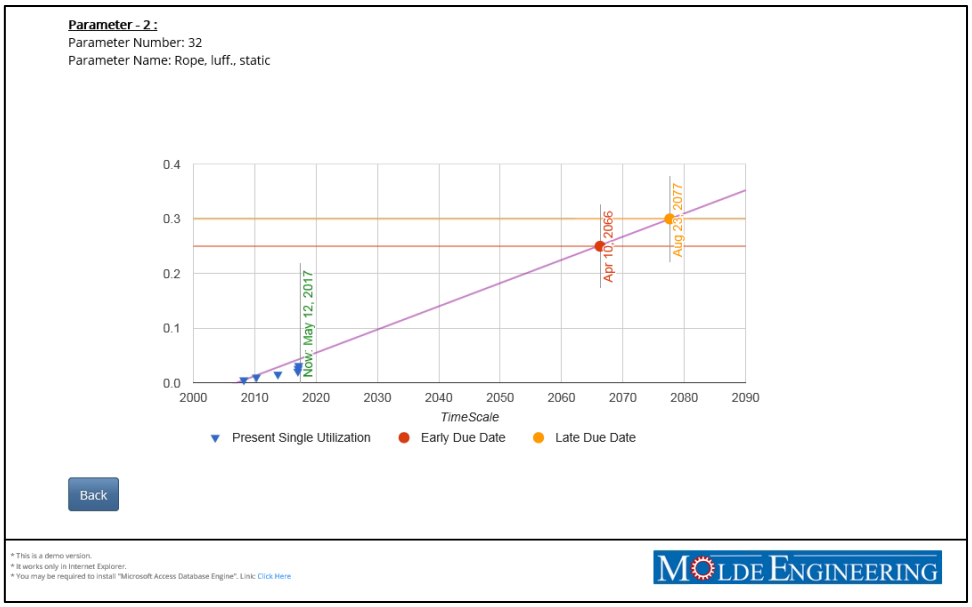


Figure 14: Snapshot of Parameter History and Extrapolation Page – 3

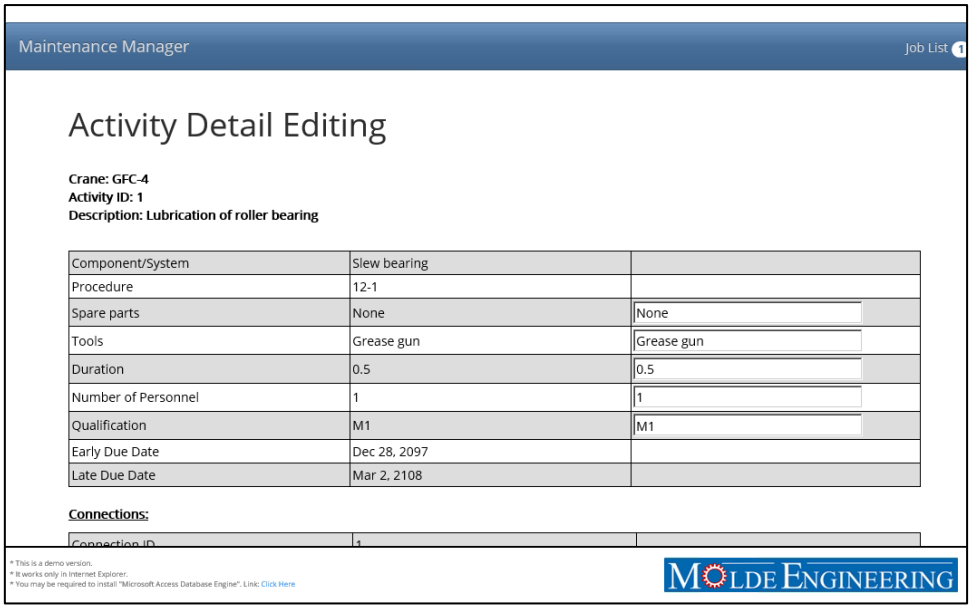
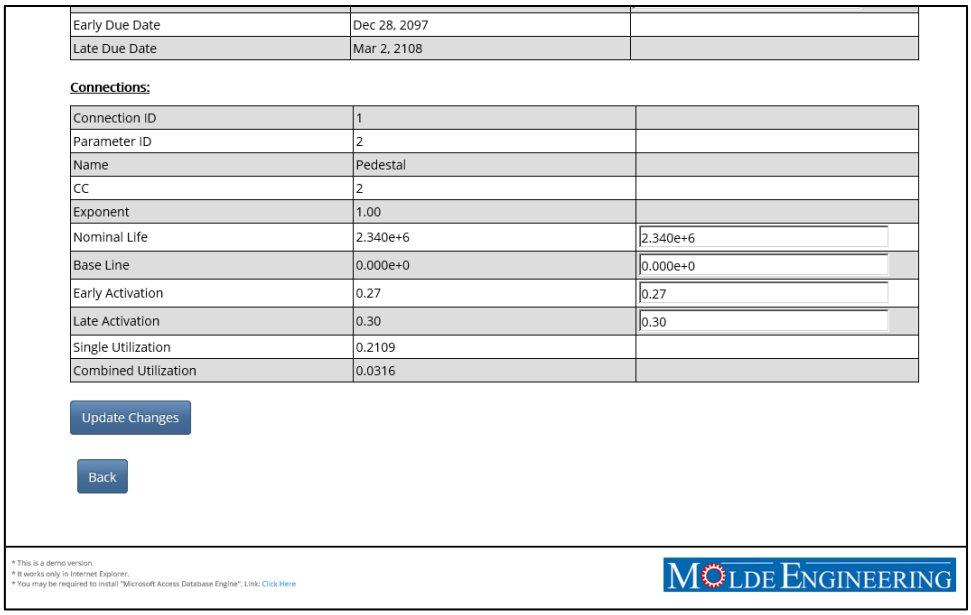


Figure 15: Snapshot of Activity Details Editing Page – 1

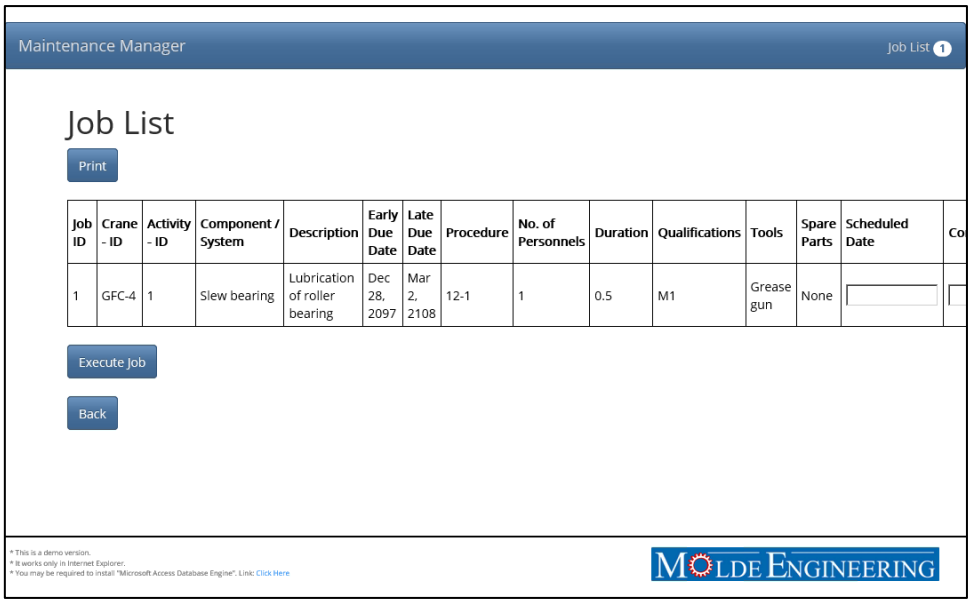


Early Due Date	Dec 28, 2097	
Late Due Date	Mar 2, 2108	

Connections:

Connection ID	1	
Parameter ID	2	
Name	Pedestal	
CC	2	
Exponent	1.00	
Nominal Life	2.340e+6	2.340e+6
Base Line	0.000e+0	0.000e+0
Early Activation	0.27	0.27
Late Activation	0.30	0.30
Single Utilization	0.2109	
Combined Utilization	0.0316	

Figure 16: Snapshot of Activity Details Editing Page – 2



Job ID	Crane - ID	Activity - ID	Component / System	Description	Early Due Date	Late Due Date	Procedure	No. of Personnels	Duration	Qualifications	Tools	Spare Parts	Scheduled Date	Co
1	GFC-4	1	Slew bearing	Lubrication of roller bearing	Dec 28, 2097	Mar 2, 2108	12-1	1	0.5	M1	Grease gun	None		

Figure 17: Snapshot of Job List Page

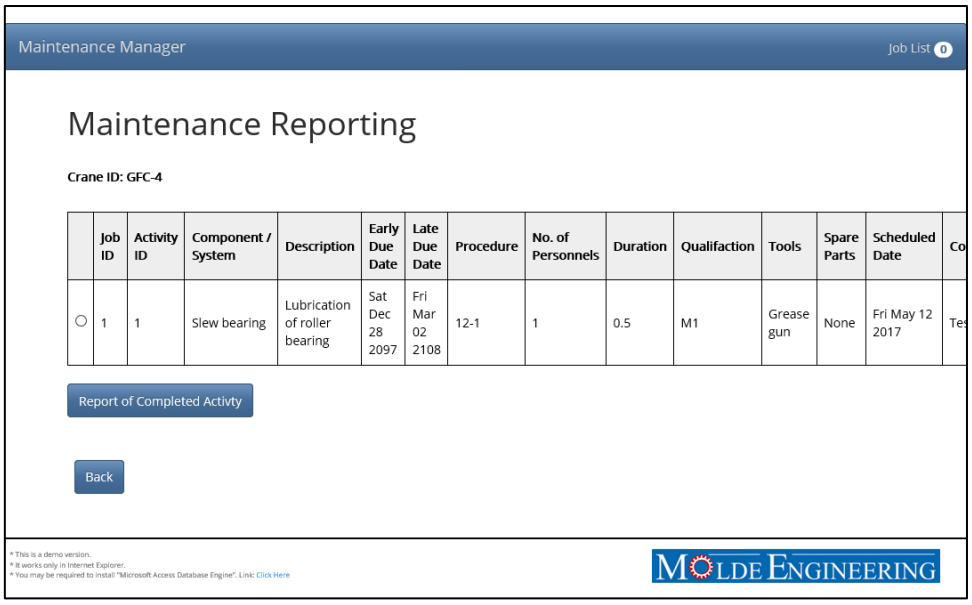


Figure 18: Snapshot of Maintenance Reporting Page

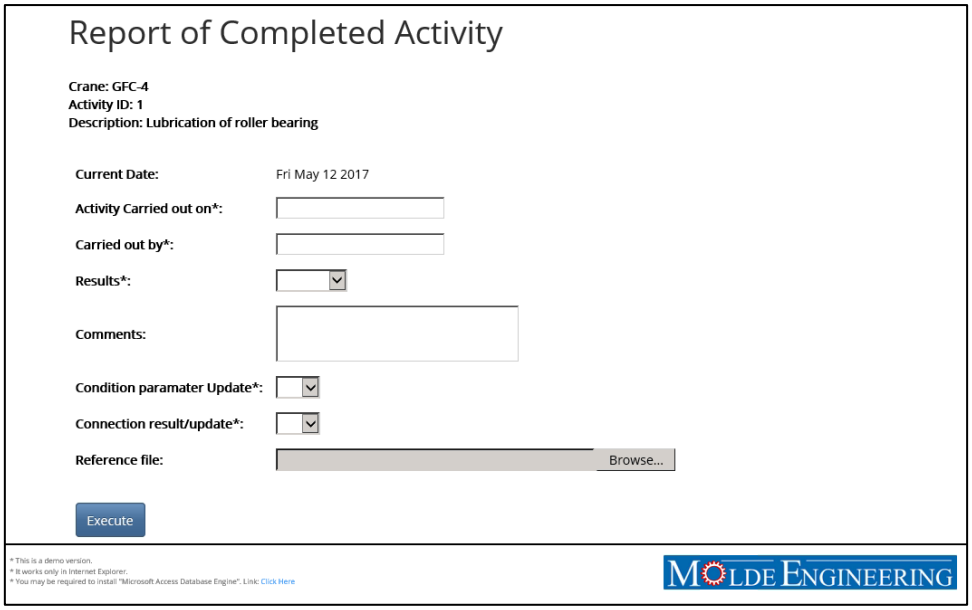


Figure 19: Snapshot of Report of Completed Activity Page

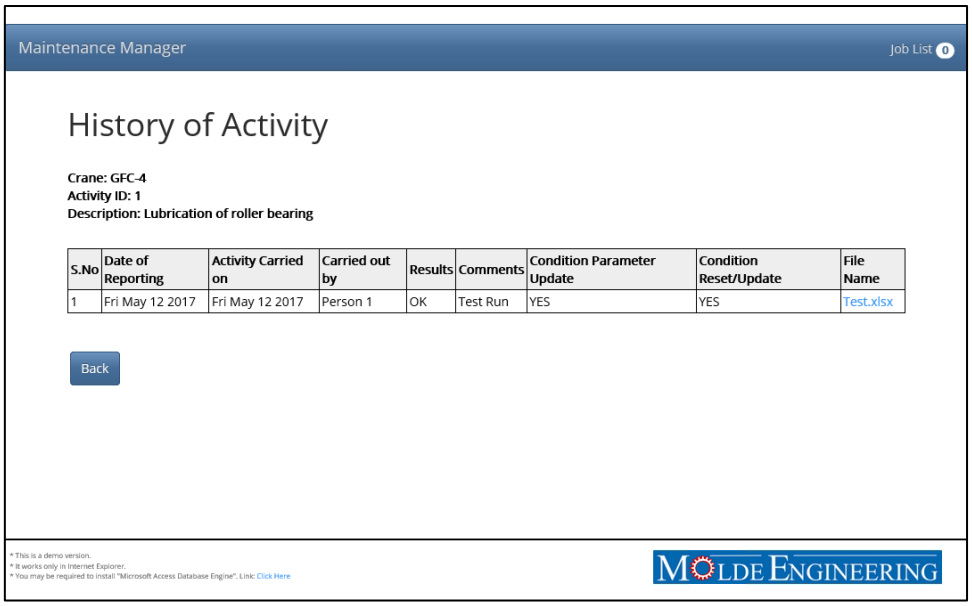


Figure 20: Snapshot of History of Activity Page

Appendix C: Condition and Load Based Maintenance – Introduction

CONDITION AND LOAD BASED MAINTENANCE

INTRODUCTION

This is a short introduction to the concept of condition and load based maintenance as proposed by Molde Engineering.

A crane is designed and built to a high standard regarding risk of damage to personnel and equipment and regarding risk of unscheduled downtime. Exposure to loads and environment will, generally, over time cause deterioration of various crane components and increase the risk of component failures that causes damage and/or downtime. Maintenance is activities aimed at compensating for this deterioration with the goal of maintaining the same risk levels as for the new crane.

Maintenance consists of a range of different activities, like inspections, tests, measurements, replacements etc. The activities are designed to keep track of the condition and deterioration of the crane components and repair or replace them when deterioration has reached a level where the risks of failure are unacceptable.

Deterioration and eventual failure of a component are normally caused by combinations of several load and/or environmental parameters. These parameters can be determined and defined. It is also possible to establish the relationship between the load and environmental parameters and the deterioration of the component. By monitoring the load and environment parameters we can then estimate the condition of the component and predict the point in time where inspection, repair or replacement will be needed.

In some cases it is possible and easy to measure or check the condition of a component. In other cases it may be impossible, difficulty or impractical. Load and environmental parameters are generally easier to monitor.

A first-class maintenance scheme must therefore be based on a combination of condition monitoring and load/environment monitoring.

Maintenance will consist of a range of maintenance activities of various types. Each activity will be connected to one or more load/environment parameters. Load data will be downloaded from the crane periodically and accumulated load and environment parameters will be calculated. Due dates for each activity will then be determined and predicted by the development of the parameters over time.

The conventional approach to crane maintenance has been to do maintenance and checks according to the calendar, with fixed intervals like 2 weeks, one month, one year or 4 years, more or less regardless of the actual use of the crane, with a yearly certification by a competent person. This is obviously not optimal.

With a system of condition and load based maintenance one will be much closer to the goals of the maintenance effort:

- Do maintenance when it is needed, with full control of all crane components throughout the life span of the crane.
- Avoid maintenance activity that is not needed.
- Ensure that the resources spent on maintenance have the maximum effect on safety and availability of the crane.

The supplier of the crane is responsible for specifying all maintenance activities that are necessary to maintain the originally safety level for the crane throughout the life span of the crane. The roll of the competent person should be redefined from being an inspection job to be a quality assurance job. Safety must be taken care of by the maintenance of the crane. The job of the competent person is to verify that the maintenance is carried out as intended.

In order to establish a set of maintenance activities and the connections to condition and load parameters an analysis has to be carried out. The basis of the analysis is requirements to safety and availability.

If there is form of load logging system on the crane the calculation of accumulated loads on the various components of the crane can be based on the logged data. It is also possible to generate hypothetical but fairly accurate load data from a detailed description of the operating environment of the crane, including platform layout and operational parameters that can be provided by personnel involved in crane operation. Any combination of logged data and data from an operating environment description is also possible. There are load logging systems installed on most cranes but many of them are more or less incomplete. A combination of logged and hypothetical data will be the most common.

The proposed concept of condition and load based maintenance has a great potential for improving crane maintenance, both for new and existing cranes. Molde Engineering has an interest in developing, marketing and assisting in running maintenance systems based on this concept.

The main expertise of Molde Engineering is in all types of engineering calculations for cranes. This expertise is highly relevant for the development and maintenance of all major part of a condition and load based maintenance system. However, our company is not engaged in crane maintenance operations. A close cooperation with the maintenance provider for the crane is therefore necessary. Our main contribution will be:

- Development of the system.
- Development and maintenance of the necessary software.
- Analysis to define maintenance activities and connections to load parameters.
- Start-up activities, including providing all necessary crane data and crane environment data and calculating start values (if the crane is not new).

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