Evaluation of the decision support demonstrator (Final Version)

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DELIVERABLE NO	DR8.9: Evaluation of the decision support demonstrator (Final Report)
DISSEMINATION LEVEL	**Confidential**
DATE	15th of March, 2008
WORK PACKAGE NO	WP R8: Methodologies for decision making for BOL, MOL, EOL
VERSION NO.	2.0
ELECTRONIC FILE CODE	20080221 DR8.9 v0-1
CONTRACT NO	507100 PROMISE A Project of the 6th Framework Programme Information Society Technologies (IST)
ABSTRACT:	This report contains the final version of the rolling report started with PROMISE WPR8 deliverable DR8.4 and continued as PROMISE WPR8 deliverable DR8.7: "Evaluation of the decision support demonstrator". Its purpose is to evaluate the overall implementation of the decision support activities carried out in the PROMISE project.

STATUS OF DELIVERABLE		
ACTION	**BY**	**DATE** (dd.mm.yyyy)
SUBMITTED (author(s))	Gerd Große	15.03.2008
VU (WP Leader)	Gerd Große	15.03.2008
APPROVED (QIM)	D. Kiritsis	15.03.2008

Revision History

Date (dd.mm.yyyy)	Version	Author	Comments
14.09.2006	0.1	Julien Mascolo (CRF)	Structure of document
06.10.2006	0.2	Dario Leo, Julien Mascolo (CRF)	Methodology of assessment
09.10.2006	0.3	Christian Seidemann, Martin Schneider, Gerd Große, Cognidata Dario Leo, Julien Mascolo, CRF, Marcel Huser, Bertram Winkenbach, Bombardier Transportation	First version including the evaluations of CRF and Bombardier
20.10.2006	0.4	Marcel Huser, Bertram Winkenbach, Bombardier Transportation	Refinement of Bombardier evaluation
23.10.2006	1.0	CRF	Final integration and check
15.11.2006	1.1	CRF	Corrections after quality check
16.04.2007	1.2	Christian Seidemann, Martin Schneider, Gerd Große, Cognidata	Preparation of next Version
25.04.2007	1.5	Cecile Corcelle, Jaime Krull, Caterpillar Julien Mascolo, CRF Daniele Panarese, Fidia Hui Cao, Cimru Dimitra Pli, Intracom Maurizio Tomasella, Polimi Giovanni Felicetti, Indesit	A2, A5 A4 A6 A3 A9 A11 A8
25.04.2007	1.7	Christian Seidemann, Martin Schneider, Gerd Große, Cognidata	Final integration and check
21.02.2008	2.1	Cecile Corcelle, Jaime Krull, Caterpillar David Potter, Indyon Julien Mascolo, CRF Daniele Panarese, Fidia Jacopo Cassina, Polimi Chris Pronios, Intracom Bertram Winkenbach, BT Maurizio Tomasella, Polimi	A2, A5 A3 A1,A4 A6 A8 A9 A10 A11

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Abbreviations:

BOL	Beginning Of Life
DfX	Design for X
DPN	Degradation Priority Number
DSS	Decision Support System
ECC	Error Correction Code
EEE	electrical and electronic equipment
ELV	End of Life Vehicle
EOL	End Of Life
GUI	Graphical User Interface
LCC	Life Cycle Cost
MOL	Middle Of Life
MTBF	Main Time Between Failures
PDKM	Product Data and Knowledge Management
PEID	Product Embedded Information Device
RAM	Reliability, Availability, Maintainability
SAP	Systems Analysis and Product

1 Purpose of this document

This report contains the PROMISE WP R8 Deliverable DR8.9: Evaluation of the decision support demonstrator. It is the continuation of PROMISE WP R8 Deliverable DR8.4. Its purpose is to evaluate the implementation of the second prototype of the PROMISE decision support system (DSS) described in Deliverable DR8.5. In DR8.4 the first two DSS solutions were evaluated, in DR8.7 the evaluation of the remaining eight DSS solutions is added[1].

Based on two questionnaires the feedback of the users is requested. Hence, this document involves two main issues: (i) the presentation of a questionnaire and (ii) the presentation and evaluation of the feedback.

2 Introduction

2.1 Objectives of work package R8

According to *PROMISE Description of Work* the goal of this work package is to provide the analytical basis of the PROMISE project. This WP concentrates on predictive maintenance, diagnosis and analysis of use patterns, which rely on algorithms originating from the fields of statistics, data mining, pattern recognition and computational intelligence. Based on the PROMISE research clusters 1, 2 and 3 and the PROMISE application clusters, this work package specifies decision-making systems supported by automatic identification systems, product embedded information devices, mobile reader devices, associated software and user interfaces. In a second step, methods and algorithms for beginning of life (BOL), middle of life (MOL) and end of life (EOL) decision-making systems will be developed for the evaluation in the application clusters.

2.2 Objectives of Deliverable DR8.9

As described in PROMISE_DoW, the main goal of Task TR8.4, DR8.7 and DR8.9 is to test and evaluate the DSS development, which has been executed in Task DR8.3, DR8.5 and DR8.8.

2.3 Structure of Deliverable DR8.9

The rest of this document is organized as follows:

- In Chapter 3 the method of evaluation is explained. We defined and used two questionnaires: The first compares the prototype with the definition of the expected functional characteristics. The second questionnaire is submitted to potential users, to assess the relevance of the system with respect to the expected objectives.
- Chapter 4 has a subsection for the evaluation of each application scenario. Each subsection starts with a description of the scenario and lists the expectations against the development.

[1] Note that due to the withdrawal of MTS from the project (effective July 1st 2006) there are just 10 application scenarios left.

More detailed scenario descriptions can be found in the respective documents of the application workpackages, e.g. DR8.8. Then the evaluation follows based on the method of evaluation. This is organized in form of a table and it gives grades reflecting the state of satisfaction. Finally, important remarks for the further implementation are given.

- Chapter 5 summarizes the main results presented in Deliverable DR8.9.

3 Method of evaluation

In the first phase of the definition of the DSS demonstrator (first 12 months of PROMISE), all application partners have provided a real-world problem. This has lead to a prototype DSS implemented for month 18. During the months 18-24 of the project, the testing activities have been performed, in order to provide useful feed-back on the DSS based on real tests and to enable to proceed with the spiral implementation of the PROMISE DSS. From months 24 to 34 the DSS development has mainly been carried out in the working environment of the different application partners. The reason for that is that development speed is much higher in a less complex, more suitable environment.

The major tasks of the test and validation plan are:

- Set up the objectives of the demonstrator for each application scenario
- Define the users, tasks and context of use
- Set up the Critical Success Factors
- Set up the validation, analyse data and results
- Verify if goals were achieved
- Archive information for re-use, reference and values

To support these tasks, we defined and used two questionnaires: the first one has to be finalized to the definition of the expected characteristics of respective DSS application scenario. Then a second questionnaire is submitted to potential users, to assess the relevance of the system with respect to the expected objectives. With a DSS prototype ready, the users compile a questionnaire to capture feedback by "internal assessment".

What is reported in this document are the results of the DSS assessment, available at month 34.

In the following we provide the questionnaires used in this phase:

- Questionnaire for elicitation of the PROMISE DSS objectives
- Prototype testing questionnaire (taking into account the most important attributes with end user evaluation).

The first questionnaire enables to focus the objectives of the DSS, based on a screening performed at the beginning of the project. In our process to define the software capabilities, we first interviewed the potential clients within the application companies in order to identify their requirements. This was used to drive the development of the first-step DSS. In the validation and testing phase, the DSS solutions have been assessed with respect to the expected features, as specified below, and with respect to the software usability.

The same approach and same questionnaires may be used throughout the successive testing phases.

3.1.1.1 Questionnaire 1: Focussing the objective of the DSS

1. How much time could your company afford to spend for using a software tool like the one described in the presentation?

1. Daily / intensive / more than 2 person hours

2. Daily / not intensive / less than ½ person hour
3. Weekly / intensive / more than 4 person hours by one single employee
4. Weekly / intensive / more than 4 person hours by more than one single employee
5. Weekly / not intensive / less than ½ person hour by one single employee
6. Weekly / not intensive / less than ½ person hour by more than one single employee
7. Monthly / intensive / more than 8 person hours by one single employee
8. Monthly / intensive / more than 8 person hours by more than one single employee
9. Monthly / not intensive / less than ½ person hour by one single employee
10. Monthly / not intensive / less than ½ person hour by more than one single employee
11. Annually / intensive / more than 32 person hours by one single employee
12. Annually / intensive / more than 32 person hours by more than one single employee
13. Annually / not intensive / less than ½ person hour by one single employee
14. Annually / not intensive / less than ½ person hour by more than one single employee
15. Other (Please describe) ____

2. For any of the identified options above, what do you expect that the use of the DSS should be?

1. Fully automated with input from and to other tools and applications
2. Semi-automated with partial input from and to other tools and applications
3. Non automated at all: any data should be provided manually or with some ad hoc scripted methods to the system
4. Other (Please describe) ____

3. What type of functionality do you think should be part of the DSS?

1. Spare parts warehouse management
2. Recycling management
3. Remanufacturing management
4. Spare parts logistics management
5. Product lifecycle management (reliability, warranty…)[2]
6. Lifecycle management of product's field experience on reliability, availability and maintainability[3]
7. Lifecycle management of field experience on product safety
8. Lifecycle management of field experience on Life Cycle Cost (LCC)

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[2] For FIAT, people involved in this phase are experts in the field of Spare parts management.

[3] For BT, people involved in this phase are experts in the field of RAMS/LCC .

9. Management of product's warranty and validation phase
10. Other (Please describe) ____

4a. Regarding the PROMISE "BOL management ", do you think that the DSS has to:

1. Improve the design of the product (reliability, maintainability,…)
2. Support product RAMS/LCC field data analysis
3. Support prediction of product RAMS/LCC figures
4. Support product design analysis concerning RAMS/LCC parameters
5. Support product design improvement
6. Other (Please describe) ____

4b. Regarding the PROMISE "EOL management ", do you think that the DSS has to:

1. Enable operational management of the EOL management (physical warehouse management, dismantling…)
2. Enable strategic management of the EOL management (BOM, supply chain design, contractor selection, contracts management…)
3. Concern a particular company department, without considering the needs from other departments. Please describe: ____

5. As far as the DSS data are concerned, these should be:

1. Limited to corporate-only data (sources)
2. Extended to data (sources) from other enterprise suppliers or value chain members
3. Other (Please describe) ____

6. As far as the format of the DSS data are concerned, these should be:

1. Of some predefined structured type of data
2. Totally user defined type of structured data
3. Using some internationally well-known / (quasi-)standardized type of data format
4. Other (Please describe) ____

7. How much training time are you willing to spend for learning to fully use the DSS?

1. No training at all
2. 1 hour
3. 2 hours
4. 1 full day
5. 1 full week

6. Other (Please describe) ____

8. How would you like to receive the results of the DSS system:

1. In plain graphical presentation
2. By a guided process (graphical and by figures) providing a step-by-step approach to detailed information
3. As results of a rule-based system (e.g. part of a generated decision tree, If X then Do this – else Do that)
4. As results of a rule-based system, also annotated with probabilistic information (e.g. depicting mixed strategies with multi-threaded decision trees)
5. Other (Please describe) ____

3.1.1.2 Questionnaire 2: Evaluating the characteristics of the PROMISE DSS

In each company potential users were asked to test the individual DSS solution, following a procedure indicated below. A questionnaire and a table were filled-in by the users, to evaluate the adequacy of the prototype with respect to the specifications and functionalities defined with the analysis of the answers to the first questionnaire. The questionnaire contains questions useful to: 1) capture an impression concerning the prototypical development, on tool attributes like completeness, functionality coverage and tool usefulness, 2) gather judgments concerning the real use of the tool. The questions concern, first of all, aspects of tool usability. These questionnaires (with more that 90 questions) consider a wide spectrum of aspects (attributes, needs, operative aspects) with the aim to:

- Test the whole solution
- Check its usability and utility
- Highlight if results are acceptable

In fact, during the tool design and development process, a great set of attributes should be considered. These attributes characterize the first, intermediate and final solutions. The activity of validation should consider the attributes by the same standard as requirements that a system should have.

The most important attributes are:

Workability: the ability of the system to perform work (presentation, navigation / operability, responsiveness, access control, status / progress control…)

Availability: how much a system is usefully (not merely technically) available to perform the work which it is designed to do, i.e. is it a stable system, or does it constantly need reconfiguration and support. It is assessed in terms of Stability, Reliability, Integrity/ Security.

Adaptability: The ability to change ‘efficiently’ (i.e. amount of resource required) to meet eventual changing requirements (in terms of openness / standards compliance, improvability, extendibility, portability).

Usability assesses if the user can use the system and can he or she do so effectively? Even if the system does exactly the right thing in theory, it will still be a poor system if the user cannot figure out how to get it to work. It includes the following characteristics: learnability, efficiency of use for an experienced user, effectiveness of use (quality of the outputs), memorability, error frequency and severity, subjective satisfaction – likeability.

The usability of the system is the most important aspect for the acceptance of the system by the end user. In this deliverable we use the ISO 9241-11 definition of usability: "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"

According to Jacob Nielsen, usability is the measure of the quality of the user experience when interacting with something -- whether a Web site, a traditional software application, or any other device the user can operate in some way or another.

Experience shows that usability does not happen automatically: web designs often don't produce the needed results unless the project management takes explicit care to apply usability engineering throughout the design process.

Utility assesses if the system does anything that people care about? If the system does something irrelevant or if it doesn't solve the main problem, then it does not matter whether it is easy to use: it will be a poor system in any case.

The two final attributes sum up in the **usefulness** of a system.

All these characteristics need to be considered in any design project. But some of the characteristics are more important than others. All the components are relevant validation aspects.

4 Description of the applications

4.1 End of Life: Decision support for Disassembly (A1)

This section contains the evaluation of the A1 DSS demonstrator delivered in M36.

4.1.1 Objective of the A1 DSS demonstrator

The ELV (**E**nd of **L**ife **V**ehicle) directive (EU/2000/53) introduced by the EU in 2000 addresses pollution arising from vehicles that have reached the end of their useful life. The directive specifies thresholds for the reuse, recycling and recovery of materials from ELVs. By 2006 the ratio of materials in an ELV which should be reused, recycled or recovered will reach 85% of the total vehicle weight and 95% by 2015.

The objective of CRF is to assess the use of PEID for improved decision making (based on information concerning parts status and history stored on the PEID, materials tracking and for testing the achievement of recycling and reuse targets as stated by the European directives.

- PROMISE-PLM allows CRF to monitor and work towards achieving ELV directive (EU/2000/53)
- Marketing and Engineering can derive useful information from EOL, identifying among other over-designed components/subsystems.
- Engineering is able to provide detailed data concerning BOM, materials, dismantling and processing information back into design and manufacturing.
- Data concerning the rate of recycling and reuse is of use for design purposes and for detecting potentially over-designed parts.
- Information may be collected globally at vehicle level and/or subsystem level (local information)
- Detached parts may be reused as used spare parts directly or after some remanufacturing/repair based on fact based decision process.

In the following Figure 1 represents the relationship and position of the DSS with respect to the other PROMISE components and the product (the vehicle).

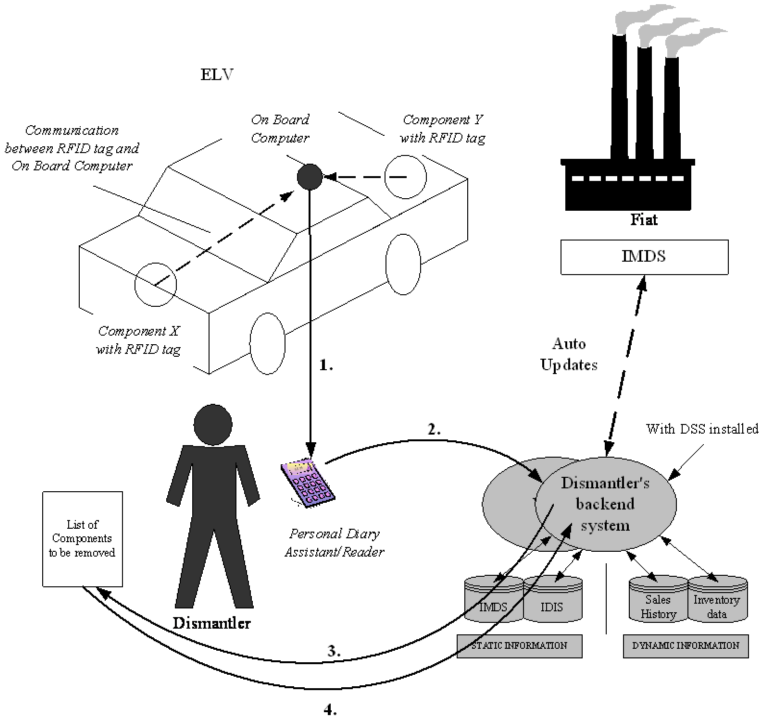


Figure 1. DSS as the unique interface of the dismantler in the A1 demonstrator

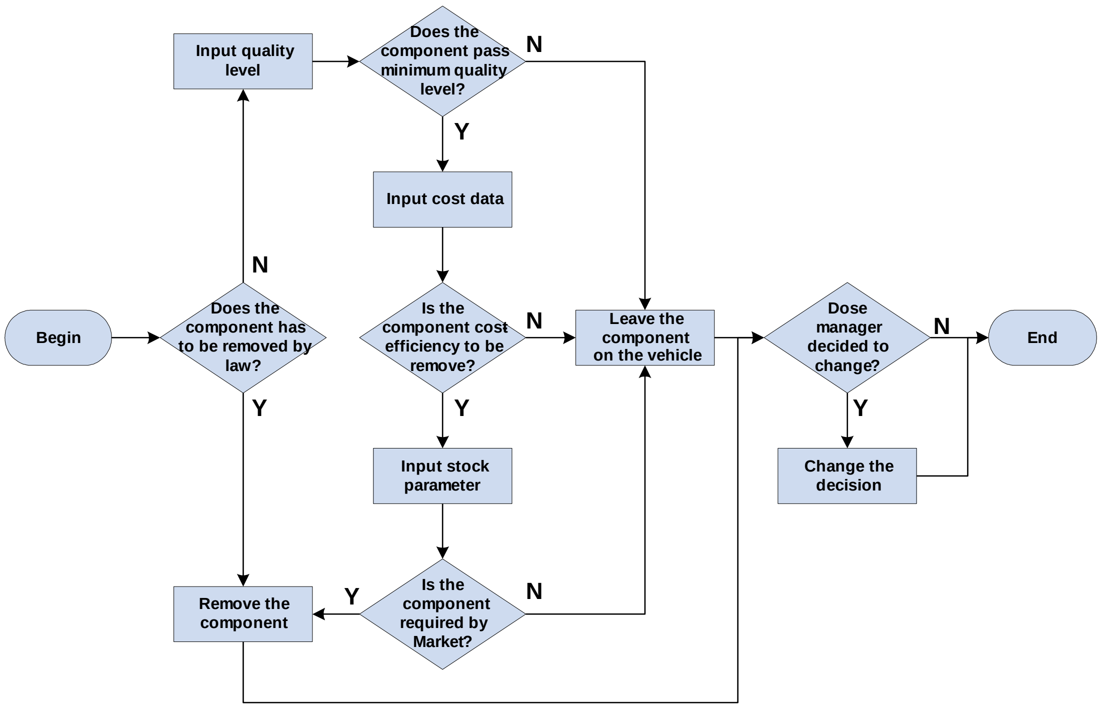


Figure 2a. Decision flow chart

Figure 2a presents the decision flow chart, internal to the DSS, to achieve the list of actions to be performed by the dismantler.

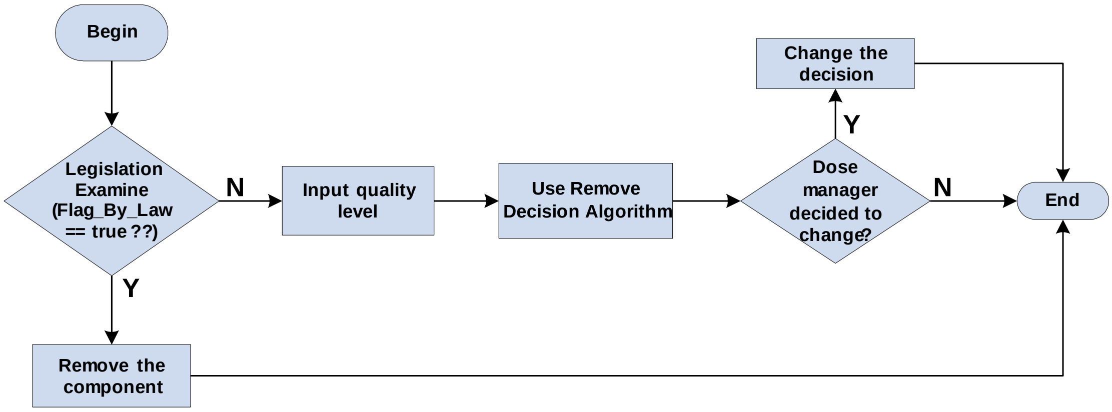


Figure 2b. Using the A1 EOL DSS

Figure 2b presents the interface between the user and the system, to be supported by the DSS.

4.1.2 Evaluation and requirements of the solution

CRF has provided a real-world problem within the FIAT Group, to be used to drive the development, test and validate the PROMISE A1 DSS prototype.

The test procedures we followed were the following:

- Start the A1 DSS
- Choose a vehicle
- Browse the BOM of material
- Evaluate the status of 2 components
- Download legal info on selected components
- Compute final list of actions
- Print list of actions

At the end of the test the users were asked to evaluate the PROMISE A1 DSS with respect to the questionnaires. The result can be seen in the Table 1 below:

Importance [1-10]	Functionality	Evaluation of A1 DSS v.3	Comments to A1 DSS v.3	Roadmap for industrialisation (M42+)	N.
DSS Functionalities					
10	Compliant/ enables compliance with international regulations	4	User specifies compliance through menu	Link to external DB to be implemented	A
10	Enable assessment of residual life of components	5	Wear-out models are implemented for two components	Wear-out models to be downloaded from external DBs	B
10	Capability of modelling the wear-out of different types of components	5	Idem	Idem	C
10	Adequacy of the modelling (true wear-out estimation)	5	Wear-out models based on extensive tests are implemented	Idem	D
10	Integration with external data repository (e.g. PDKM)	5	Link to PDKM is active	Link to external DB to be implemented	E
1	Specify type of vehicles	1	One type of vehicle implemented	Full portfolio of vehicle should be available	F
1	Management of multiple vehicles	1	Not required for demonstration	Required for industrialisation	G
1	Identification of vehicle and components history (production, owners, substitution...)	1	Not required for demonstration	Required to resolve problems of incoherency	H
6	Present summary of data (dynamic, static)	1	Not required for demonstration	Required for industrialisation	I
6	Export data in .txt	1	Not required for demonstration	Required for industrialisation	J
7	Access and modify some of the data, with credentials	1	Not required for demonstration	Required to resolve problems of incoherency	K
8	Support to operational dismantling	5			L
9	Support to recycling, remanufacturing, reuse	5			M
1	Back up data storing solution	1	No electronic or paper back up (e.g. print list of actions)	Not required: back up data in the onboard telematic platform	N
	Security and reliability (protected access)	5			O
6	Extendability (Capability of extending the number of relevant handled objects)	1	Not required for demonstration	Required for industrialisation	P
6	High processing capability	3	Processing power is ok for the number of components	Required for industrialisation	Q
	Other				R
Importance [1-10]	**Attributes**	**Evaluation of A1 DSS v.3**	**Comment to A1 DSS v.3**	**Roadmap for industrialisation (M42+)**	**N.**
10	DSS cost of installation	3	Difficult to assess for this demonstrator.	Required for industrialisation	I
10	DSS cost of maintenance	3	Difficult to assess for this demonstrator.	Required for industrialisation	II
10	Accessibility via web	5			III
10	Simplicity of use	4			IV
8	Workability	5			V
8	Availability	5			VI
6	Adaptability	3	Adaptability is ok for the number of components		VII
10	Usability	5			VIII
	Other				IX
	Evaluation. 1: not satisfactory; 5: highly satisfactory				

Table 1. Evaluation of the DSS versus expected functionalities

The first column indicates from 1 (low) to 10 (high) the importance of each functionality or technological attribute of the DSS, which is specified in column 2. Its evaluation is reported in column 3. Comments to the actual implementation and requirements for industrialisation after the PROMISE project end (month 42) are indicated in the next two columns.

All functionalities needed to assess the demonstrator (with importance from 8 to 10), regarding for example the compliance with regulations, have been developed in accordance with expectations, achieving an evaluation superior or equal to 4.

Other functionalities or attributes not required for this demonstrator will be relevant during industrialisation, for example the ability to retrieve wear-out models from an external database, regularly updated. These will be further elaborated in deliverables DA1.6 and DA1.7, where the development roadmap from a technology and business point of views are evaluated.

In conclusion, the solution developed is highly satisfactory, enabling to demonstrate and evaluate the expected functionalities, and in particular:

- Support operations at end-of-life of the vehicle
- Take actions based on actual wear-out of components
- Use real wear-out models developed with extended tests data
- Support user with efficient and useable front-end

4.2 End of Life: Heavy Equipment Decommissioning (A2)

This section contains the evaluation of the A2 DSS demonstrator Version 2 delivered month 36. The former version, Version 1, was delivered in month 24.

4.2.1 Objective of the A2 DSS demonstrator

The DSS for the A2 EOL Demonstrator is intended to assist in the decision process regarding a components value at its EOL. The component can be an entire engine with PROMISE technology enabled components or a single PROMISE enabled component. When the enabled component reaches its EOL it is sent to a remanufacturing facility. At this facility a receiving operator reviews the DSS outputs.

The objective is to collect relevant information throughout the components life on the PEID and the PDKM to allow a decision to take place about the value of the component at its EOL. The parameters that will be recorded to formulate this decision are:

- Oil change frequency
- Number of times coolant is added
- Coolant temperature history
- RPM history
- Operating hours
- Fuel consumption

This information will be related to parameter limits set in the DSS allowing an assessment of the component value. Additionally, this will and aid in the determination of the appropriate course of action for the EOL. This aligns with the objective of the DSS functionality to define EOL for engine components.

First user requirements and DSS functionalities were specified in deliverable DR8.1 (delivered month 12) as the detailed DSS specifications have been provided for DSS V2 development and integrated to deliverable DR8.5 by month 24. Figure 3 extracted from DR8.5 shows the decision tree specified at month 24.

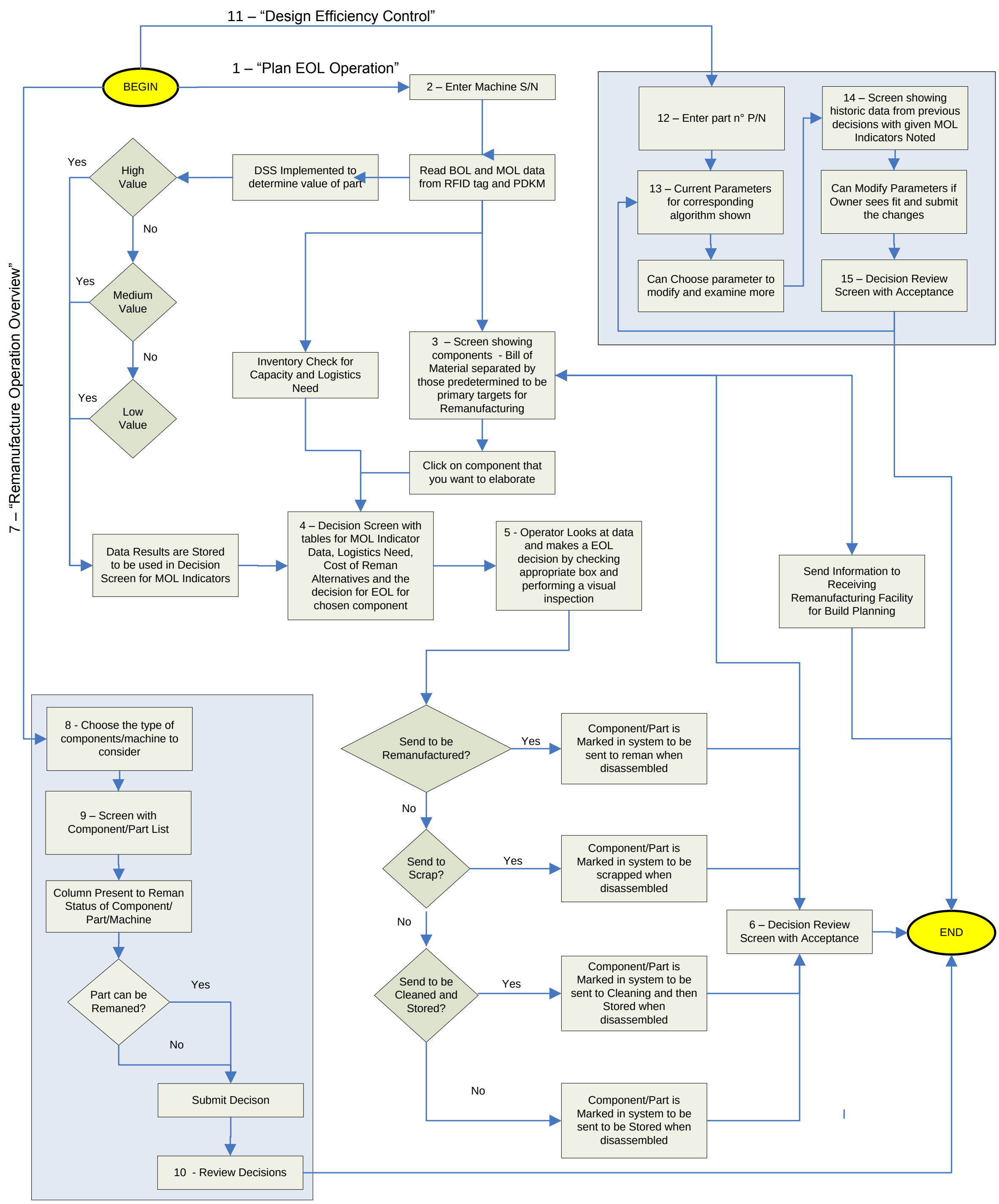


Figure 3: Decision flow chart for A2

4.2.1.1 Users of the DSS

Considering DA2.3: "design of the A2 demonstrator" delivered month 18, the DSS will be used during Scene 6: When a Promise enabled component requires **decision-making for CAT "Reman"**. This is the only time the DSS will be enabled in the A2 demonstrator scenario.

Figure 4 is an UML use case to represent the Promise architecture and DSS end-users.

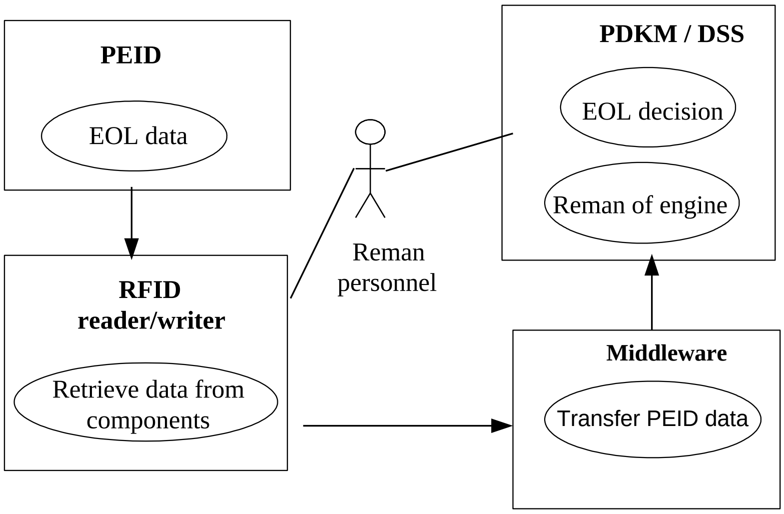


Figure 4: DSS use for A2

The EOL data collected by the PEID will compose of dealer inputs and Electronic Control Module (ECM), which is the onboard computer, inputs.

4.2.2 Evaluation and requirements of the solution

In Table 2 below, program and screen shots of DSS V1 delivered M24 and DSS V2 delivered M36 have been evaluated regarding the DSS functionalities primarily specified and the attributes characterized in DR8.8 chapter.

Functionalities	Evaluation Score (DSS V1)	Comments on A2 DSS V1	Evaluation Score (DSS V2)	Comments on A2 DSS V2
Provide EOL decision for Engine Components	3	Only one component programmed in V1	5	Three components crankshaft, cylinder head, and engine block are included in this version.
Support service reman EOL decisions	4	GUI interface with reman operator but Java code does not match GUI	5	GUI interface works with the Java code to provide EOL recommendation
On whole engine core:				
- List of BOM avaliable on engine core	1	Not currently avaliable	1	Not currently avaliable
-Depreciation level of parts	3	Depreciation is calculated but not shown	4	The quality class of each component is displayed along with the best recovery option
-List of parts with alternate reman options (landfilled, re-used, stored, re-manned)	3	Included in GUI but DSS V1 is component based	4	The algorithm for the DSS is component based, however this issue can be tackled at the GUI level by running the algorithm on all components simultaneously
- Engine type is a parameter	2	Not avaliable (only one engine type considered)	3	Only one engine type is considered. However, multiple vehicle types are included.
Reman inspection results are entered in DSS to inform on DSS model correlation	1	Not currently avaliable	1	Not available. This is clearly future work which involves machine learning and other techniques
Graphical Results	1	Not currently avaliable	4	Graphs are avaliable to view the results of the histograms.
Attributes	**Evaluation Score (DSS V1)**	**Comments on A2 DSS V1**	**Evaluation Score (DSS V2)**	**Comments on A2 DSS V2**
DSS cost of installation	-	Not estimated	-	Not Estimated
DSS cost of maintenance	-	Not estimated	-	Not estimated
Accessibility via Web	3	Could not access till M28	3	Can access but not test, DSS and PDKM not currently integrated
Simplicity of use	3	OK	3	Simple to use, but only fake screens and data are currently avaliable at this time.
Workability	2	Impossible to assess	3	Look like the DSS GUI will be very workable, but only fake data at this time.
Availability	2	Impossible to assess	3	Avaliable through a web interface.
Adaptability	2	Should be adaptable (java program)	4	Underlaying algorithm is very adaptable, should be able to modify easily
Usabillity	4	OK	4	Intuitive for use to use, based on the available fake data.
Utility	3	Current estimated remaining lifetime	4	DSS algorithm fulfills need, GUI provides user interface for data adequately.
Evaluation 1: not satisfactory, 5: highly satisfactory				

Table 2: Basic evaluation of the DSS versus expected functionalities

Alignment issues with the DSS java code and the GUI have been resolved in V2. This is attributed to close monitoring of the development of the GUI to meet the revised java code parameters between partners.

The programmed interface is user friendly regarding the time that would be needed to learn the software to determine the EOL decision of the given component. The interface will be partially automated with limited input from the operator and other applications. The functionality of the DSS will address remanufacturing management of the incoming components via the GUI and graphical representation of the data as an option that is accessible by the operator. The DSS will give information for use in the refinement of the DSS model and at this point in time will only incorporate data from dealer activities.

The characteristics of the DSS in regards to workability, availability, adaptability and usability meet expectations in V2.

4.2.3 Conclusion

Considering the DSS specifications and solution that V2 has provided, the second end-user evaluation can be summarized as follows:

- A model has been programmed to assess the EOL value of Promise enabled components and provides the operator expected information to make a EOL decision based on the DSS outputs;
- A more complex, comprehensive, and flexible algorithm to estimate remaining lifetime depending identified parameters has been given;
- From GUI and the DSS java code, both in context are aligned, but true evaluation is not possible for both due to lack of current integration to permit testing;
- In M42+, further evaluation of the GUI and DSS working together using data from the back-end system is needed for a true full evaluation.

4.3 End of Life: Decision support for tracking & tracing of products for recycling (A3)

4.3.1 Objectives of the A3 DSS Demonstrator

The objective of the A3 Demonstrator is to show how the tracking and tracing of products identified for recycling can be enhanced using the PROMISE PEID technology and PDKM system in combination with indoor and outdoor navigation systems.

The aim of the scenario is to improve the information flow throughout the EOL phase of used plastic materials (e.g. car bumpers) and the BOL phase of the resulting recycled material (e.g. granular plastic), bridging the information gaps present in the state-of-the-art and completing the information loop.

On that basis, it aims to optimise processes within these phases by providing real-time product and context information to a number of back-end systems, and by integrating DSS into the existing backend in order to more effectively and efficiently handle these processes. The DSS to be developed must interact with a number of different systems that control various parts of the recycling process; for example, ERP system, WMS system etc. The DSS will, in turn, update these systems.

In order to integrate the DSS into the A3 scenario, an interface between the DSS and a logistics planning system must be established. The main goal of the integration is to provide real-time data for incoming materials and goods on the basis of the required specifications for PEIDs and RFIDs within the scenario.

Real-time data will be provided for all of the relevant process steps within the scenario for the support of backend systems such as Warehouse Management Systems (WMS) and Production Planning Systems (PPS). The planning system will be able to simulate basic processes like purchasing and sales planning taking into account the availability of materials, maintenance costs, etc. on the basis of real-time information provided by PEIDs.

The DSS will support purchase in purchase planning on that basis, as well as supporting sales in determining available materials and sales planning. The DSS will also be designed to be open to external systems such as WMS, PPS, ERP (e.g. as provided by SAP or already available in the OPAK scenario) as well as systems that support batch tracing.

4.3.2 Evaluation and requirements of the current solution

Functionality	Evaluation[4]	Comment	Requirements
Make movement decision for Incoming Goods	5		
Make target container decision for Sorting	5		
Make target container decision for Clearing	5		
Make movement decision for Normal Storage	5		
Respond hazard-monitoring-interval-expired event	5		
Respond safety-threshold-passed event	5		
Make movement decision for Production	5		
Configure PEID data for Production	5		
Make movement decision after Production	5		
Configure RFID data for tag replacement for Outgoing Goods	5		
Make movement decision for Outgoing Goods	5		
Retrieve container RFID/PEID data via PDKM	5		
Retrieve item tag data via PDKM	5		
Retrieve position information via PDKM	5		
Write process instruction into container RFID/PEID	5		
Save process information into PDKM	5		
Instruct WMS to get goods	5		
Attributes	**Evaluation**	**Comment**	**Requirements**
Accessibility via web	5		
Simplicity of use	5		
Workability	5		
Adaptability	3	Process oriented	
Usability	4		

Table 3: Basic evaluation of the DSS versus expected functionalities

4.4 Middle of Life: Maintenance of a fleet of trucks (A4)

4.4.1 Objective of the A4 DSS demonstrator

The overall objective of the IVECO demonstrator is to support the maintenance of a fleet of trucks, optimising the maintenance plan and increasing the overall availability of the trucks.

Closing the information loop using the Demonstrator "Information management for predictive maintenance" will improve the knowledge about the customer habits and the mission profile of the vehicle and finally enable to:

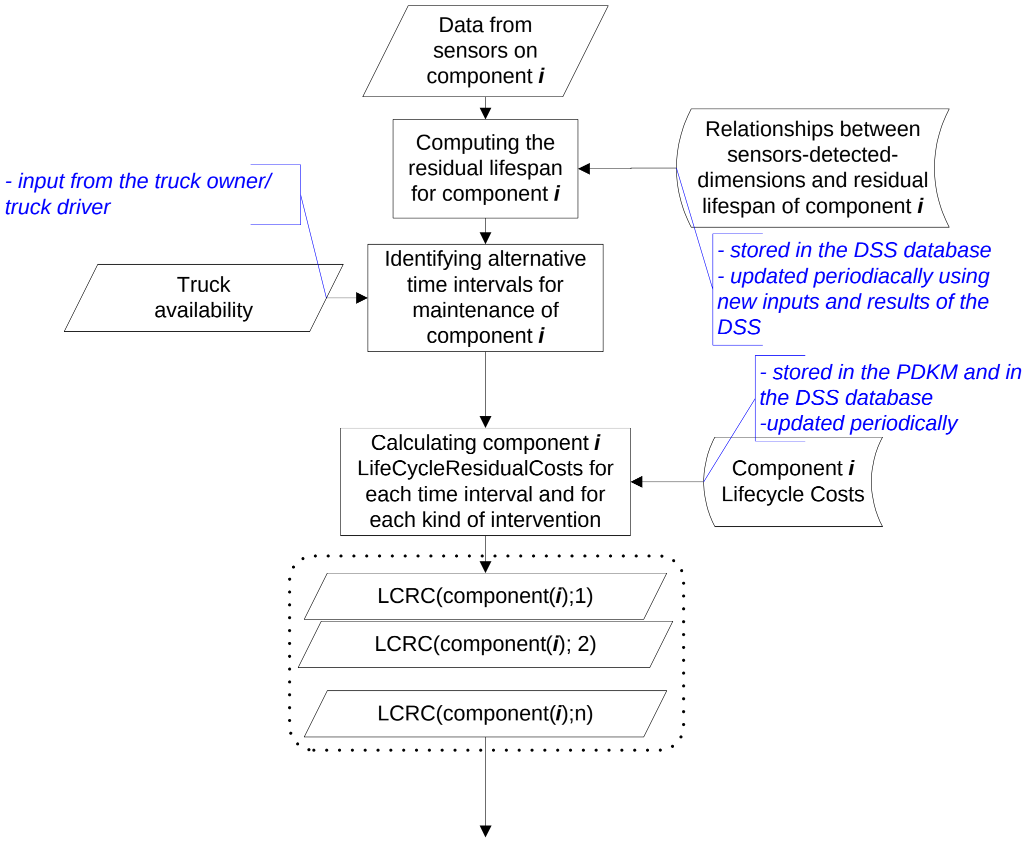
- Reduce the number of vehicle stops for maintenance
- Minimise the overall lifecycle costs of the components
- Avoid component breakdowns

[4] Evaluation: 1. not satisfactory; 5. highly satisfactory

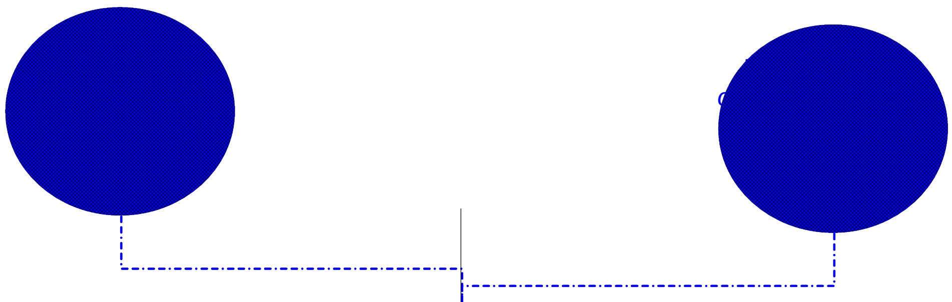
- Take into account vehicle availability while planning maintenance interventions
- Take into account maintenance crew availability for performing maintenance

The idea behind predictive maintenance is the identification of slow degradation trends in the performance of specific systems in order to identify with reasonable warning the need of an intervention. This allows the optimisation of maintenance intervention with the implementation of a customised maintenance policy and contributes to make explicit the residual life of the component in order to better manage the total Life Cycle Cost (LCC). For further information please refer to deliverable DA4.4.

The following Figures represent the flow of operations supported by the DSS.



These steps go from the collection of data from sensors to computation of Life Cycle Residual Cost for a single component.



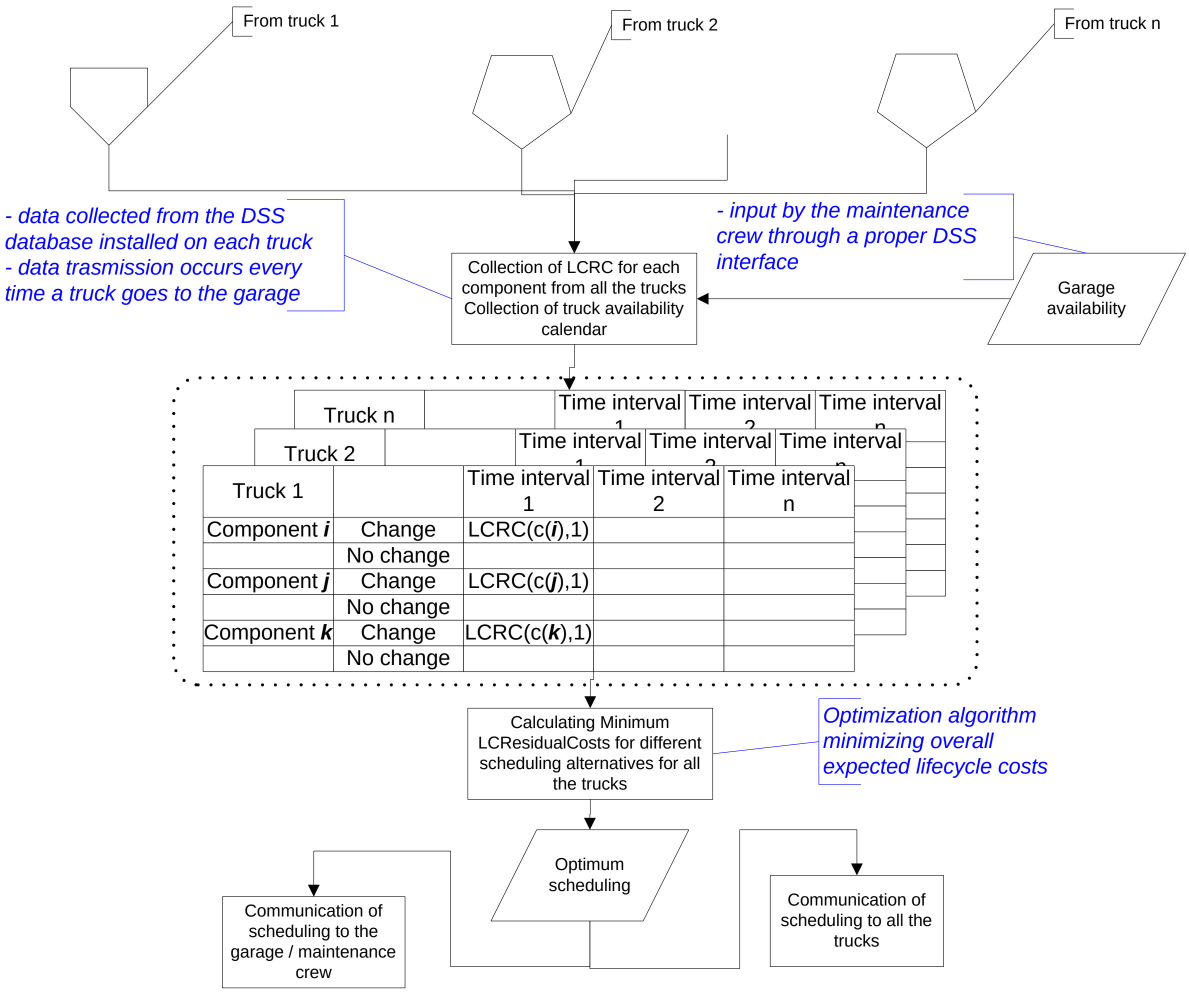
Calculating the overall LCRC for the different time-intervals options and for the different maintenance options (change/ no_change of each component)

		Time interval 1	Time interval 2	Time interval n
Component ***i***	Change	LCRC(c(***i***),1)		
	No change			
Component ***j***	Change	LCRC(c(***j***),1)		
	No change			
Component ***k***	Change	LCRC(c(***k***),1)		
	No change			

Identify the Time Interval that minimizes the Global LCRC for all the components

Send a mesage to the truck cockpit suggesting stop for maintenance on identified Time Interval

Life Cycle Residual Costs for the different components monitored on a single truck are put together and optimization for the single truck is performed.



Data of the different trucks belonging to the same fleet are here grouped and optimization for the fleet is performed. Calendar of interventions is sent to the maintenance crew and to the different trucks.

4.4.2 Evaluation and requirements of the solution

The real-world problem at stake is the maintenance of a fleet of trucks operated by a client of IVECO.

The test procedures followed was the following:

- Start the A4 DSS
- Choose a fleet
- Browse data from vehicle
- Enter availability of garage
- Compute maintenance plan
- Print list of actions

At the end of the test the users were asked to evaluate the PROMISE A4 DSS with respect to the questionnaires. The result can be seen in the table below:

DSS Functionalities					
Importance [1-10]	**Functionality**	**Evaluation of A4 DSS v.3**	**Comment to A4 DSS v.3**	**Roadmap for industrialisation (M42+)**	**N.**
10	Compliant/ enables compliance with internal procedures	5			A
10	Computation of maintenance plan	5			
10	Enable visualisation of maintenance plan	5			B
6	Enable manual modification of maintenance plan	3	Not required for demonstration. Can be done off-line	Required for industrialisation	C
10	Specify type of vehicles	5			D
1	Management of multiple fleets	1	Not required for demonstration	Required for industrialisation	E
5	Export data in .txt	1	Not required for demonstration	Required for industrialisation	F
6	Send message to single vehicle	1	Not required for demonstration	Required for industrialisation (integration with telematics platform)	
10	Security and reliability (protected access)	5			G
8	Extendability (Capability of extending the number of relevant handled objects)	5			H
8	High processing capability	3	Processing power is ok for the test fleet		I
	Other				J
Importance [1-10]	**Attributes**	**Evaluation of A4 DSS v.3**	**Comment to A4 DSS v.3**	**Roadmap for industrialisation (M42+)**	**N.**
10	DSS cost of installation	3	Difficult to assess for this demonstrator.	Required for industrialisation	I
10	DSS cost of maintenance	3	Difficult to assess for this demonstrator.	Required for industrialisation	II
10	Accessibility via web	5			III
10	Simplicity of use	4			IV
8	Workability	5			V
8	Availability	5			VI
6	Adaptability	3	Adaptability is ok for the number of vehicles		VII
10	Usability	5			VIII
	Other				IX
	Evaluation. 1: not satisfactory; 5: highly satisfactory				

Table 4. Evaluation of the DSS versus expected functionalities

The first column indicates from 1 (low) to 10 (high) the importance of each functionality or technological attribute of the DSS, which is specified in column 2. Its evaluation is reported in column 3. Comments to the actual implementation and requirements for industrialisation after the PROMISE project end (month 42) are indicated in the next two columns.

All functionalities needed to assess the demonstrator (with importance from 8 to 10), regarding for example the ability to visualise and modify the maintenance plan, have been developed in accordance with expectations, achieving an evaluation superior or equal to 4.

Other functionalities or attributes not required for this demonstrator will be relevant during industrialisation, for example sending a predefined message to the vehicle. These will be further elaborated in deliverables DA1.6 and DA1.7, where the development roadmap from a technology and business point of views are evaluated.

In conclusion, the solution developed is highly satisfactory, enabling to demonstrate and evaluate the expected functionalities, and in particular:

- Support the fleet manager in defining and update maintenance plan
- Base the maintenance plan on actual wear-out of components
- Use real wear-out models developed with extended tests data
- Support user with efficient and useable front-end

4.5 Middle of Life: Decision support for predictive maintenance on structures (A5)

This section contains the evaluation of the A5 DSS demonstrator Version 2 delivered month 34.

The original version, Version 1, was delivered month 24.

4.5.1 Objective of the A5 DSS demonstrator

Objectives of the A5 DSS are twofold, implement predictive maintenance on structures for service dealer and machine owner and analyse fatigue behaviour of structures in the field for designer and marketing product support.

These objectives lead to the following DSS functionalities:

- Schedule maintenance on structures (rework, remanufacturing, part change)
- Forecast the manufacturing orders & logistics supplies of repair parts
- Work site management considering application severity versus machines status
- Field support with the overview of all machines in the field
- Optimise manufacturing and quality processes depending on structures responses in the field
- Optimise DfX ability thanks to MOL data on structures in the field for various applications and markets

First user requirements and DSS functionalities were specified in deliverable DR8.1 (delivered month 12) as the detailed DSS specifications have been provided for DSS V1 development and integrated to deliverable DR8.5 by month 24.

Figure 5 extracted from DR8.5 shows the decision tree specified at month 24.

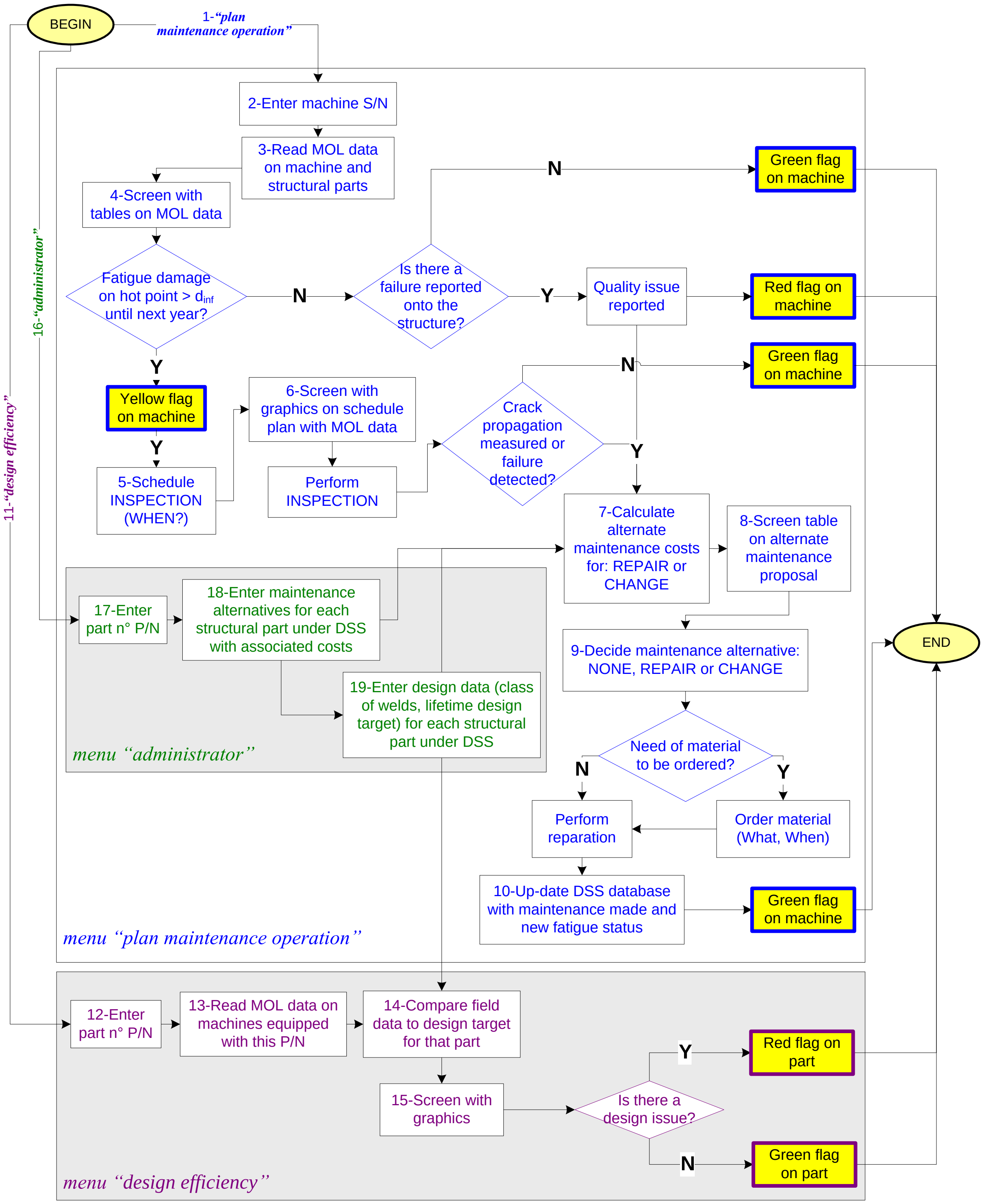


Figure 5: Decision flow chart for A5

4.5.2 Users of the DSS

Considering DA5.3: “design of the A5 demonstrator” delivered month 18, the DSS will be used during the following scenes of the demonstration case:

- Scene 4: in case **machine owner changes**, application severity or machine configuration may change; the fatigue damage and inspection plan must be up-dated.
- Scene 5: if **application severity change** is detected, the fatigue damage and inspection plan must be up-dated as well.
- Scene 6/7: When a **maintenance operation is made**, DSS should be up-dated with new status and fatigue damage of critical point may change (in case of rework/repair, or part change).
- Scene 8: At any time, DSS on **design efficiency** could be made by CAT designers

Figure 6 is a scheme to represent the Promise architecture and DSS end-users.

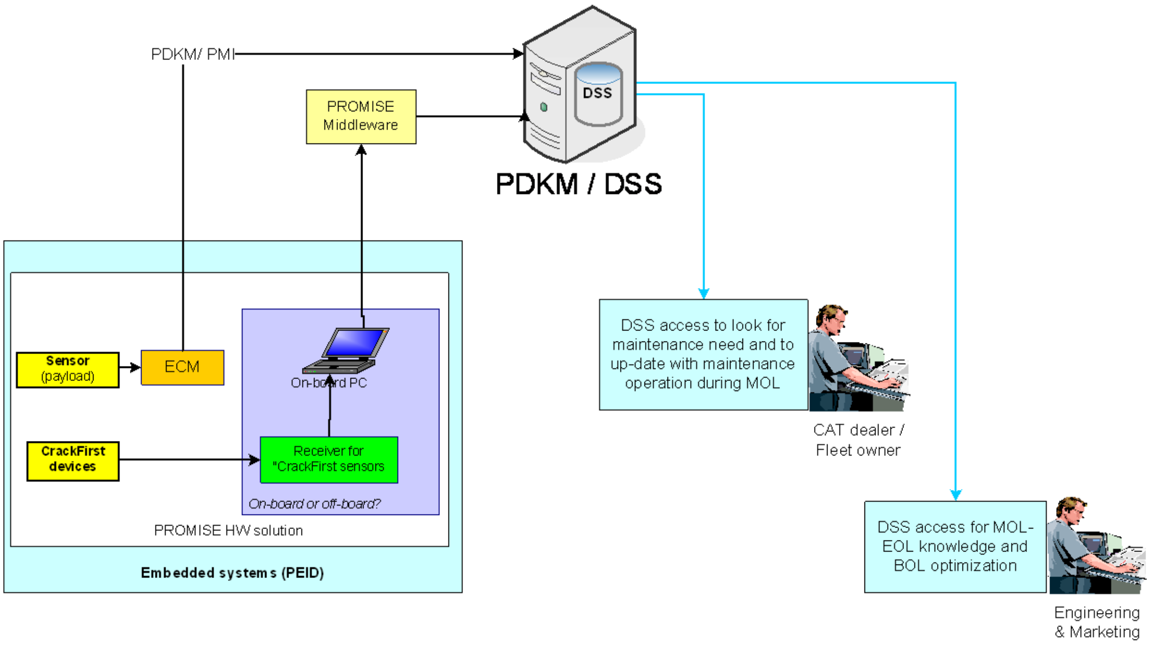


Figure 6: DSS use for A5

4.5.3 Evaluation and requirements of the solution

From DSS user requirements (DR8.1) and DSS specifications for DSS V1 development (DR8.5), the complete set of DSS functionalities were provided (status at month 24).

In table 1 below, DSS V2 program and screen shots have been evaluated regarding the DSS functionalities primarily specified and the attributes characterized in DR8.4 chapter 3.1.1.2.

Unfortunately, at month 39, the A5 DSS V2 being neither integrated to PDKM nor interfaced with DSS/GUI, it is not possible to determine the interfaces functionalities and to check what has been programmed. Our evaluation is therefore based on screen shots specified by the A5 DSS programmer

Functionalities	Evaluation score (DSS V1)	Comments on A5 DSS V1	Evaluation score (DSS V2)	Comments on A5 DSS V2
Estimation of remaining life of structural parts	4	based on fatigue damage sensors	5	based on fatigue damage sensors
Support service dealer for scheduling maintenance & repairs	3	no automation	3	no automation
- Provide logistics outputs (for repair parts to be supplied)	1	not included	1	not included
- Propose alternate maintenance (inspect, repair, change)	4	OK	4	available from DSS V1
- User interfaces for parameters inputs	5	OK on Java program (screen shots)	5	OK on Java program (screen shots)
Support work site management of fleet owner	2	not included (possible DSS manual use)	2	not included (possible DSS manual use)
Capability of machine usage follow up	1	not included	4	considered in DSS v2
- Follow up on machine payload	1	" "	4	considered in DSS v2
- Follow up on machine owner	1	" "	1	not included
- Follow up on machine configuration	1	" "	3	considered in DSS v2
Capability to give field results on quality	1	not included	1	not included
Capability to provide recommendations to designers	1	not included	1	not included
- Capability of field data access for fleet of machines	3	partially	3	partially
- Weibull analysis provided	1	" "	1	" "
- Graphical results for a population of machines	2	done only for one machine (screen shot)	1	not included in DSS v2 algorithm
- Capability to provide segmented results (market, application)	1	" "	1	" "
- Capability to identify mass customization opportunity	1	" "	1	" "
- Field data collection in accordance to design hypothesis	1	" "	1	" "
Capability to access recurrent problems for a fleet of machines	1	not included	1	not included
- Provide design analysis (quality issue, design conformance)	1	not included	1	not included
Attributes	**Evaluation score** (DSS V1)	**Comments on A5 DSS V1**	**Evaluation score** (DSS V2)	**Comments on A5 DSS V2**
DSS cost of installation	-	not estimated	-	not estimated
DSS cost of maintenance	-	not estimated	-	not estimated
Accessibility via Web	1	no access available at month 23	1	no access available at month 23
Simplicity of use	3	should be	3	should be
Workability	1	impossible to assess	1	impossible to assess
Availability	1	impossible to assess	1	impossible to assess
Adaptability	2	should be adaptable (java program)	2	should be adaptable (java program)
Usability	2		2	
Utility	3	current estimated remaining lifetime	3	current estimated remaining lifetime
Evaluation 1: not satisfactory, 5: highly satisfactory				

Table 5: Basic evaluation of the DSS versus expected functionalities

4.5.4 Conclusion

Considering the more complete DSS specifications, the second end-user evaluation can be summarized as follows:

- A predictive maintenance model has been programmed using fatigue damage data, application severity (machine payload, fuel consumption rate), and design information to calculate estimated remaining lifetime of the structure;
- More complex algorithm to estimate remaining lifetime depending on application severity (payload and machine configuration) was programmed in version 2;
- Real DSS GUI is not available since there is not much progress on integration between PDKM and DSS algorithm.

- For engineering and marketing support, a decision system module should be added to analyze design performance of a fleet of machines considering existing design criteria. This module is critical to one major economic benefits which is mass customization; In the DSS version 2, this functionality was not implemented.
- Further DSS refinement could be required at last, regarding attributes of the system, and in particular, usability of the system to improve value added to the end-user (by adding DSS outputs for example such as logistics information)

4.6 Middle of Life: Predictive Maintenance of machine tools (A6)

FIDIA has carried out an investigation on the "maintenance issue" in the machine tools field and has verified among its customers and partners the will of investing in the reduction of costs in maintenance. Our clients have evaluated that "maintenance" is very important in present industrial processes. A sudden interruption of the machine impacts on the competitiveness of the company and is often the most important contribution to the "total production cost".

All above mentioned, brought FIDIA to dedicate efforts in developing a new idea and concept of maintenance in machine tool field: the Predictive Maintenance.

The development of a Predictive Maintenance framework is expected to improve the quality of our product and service that will result in a business opportunity for FIDIA.

4.6.1 Objective of the A6 DSS demonstrator

The main objective of the demonstrator is to demonstrate that maintenance practices for machine tools can be enhanced shifting from preventive maintenance and breakdown intervention to predictive maintenance approaches in order to:

- Reduce the number of machine stops for maintenance
- Keep high the quality level of the products
- Minimise the overall lifecycle costs of the components
- Avoid component breakdowns
- Take into account machine availability while planning maintenance interventions

Periodic diagnostic tests on the milling centre provide indicators on the "health state" of its mechanical components. These indicators are analysed by SW tools that support the user and service to analyse the working conditions of the machine.

The A6 DSS is made of three modules:

- the diagnostic module that transforms field data collected from sensors in useful indicators of the working condition of the machine
- the ageing module that transforms the previous indicators in an estimate of the wear and the "health state" of the machine
- the cost maintenance module that enables the service provider to interpret the aging data to plan maintenance actions (technical and economical).

The DSS is integrated with a PDKM (Product Data Knowledge Management) at the producer site to integrate and re-use information from different phases of the product life.

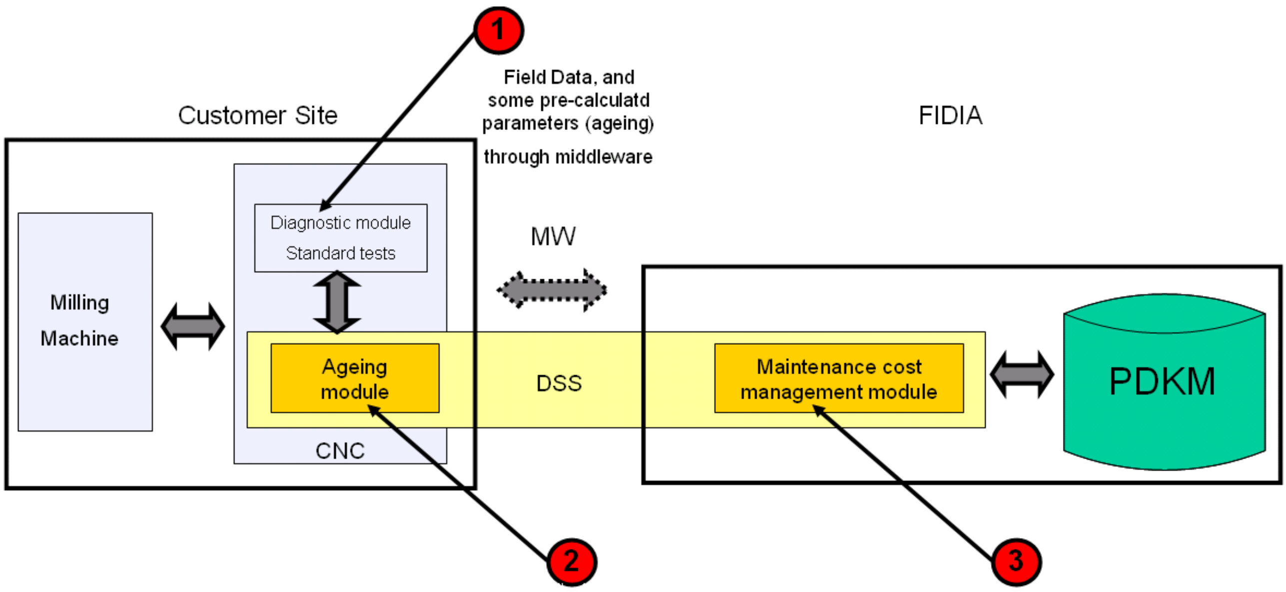


Figure 7: Architecture of A6 scenario

Innovation proposed in this scenario is mainly linked to DSS developments. DSS is not simply a tool used to manage "remotely" service of the milling centres (concept known as teleservice or telediagnostic), but innovation is reached when DSS *predicts* a possible incipient fault on the machine (i.e. ageing module) and *suggests* the service technician the most appropriate strategy in providing service to the customer (i.e. maintenance cost management module). These results are due to the implementation of complex algorithms (by means of analytical and fuzzy logic calculations) in the DSS.

Points of strength of algorithms developed in DSS are that, they have been developed using a methodology that allows to implement new algorithms on different machines without huge efforts; they didn't require an extensive data acquisition campaign since they are based half on data from machine tests and half from experience; they are ready to be fine-tuned when new data from the field will be available.

These algorithms obviously use as input data available from a diagnostic layer also developed during the project. This diagnostic module is strictly related to the "special" milling machine product.

Diagnostic is not a recent innovation in the field of the machine tools but the approach used is new. In fact the diagnostic tool doesn't require any additional sensor, while in all the applications found in literature other sensors were mandatory (mainly vibration sensors). Instead it uses already installed sensors that record useful data during motion tests appropriately characterized. These tests can give information about the working conditions of the machine.

However, both diagnostic and the predictive data are used to minimize the lifecycle cost of the machine, so maintenance is viewed in a broader way and optimized not only by the technical factor.

The overall integrated DSS is innovative in the market of the milling centres because it allows communication and integration of the user and the maintenance provider which can exchange and share data and information on the status of the machine and components. The approach proposes to delegate some maintenance actions to the user itself without the need of the maintenance provider on site, while other actions may be planned more efficiently for all the machines considering the impact of these actions on the residual life of the machine.

4.6.2 Evaluation and requirements of the solution

FIDIA has developed PROMISE A6 DSS prototype for predictive maintenance purposes. The approach used was based on the retrieval of data from a real industrial environment. However, due to the difficulty of testing the DSS on machines characterized by an incipient failure state (i.e. milling machines work for many years without any mechanical problems), the test has been executed on historical data (when available) and simulated data, following the procedures below:

- Start the A6 DSS
- Choose a machine
- Collection of historical test data
- Evaluate the status of the mechanical axis
- Provide a list of suggested actions for maintenance

At the end of the test, the results have been evaluated and a global assessment of the system functionality has been made. A brief list of comments and notes can be seen in the table below:

DSS Functionalities		
Functionality	**Evaluation of DSS v.2**	**Comments to DSS v.2**
Classification of maintenance action (do nothing, modify, replace)	4	The suggested action is adequate all times
Assessment of residual life of components	-	No more performed (see item 3)
Assessment of residual life of axis	4	DSS has been fully implemented for 3/5-axes machines
Adequacy of the modelling (true wear-out estimate)	4	Thresholds have been set accurately based on the technical service experience
Retrieve data from other devices (PDKM,RFIDs,CNC,etc.)	3	Link CNC-PMI-PDKM is active but not always correctly working and available
Management of multiple machines	5	The integrated DSS has been extended to manage cost of maintenance of many machines which are clustered in geographical areas
Identification of machine and components history (production, owners, replacements, maintenance actions, etc.)	3	Data migrated into PDKM
Import residual life data from CNC	4	Automatic import available
Support to predictive maintenance	4	See item 1
Security and reliability	-	Not assessed because only authorized personnel has access
Other		
Attributes	**Evaluation of DSS v.2**	**Comments to DSS v.2**
DSS cost of installation	-	Installation cost estimate is low because SW modules installation doesn't require any special efforts
DSS cost of maintenance	-	Low because main cost is related to the start-up of the system
Accessibility via web	3	Access available using only Firefox browser
Availability	-	Not fully available due to PDKM connection problems
Adaptability	3	Difficult to customize
Usability	5	Easy to use
Other	-	Difficult to customize
Evaluation 1:not satisfactory; 5:high satisfactory		

Table 6: Evaluation of the DSS versus expected functionalities[5]

[5] DSS v.2 is the version delivered at M36. A6 did no evaluation in M18.

PROMISE DSS seems to cover all the functionalities required at the beginning of the project. Due to refinements done during the work, minor changes have been executed to DSS v.3 to fit A6 requirements.

For instance the integrated DSS has been extended to manage cost of maintenance of many machines which are clustered in geographical areas. The system can suggest to the maintenance provider actions which are necessary in the different components of the machines, so that the maintenance provider can prioritize its intervention in the different geographical areas.

The most important issues have been faced setting up the PMI-PDKM connection, for exporting data from CNC into the central database.

The total costs of the solution has not been yet quantified and made available to the DSS users, in order to implement an adequate exploitation strategy.

4.7 Middle of Life: Predictive Maintenance of EEE (A8)

The main purpose of Indesit demonstrator is to show the possibility of using predictive maintenance for white goods applications, for satisfying the customer with a timely and more effective technical assistance service and offering new business opportunities to household appliance manufacturers, by selling the extension of guarantee period at a competitive cost level.

This could be reached by implementing the scenario showed in Figures 8a and 8b, where the actors are: a refrigerator DA (Digital Appliance), an interface device SA (Smart Adapter) placed between the power cable of the household appliance and its electric plug (Outlet), a wireless communication link (RF comm. system) between said SA device and a remote monitoring centre, where the Decision Support System (DSS) performs predictive maintenance.

This monitoring centre is typically placed in a remote web site (Fig 8a), accessible via internet, but it could also be installed locally (Fig 8b), as a tool used by technical assistance staff.

In the first option the interface device SA should be connected, through a suitable gateway RG (Residential Gateway) able to communicate via internet, to a remote web site where is placed the monitoring centre; in the second option, SA device simply communicates with a local monitoring system, represented, for instance, by a notebook Computer or a PDA.

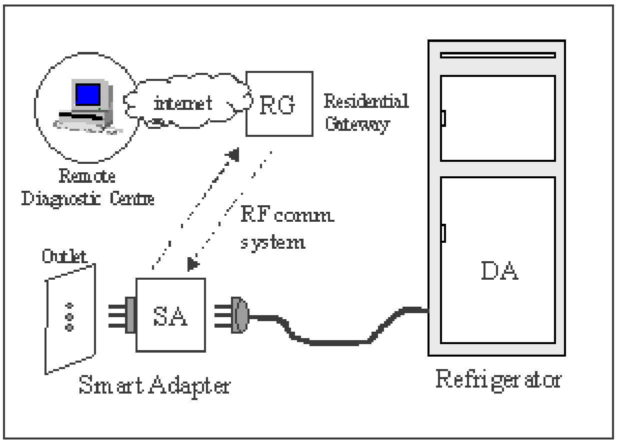


Figure 8a

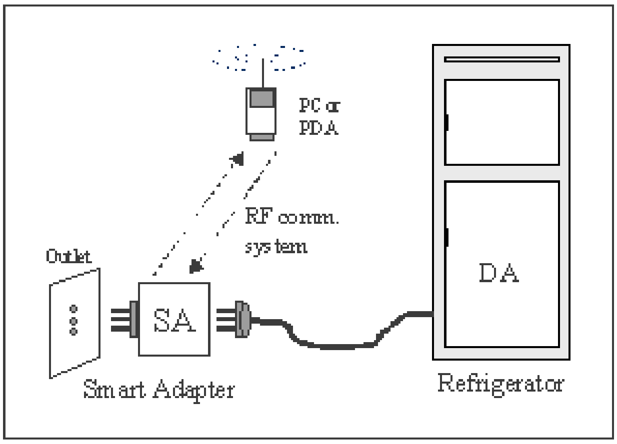


Figure 8b.

In order to pursue the aim of predictive maintenance, the household appliance should exchange data, day-by-day, with said remote monitoring centre, using a data transmission system suitable with the cost restrictions of white goods.

To solve price problems is absolutely strategic to make the product marketable; the ideal solution should be using a communication technology without additional costs for the household appliance.

The communication technology adopted by Indesit to solve these cost problems is named ULC (Ultra Low cost power cable Communication), an inexpensive technology developed inside TEAHA European project. This technology uses the interface device SA, represented in previous figures and described in detail in chapter 4, which carries out a PROXY function between the household appliance and the wireless system that transmits data to the remote (or local) apparatus that performs the predictive maintenance expected by PROMISE.

4.7.1 Objective of the A8 DSS demonstrator

The PEID (refrigerator electronic board) controls constantly the behaviour of the refrigerator, doing a first diagnosis of the components, and providing summarized data about the daily behaviour of the monitored device. The PEID send such data to the SA, which stores these data and adds the measuring of the electrical quantities.
Data coming from PEID together with the electrical quantities measured by the SA are sent to the centralized server to be further analyzed; this will allow the DSS to estimate the condition of the whole refrigerator and especially of complex subsystems like the thermal circuit.
This esteem is achieved using a fuzzy expert system, which is composed by four ageing modules, one for each subsystem and is tuned with Indesit experts' experience. After this esteem of the ageing, the failure is evaluated using statistical regression. Until now, with the data acquired, the linear regression seems the one that fits best, in future, with more data, it will be possible to use also other regression shapes.
After all the diagnostic is done, all the data and the estimated aging of the components will be stored and made available on the PDKM. The user will be able to select the different refrigerators using refinement keys to have different views on the status of the installed fleet.
In details there will be the following views and sub-views:

- Warning view
    - Single product Item warning view
- Predictive maintenance DSS
    - Single product Item view
    - Component diagnostic view
    - Sensors of the item
- Spare Parts Management
- Maintenance mission management
- Management of the Aging DSS

The different views will allow the user of the system to see all the products that have a warning, or a breakdown or an incipient fault (Warning view and Predictive Maintenance DSS), looking also directly to the data to understand better the behaviour of the device (the sub-views of the previous two). Moreover it will be possible to subdivide the products from the place they are installed, and all this will allow a planning of the maintenance missions (Maintenance mission management).

Finally the system will provide an estimate of the spare parts required, allowing a better management of them (Maintenance mission management).
A DSS management view is also desired to allow an easy modification of the DSS thresholds.

4.7.2 Evaluation and requirements of the solution

The development of the solution has been guided by the following needs:

- The identification of faults on the products
- The identification of incipient faults on the products
- An easy overview of the whole installed product fleet
- A structure to improve maintenance missions management
- A structure to improve spare parts management

To achieve all these objectives the DSS has been structured in three parts;

- **The onboard diagnostic module**: it is a software module that is running continuously on the device and analyzes all the data of the refrigerator and provides a warning or an alarm on unexpected or faulty conditions
- **The remote diagnostic module**: it is a software module that will run once a day or once a week for every refrigerators when the data from the field arrives to the centralized server. It will be able to do more complex diagnostic analysis, as these of the thermodynamic circuit.
- **The DSS GUI interface:** it allows an easy management of all the installed refrigerators, allowing different views on them, knowing all the incipient and occurred faults, providing a list of geographically ordered items and of the spare parts needed for the forecasted maintenance actions.

The usage of the first two parts will be asynchronous from the usage of the GUI and so the usage of the system from the users.

The user will mainly do the following steps:

- Start the A8 DSS
- View a list of the refrigerators with warnings or incipient faults
- View the list of the refrigerators ordered by geographical location
- Send the list to the maintenance crew
- View a list of the needed spare parts
- Send the list to the spare parts warehouse.

DSS Functionalities		
Functionality	Evaluation of DSS v.3	Comments to DSS v.3
On site Diagnostic	5	Works well and provides useful data to the maintenance crew.
Remote Diagnostic	4	The diagnosis is adequate to the analized product.
Adequacy of Aging DSS	4	It is based on technical service experience, and can be improved with statistical data from the system.
Management of multiple products	4	It is possible to check all the products connected to the system.
Maintenance Missions Management	4	Allows to manage maintenance mission minimizing them and their cost.
Spare Parts Management	4	Allows a prevision of spare parts needed in next period.
Attributes	Evaluation of DSS v.3	Comments to DSS v.3
DSS cost of installation	3	It has a fixed cost since it requires changes in the product board. This cost has been minimized but cannot be removed; the advantages for the customer should be so high to convince him to spend more.
DSS cost of maintenance	4	The centralized system is easily maintenanceable through a txt config file.
Accessibility via web	3	Problems related to the browser program/version
Availability	2	Problems connected to the SAP server, which is difficult to access.
Adaptability	4	The system can be easily adapted to different products.
Usability	5	The system interface is easy to use
Other		
Evaluation. 1: not satisfactory; 5: high satisfactory		

Table 8: Evaluation of the DSS versus expected functionalities

The tests did on the four diagnostic modules provided good results. They have been tested with real data coming from some experiments designed together with POLIMI and executed in Indesit's labs, and the esteem is sound with the expected results. The refrigerators were aged artificially reducing the pressure of the gas of the thermodynamic circuit. The DSS modules recognize this problem evaluating the efficiency of the whole refrigerator, and provide an evaluation of the ageing of it. This results have been compared and confirmed by Indesit's maintenance experts.
The prediction module, using the diagnostic data, has been able to provide a correct esteem of the time left before the inducted failure.

The DSS interface, developed by POLIMI together with Indesit management, has been implemented by SAP; the system provides the expected functionalities.

Concluding the diagnostic modules proposed have been tested, verified and proved to achieve their aim; the DSS GUI has been developed and will provide a useful and usable interface that allows to achieve a centralized and prediction based maintenance mission management.

4.8 Middle of Life: Decision support for Telecom equipment (A9)

This section contains the evaluation of the A9 DSS demonstrator.

4.8.1 Objective of the A9 DSS demonstrator

The DSS for the A9 MOL Demonstrator is intended to provide assistance to customers (users of Intracom Telecom components and systems) and trained Intracom Telecom technicians to solve the problems they encounter through the reuse of best practices i.e. the best solutions of previous cases.

An overall view of the functional modules in A9 including DSS and main sources of data is provided in Figure 9.

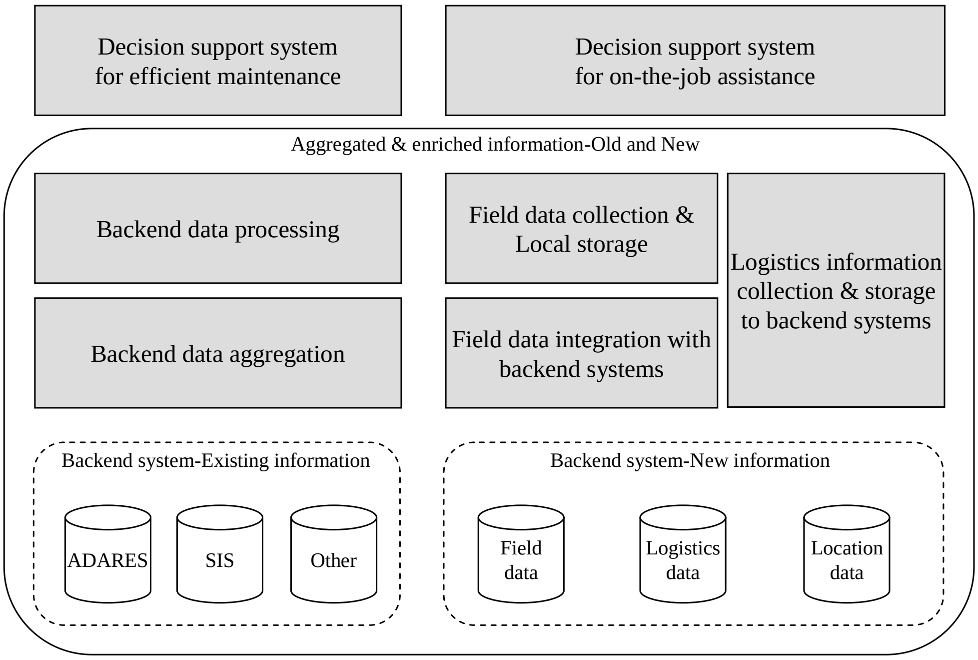


Figure 9: Functional modules in A9

There are 3 main problem solving/decision making activities within the application scenario A9 which are:

- **Corrective maintenance**: decision making regarding what actions to take when a failure occurs;
- **Solving IBAS problems**: solutions for technicians/service to solve problems in IBAS (Intracom Broadband Access System);
- **Online customers problem solving**: online “troubleshooting” solutions (to frequent well-defined problems).

Other problem solving/decision making activities can be considered:

- **Product performance traceability**: access to information about incidents happened in a certain time and place regarding product performance (for example: CPU utilization);
- **Identification of causes of problems/failures**: Decision making about product improvements;
- **Identification of components/aspects to improve**: Decision making about improvements to make on the next generation of products.

All the decision strategies that were described in DR8.2 are case-based techniques.

The main concept in case-based technique is that of "case". According to Avramenko and Kraslawski (2006) a case can be defined as a problem solving episode of experience that is represented as a pair composed of a problem and its solution. Many cases are collected in order to build a case library (case base).

To solve a current problem, the technique retrieves a past problem (together with its solution) that is judged to be similar to the current problem according to some similarity measurement.

Often some adaptation of the past solution is required to make it suitable to the current problem. Sometimes adaptation rules are needed for an automatic adaptation of past solutions to the current problems. However, in the case of well defined repetitive problems, exact matching between the current case and a past case can be assumed.

A general view of the case based technique is shown in Figure 10.

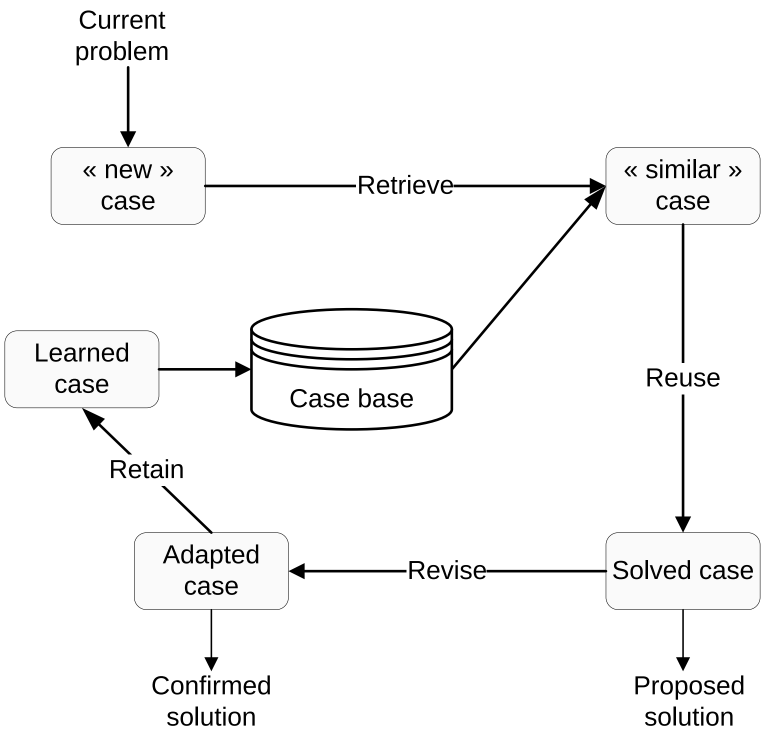


Figure 10: Case-Based Reasoning cycle developed by Aamodt (Schmidt et al., 2001)

4.8.2 Evaluation and requirements of the solution

First user requirements and DSS functionalities were specified in deliverable DR8.1 (delivered month 12). The following table presents the results of the final evaluation performed regarding the DSS v.3 functionalities delivered in M36.

DSS Functionalities		
Functionality	**Evaluation of A9 DSS v.3**	**Comments on A9 DSS v.3**
Solving IBAS problems: solutions for technicians/service to solve problems in IBAS (Intracom Broadband Access System)	-	-
- Capability to retrieve the most similar case(s)	4	Ok
- Capability to use the case(s) to attempt to solve the problem	4	Ok
- Capability to revise the proposed solution search if necessary	2	-
- Capability to retain the new solution as part of a new case	4	Ok
- Representation of cases	3	Need to evaluate with real data
- Fine tuning of DSS parameters	1	Algorimths only evaluated
- Similarity measurement	4	All "similarity"parameters included in algorithm
Product performance traceability: access to information about incidents happened in a certain time and place regarding product performance (for example: CPU utilization)	2	PDKM related. Functionality is available from PDKM.
Identification of causes of problems/failures: Decision making about product improvements	-	Future
Identification of components/aspects to improve: Decision making about improvements to make on the next generation of products	-	Future
Attributes	**Evaluation of A9 DSS v.3**	**Comments on A9 DSS v.3**
DSS cost of installation	-	No estimated
DSS cost of mantainance	-	No estimated
Accessibility via Web	5	Only interface is WEB
Simplicity of use	3	NOT tested with data
Workability	3	
Availability	3	Easy access
Adaptability	2	iViews-only based environment
Usability	-	
Utility	3	
Other		
Evaluation 1: not satisfactoty, 5: highly satisfactory		

Table 9. Evaluation of the DSS versus expected functionalities

4.9 Begin of Life: DfX knowledge generation (A10)

The new, improved algorithm is now implemented in the current version of the A10 DSS. It is worth to mention that due to the complex data set structures and the high quantity of diagnostics data related to the failure reports (FAM) several modifications were needed to meet the specified targets.

The new version uses FAM as main clustering reference points for diagnosis, operational and environmental data (further called “Field data”) and allows a real advantage to support the search for the root causes.

4.9.1 Objective of the A10 DSS demonstrator[6]

While data contained on FAM focus on quality indicators (like reliability, availability, maintenance efforts, etc.) diagnostics data contain information about the operational environment and the behaviour of parameters in the context of failures and faults.

The combinations of these two sources of information can create new knowledge which gives the engineer strong hints on i.e. failure causes, systematic errors and other information necessary to enhance the quality of a new design.

Today, this combination of data is not only a wasteful task. In many cases the knowledge is hidden behind complex dependencies and therefore never discovered.

The availability of data depends on the kind of component and thus the possibilities for findings through the DSS will be different as well.

FAMs:

Safety related, non redundant components (like wheels) shall never fail randomly (because this could cause severe accidents). Therefore no data for corrective maintenance (= failures) are available. To achieve this, these components underlay a very rigid preventive maintenance schedule. These kinds of data are therefore available in the test data set.

Electronic components underlay almost no preventive activities. They fail randomly.

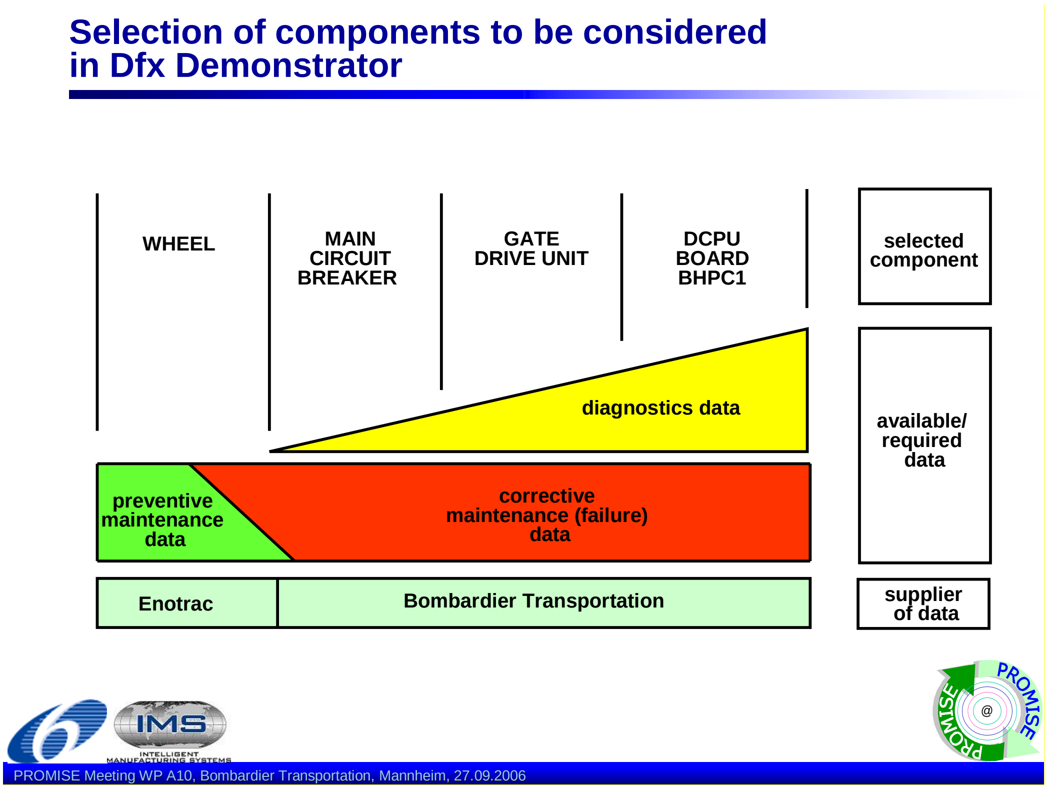
Thus for these components FAM can be provided.

Some components are in between, like the MCB. They comprise an electrical part and a mechanical part.

Initially four test components were selected to cover the entire range of practical possibilities.

Due to availabilty of diagnostics data (which were not needed in the algorithm approach) now only the DCPU board was selected as test component (see figure below).

[6] A detailed description of the DSS scenario of A10 can be found in DR8.3.



Diagnostics data:

The availability of diagnostics data depends on the connectivity of the considered component to the onboard control system.

Components of the control system itself have a very good coverage. Mechanical components are not extensively monitored in terms of diagnostics (they are maintained preventively). This will for sure change in future and the DfX process will support this development by its gained knowledge.

The chosen product that is considered for the evaluation of the DfX demonstrator is part of the traction chain of an electric locomotive. The traction chain is a central function of an electric locomotive, where BT gathers various field data which can be used to validate the demonstrator.

In accordance to DA10.3 and by using methods of data mining and pattern search as mentioned in DR8.3 based on field data of the TRAXX locomotive fleet the DSS will provide :

- information on reliability indices, like failure rates or MDBF of the considered system;
- information on root causes of failures and faults of the considered systems;
- the possible causes should be ranked on their resp. likelihood

Therefore the system will identify interdependencies between the considered field data and point out the respective significance.

These will finally support the applying engineer to find the root causes of failures and faults and to improve the respective product.

Structure of the DfX decision strategy

The DfX decision strategy is composed of two main steps: (i) information generation, and (ii) knowledge generation. The purpose of the information generation step is to determine how well the component/subsystem/system is performing and the purpose of the knowledge generation step is to determine the main causes behind the level of performance achieved with respect to the design aspects considered in order to aid designers in improving the next generation of locomotives.

While defining the current DfX decision strategy the following restrictions are considered:

- the decision strategy relates to reliability design aspect;
- only selected components are considered;
- The field data to be considered for the information generation is selected by the FAM reports;
- For the calculation of the DINF which represents the trend of the failure number, the value of parameters which is required is given;
- The information generation is included in the demonstrator of DSS;
- The generation of knowledge is included in the document as a case study;
- The coefficient between field data and DINF is calculated by one FAM report;
- The field data is enough to calculate the coefficient during the selected period of the FAM;
- The value of parameters for clustering is given;
- The function structure are given for the selected component;

A general view of the current DfX decision strategy is shown in the flowchart of Figure 31

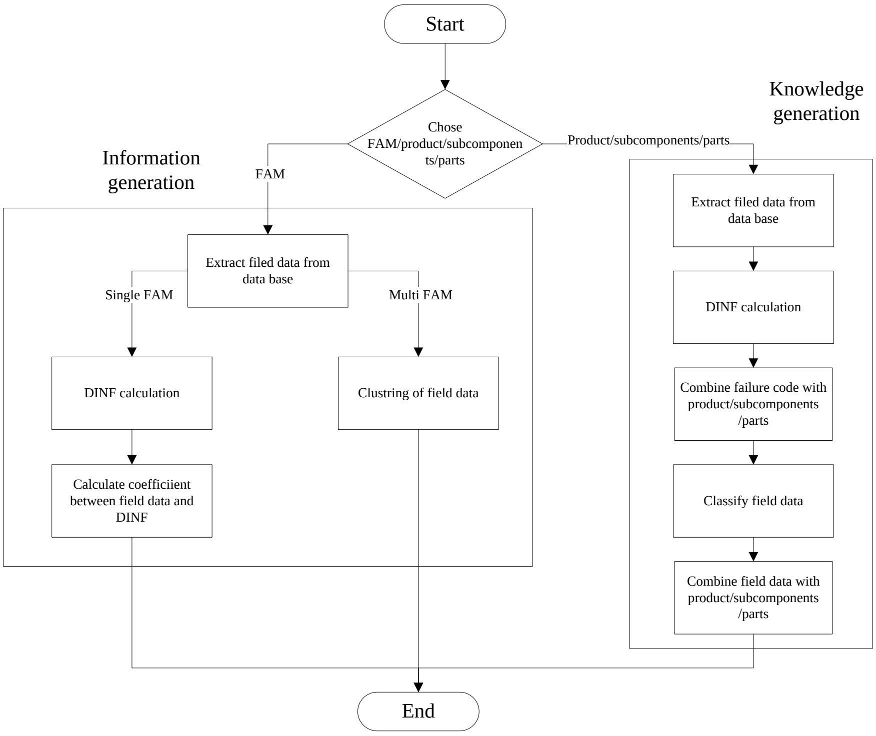


Figure 31: Flowchart for the current DfX decision strategy

In our decision strategy, the measure for component/subsystem/system performance is the reliability. Hence, we evaluate the reliability with the failure number considering the change over time. This evaluation is calculated as a kind of index value named a degradation index of the number of failure (DINF). The DINF represents how the failure number is changed during selected period. It includes three concepts; how much failure number happen from usual failure number, how much the failure number are close to the critical level of reliability, and how quickly the failure number increases. The DINF is calculated for each failure code during the selected period.

In addition, we apply clustering method for the gathered field data during the selected period. The clustering method is used to separate the distinctive data from usual data set.

Figure 14 shows the flowchart of information generation in our decision support system demonstrator.

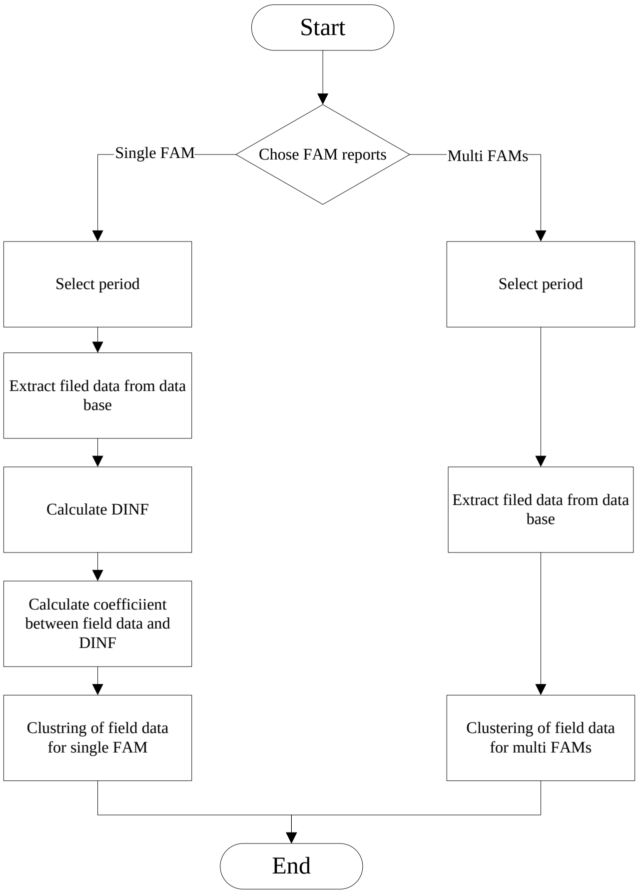


Figure 14: Flowchart for information generation

For the knowledge generation, we extend the generated information so as to find root cause using structure model applying the process shown in Figure 15 below.

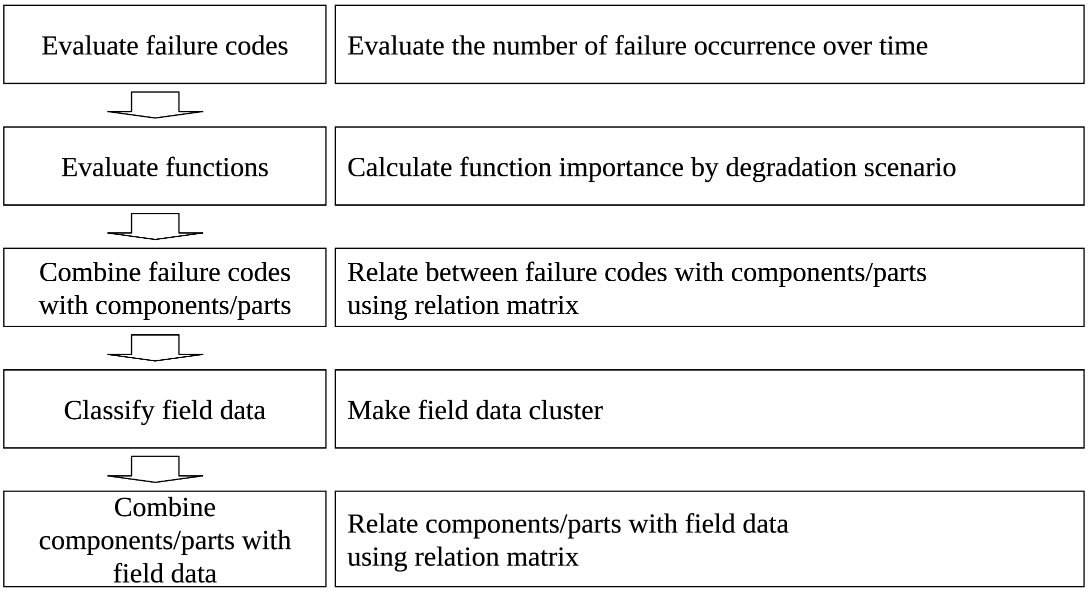


Figure 15: The knowledge generation procedure

4.9.2 Evaluation and requirements of the solution

With the DfX demonstrator implemented, the engineer will be provided with a single point of entry to all these available information (raw data) in convenient graphical way, the graphical user interface GUI. This feature is important, because not all information contained in the raw data will be subject to the algorithm in any case. Therefore the engineer must have the possibility to get access to the full data information after he gets a design hint following the scenarios described above.

In the current version of the DSS the following points are considered. It is now possible to consider all parameters relevant for the aspect to analyse at the same time. The following table presents the results of the final evaluation performed regarding the DSS v.3 functionalities delivered in M36.

DSS Functionalities		
Functionality	**Evaluation of DSS v.3**	**Comments to DSS v.3**
Coverage of BOL scenarios	5	Spec. scenarios are covered
Coverage of selected systems	4	Not all spec. systems are covered due to non-adequate input data
Performance of data provisioning process	3	Too many manual actions; has to be improved
Performance of algorithm	5	Tested with restricted data set
Usage of data	5	Link between failure report and diagnostics data is implemented
GUI usability	4	estimation by spec. GUI (not yet implemented)
Root cause analysis	4	Basis results are available; engineering judgement essential
What-if analysis/cross-level results	3	Available by manipulating input data
Retraceability of results	4	Possible in principle; takes some effort
Presentation of results	4	Quick overview; outstanding tests in practical engineering
Support to system design	4	Good starting point for root cause analysis; extended analysis due to future enhancement
Portability	-	Not assessed due to lack of experience
Security and reliability	-	Not assessed because only authorized personnel has access
Other		
Attributes	**Evaluation of DSS v.3**	**Comments to DSS v.3**
DSS cost of installation	-	Cost estimation low; depends on SW portability
DSS cost of maintenance	-	Low. Cost related to system start-up &future enhancements
Accessibility via web	-	Due to further enhancement
Availability	-	Not fully available due to PDKM connection problems
Adaptability	4	Estimated as no complex task
Usability	5	Estimated easy to use (if GUI is implemented to spec.)
Other	-	
Evaluation 1:not satisfactory; 5:high satisfactory		

Some requirements regarding the selection of inputs and functional extensions are provided below:

Selection of inputs:

- It is possible to collect the available field data of a selectable time interval for the consideration of failure events (FAM as clustering point) of the data objects (like from 1.1.2002 to 31.12.2004)
- It is possible to define a time span for the consideration of attributes per failure event like for each failure event of a data object a consideration of diagnostic data 4 weeks backwards and 0,5 h after the event).
- For the case where more than 3 attributes are to be considered, it will be possible to generate a graphical presentation by choosing 3 parameters after the calculation

Functional extensions:

- The objective of the current DfX decision strategy implemented in the new version of DSS prototype is to illustrate the transformation process of product field data into DfX knowledge. It is only part of the overall decision strategy of the DfX demonstrator and focuses only on the chosen component. Further refinements and extensions may be performed continuing this project in future.
- The ultimate goal of PROMISE DSS is to access data that is stored in PDKM.This will be possible after the integration between the current DSS prototype and PDKM.

4.10 Beginning Of Life: Adaptive Production (A11)

4.10.1 Objective of the A11 DSS demonstrator

In the A11 application scenario, Teksid Aluminum is supported by a DSS during the preparation of the offer to FIAT, from both the technical and commercial sides. To accomplish a request for product modification means for Teksid Aluminum to decide how to modify its production systems.

The DSS has the purpose to help Teksid Aluminium in:

- decreasing the total lead time of the requests for product modification by exploiting the speed of the developed algorithms;
- decreasing production costs by suggesting the most profitable solutions;
- decreasing unnecessary investments by adsorbing the future requests in an adaptable way.

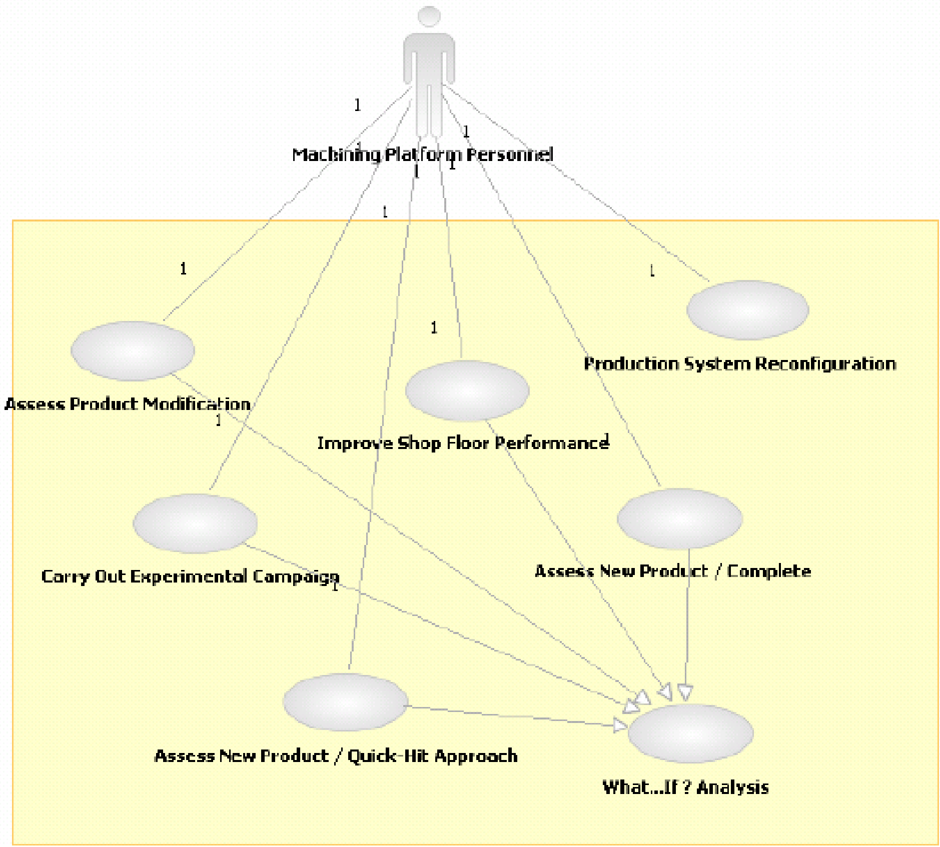


Figure 14: Use Case Diagram for the A11 DSS Demonstrator

There are two main classes of decision functionalities inside the A11 DSS Demonstrator:

- The **What … If? Analysis** set of functionalities enables the user to carry out different kinds of analyses on the effect of a particular change in the production process and/or production system, given as input a specific request of changing the demand level and/or some of the technological features of a particular product. This change in the product requirements is driven by the data collected on currently existing product instances or on instances of former product types. The same What .. If? analysis can be also carried out on a new product. It must be possible for the user to choose the set of parameters to be displayed as output of the analysis, and the parameters of the computation as well.
- The **Production System Reconfiguration** functionality is recalled by the user when he wants to determine the optimal reconfiguration policy for the production system/process, given a certain production problem, where the product can vary over time not only in demand but also in its technological features. These potential changes are specified in a user-friendly fashion directly by the user, in form of product evolution scenario, directly starting from the field data collected on previous products of the same type/family.

The users of the A11 DSS Demonstrator are, as specified in Figure 14 (see the indicated actor), the production process and production system designers of the Machining Platform, which is the Technological Platform of the end-user that most needs the A11 DSS Demonstrator. The identifier of the actor in the Use Case Diagram, i.e. "Machining Platform Personnel", indicates the generic employee of the Machining Platform, who generally acts both as production process designer and as production system designer and who generally performs the whole decision process. In case the two people are actually different (imaging another firm adopting the A11 DSS Demonstrator), each of them can use the portion of the tool and of the related interface corresponding to his own competence.

Detailed descriptions of the specific use cases/functionalities can be found in previous deliverables produced by WPR8, in particular DR8.8.

The core of the analytical performance of the A11 DSS, on which each of the use cases/functionalities above are based, is represented by the **Physical Performance Evaluator**, one of the components of the overall A11 DSS, also already described in some details inside document DR8.8.

This component directly impacts on the overall performance of the Adaptive Production DSS, and specially on the possibility to sensibly cut down the lead times for Teksid personnel to prepare the commercial and technical offer to be delivered to the customer. This represents the most important business outcome of the whole A11 scenario and demonstrator. Next section will briefly summarize the analytical performance of the **Physical Performance Evaluator** component.

4.10.2 Evaluation of the analytical performance of A11 DSS

The physical performance of each production system configuration under evaluation is represented by its throughput (pieces/hour) and the steady-state probabilities of being blocked or starved. Each run of the Physical Performance Evaluator algorithm provides these results for a pre-specified system configuration.

The most important set of performances for the Physical Performance Evaluator as an algorithm are:

- *Lead Time* to solve the estimation problem;
- *Accuracy* in the estimation of the throughput and steady-state probabilities.

The *Lead Time* performance is very satisfactory in every practical case, since the Physical Performance Evaluator algorithm is based on an analytical approach and a related solution method (analytical decomposition). The typical CPU-time for evaluating a single system configuration is only of a few seconds – always below 2 seconds in the cases of Teksid Aluminum production lines. This only thanks to the analytical approach.

The only alternative would have been to adopt a (discrete-event) simulation-based approach which, depending on the simulation tool used (or implemented from green-field), would always require much longer times. These longer times, if not always explainable with longer CPU-times (sometimes very good simulators are available), are always explainable with the time efforts needed to tune the simulation tool to simulate each specific configuration, to carry out the – generally many – runs of the experimental campaign needed to estimated the values of the parameters above, and for statistically analyzing the results obtained.

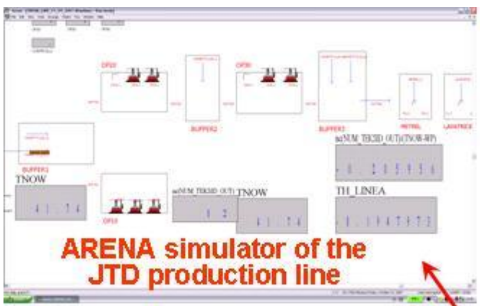
The *Accuracy* performance is also satisfactory, despite the fact that any analytical approach represents an abstraction of the system to be evaluated differing from reality more than what a simulator does. This because of the less number of details of the system manageable at the analytical level.

To evaluate this accuracy, a series of experimental campaigns was carried out, comparing the results obtained by the analytical solution – provided by the Physical Performance Evaluator – and the simulation-based solution - provided by a detailed simulation tool developed for this purpose – on the most recent configuration of the JTD Production Line at Teksid Aluminum Carmagnola Plant (Turin, Italy). This configuration was evaluated with respect to the production of all the three variants of the JTD 4- and 5-cylinders camshaft carriers currently in production.

In the following, a demonstration of this accuracy performance related to the estimation of system throughput is provided. The performance measure of this accuracy is the percentage error on the average throughput *eTh%*, defined as:

$$eTh\% = \frac{Th_s - Th_c}{Th_s}$$

where the subscripts *c* and *s* refer to analytical and simulative quantities respectively. Three different simulation campaigns were carried out (see next table), one for each product type. For each campaign, 20 runs were performed. A warm-up period correspondent to 750 finished work-pieces was set and each run terminates when 2000000 work-pieces have been produced. The average throughput provided by the analytical decomposition approach (Th_c), the average throughput provided by simulation (Th_s) – with the corresponding 95% confidence interval (in brackets), and the percentage error of the analytical throughput $e\%Th_c$ with respect to simulated throughput are shown in the table.



New analytical decomposition algorithm

	Th_s (±C.I./2) [pz/min]	Th_c [pz/min]	$e\%Th_c$ [%]
4 cylinders (46814176)	0.5783 (0.0006)	0.6139	-6.16
4 cylinders (55182788)	0.5782 (0.0004)	0.6183	-6.94
5 cylinders (46814178)	0.5686 (0.0005)	0.5830	-2.53
		Average Error	5.21

Tested cases: numerical results

Numerical results show that the analytical method is accurate and reliable for throughput assessment, being the percentage error around 5%. The most-widely used benchmarks for the judgement of the accuracy of an analytical method requires that it should be at maximum 10%.

Finally, the CPU-time was always below 2 seconds and the highest error (max(|e%Th_d|)) was 6.94%.

Functionality	Evaluation	Comment
Ability to cut down the lead time to prepare a complete offer for the customer	4	-
Ability to cut down the lead time to evaluate the physical performance (i.e. the throughput) of a single system configuration	5	-
Precision in estimating the physical performance of a single system configuration	4	-
Capability of providing optimal solutions for the system reconfiguration problem	5	-
Integration with application data from PDKM to ease the decision process	3	-
What If Analysis? - overall judgement	4	-
Production System Reconfiguration - overall judgement	4	-
Attribute	**Evaluation**	**Comment**
DSS cost of installation	1	see results from the A11 business analysis
DSS cost of maintenance	4	see results from the A11 business analysis
Accessibility via web	5	-
Simplicity of use	3	-
Workability	4	-
Availability	-	-
Adaptability	1	-
Usability	4	-
Utility	5	-

Table 10. Evaluation of the A11 DSS

5 Conclusion

The evaluation through the potential users of the application has yielded that the developed decision support technology has fulfilled the objectives for the PROMISE project. The following table summarizes the state of the development:

Scenario	Lifecycle Phase	Partner	Topic	Fulfillment rate of planned implementation
A1	EoL	CRF	Decision support for Disassembly	86%
A2	EoL	Caterpillar	Heavy Equipment Decommissioning	80%
A3	EoL	INDYON	Decision support for tracking & tracing of products for recycling	100%
A4	MoL	CRF	Maintenance of a fleet of trucks	90%
A5	MoL	Caterpillar	Decision support for predictive maintenance on structures	50%
A6	MoL	Fidia	Predictive Maintenance of machine tools	80%
A8	MoL	Indesit	Middle of Life: Predictive Maintenance of EEE	85%
A9	MoL	Intracom	Decision support for Telecom equipment	80%
A10	BoL	Bombardier	DfX knowledge generation	80%
A11	BoL	Polimi	Adaptive Production	85%

Most of the deficiencies relate to missing functionality that is required to turn the DSS prototype into a nice and convenient tool. However, since PROMISE is pre-competitive research not all of these features are really needed to prove its feasibility. Therefore, it is left to all application partners to continue the work in the desired direction.