Evaluation of the decision support demonstrator (Version 2)

Written by:
Gerd Große, Cognidata
Christian Seidemann, Cognidata
Martin Schneider, Cognidata
Dario Leo, CRF
Julien Mascolo, CRF
Bertram Winkenbach, BT
Ahmed Bufardi, EPFL
Marcel Huser, Bombardier Transportation
Daniele Panarese, FIDIA
Dimitra Pli, Intracom
Maurizio Tomasella, Polimi
Hui Cao, Cimru
Giovanni Felicetti, Indesit

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ABSTRACT:	This report contains the next 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 implementation of the second version of the prototype of the PROMISE decision support system (DSS) described in Deliverable DR8.5. It now includes the evaluation of the remaining workpackages

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APPROVED (QIM)	D. Kiritsis	

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Author(s)' contact information

Name	Organisation	E-mail	Tel	Fax
Christian Seidemann	Cognidata	christian.seidemann@cognidata.de	004961016559901	
Martin Schneider	Cognidata	martin.schneider@cognidata.de	004961016559901	
Gerd Große	Cognidata	Gerd.grosse@cognidata.de	004961016559901	
Julien Mascolo	CRF	j.mascolo@crf.it	00390119083911	
Dario Leo	CRF	Dario.leo@crf.it	00390119083189	
Ahmed Bufardi	EPFL	ahmed.bufardi@epfl.ch	0041 21 693 38 68	
Young Seok Kim	EPFL	youngseok.kim@epfl.ch	0041 21 693 53 03	
Jong Ho Shin	EPFL	jongho.shin@epfl.ch	0041 21 693 7331	
Marcel Huser	Bombardier	Marcel.Huser@ch.transport.bombardier.com	004144 3181041	
Daniele Panarese	FIDIA	d.panarese@fidia.it	0039 080 5856270	
Dimitra Pli	Intracom	dimpl@intracom.gr	0030 6972404973	
Maurizio Tomasella	Polimi	maurizio.tomasella@polimi.it	003902 2399 4892	
Bertram Winkenbach	Bombardier	bertram.winkenbach@de.transport.bombardier.com	0049621 70011388	

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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

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1 Purpose of this document

This report contains the PROMISE WP R8 Deliverable DR8.7: 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 DR8.7

As described in PROMISE_DoW, the main goal of Task TR8.4 and DR8.7 is to test and evaluate the DSS demonstrator, which were developed in Task DR8.3 and DR8.5.

2.3 Structure of Deliverable DR8.7

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 prototype.

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

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More detailed scenario descriptions can be found in the respective documents of the application workpackages, e.g. DR8.5. 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 DR8.7 and describes further steps.

3 Method of evaluation

In the phase of the definition of a 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.

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 first prototype assessment, available at month 18.

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 version of the DSS 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

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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)
9. Management of product's warranty and validation phase

[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 .

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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) ____

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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 PROMISE DSS, 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 prototype, 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 tool
- 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 tools. 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 M18.

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.

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- 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).

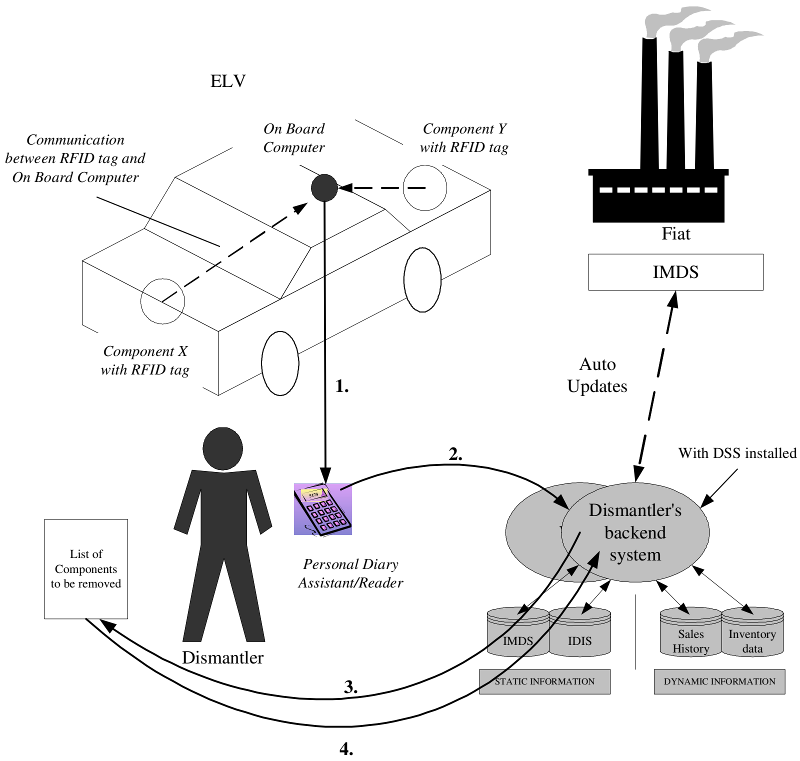

Figure 1. DSS as the unique interface of the dismantler in the A1 demonstrator

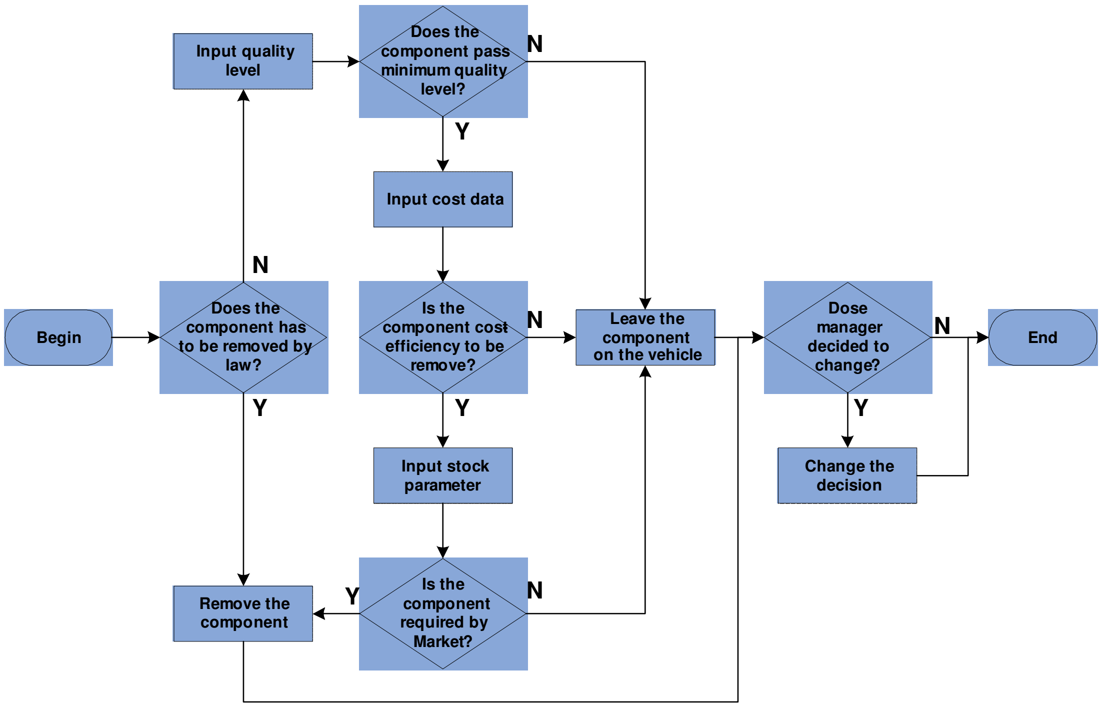

Figure 2a. Decision flow chart

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

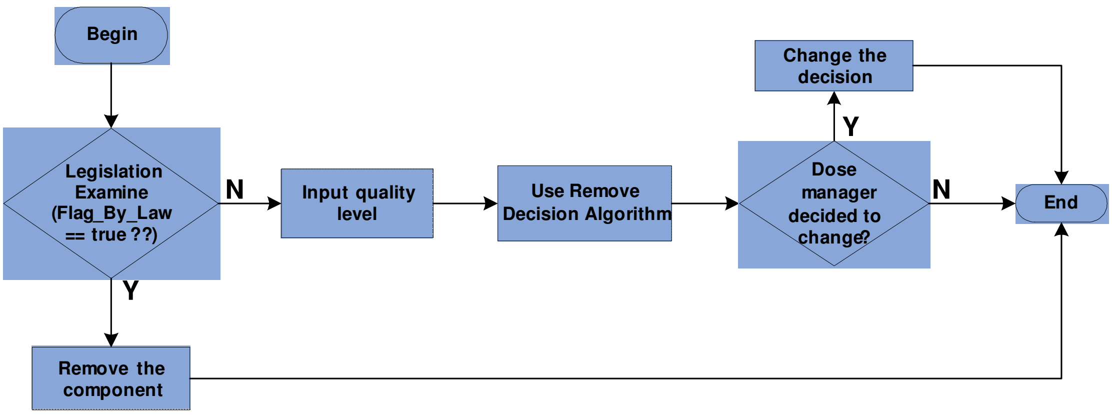

Figure 2b. Using the A1 EOL DSS

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

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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 was the following:

- Start the A1 DSS
- Choose a vehicle
- Define the BOM of material (not available)
- Evaluate the status of 3 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:

DSS Functionalities				
Functionality	**Evaluation of A1 DSS v1**	**Comment to A1 DSS v.1**	**Requirements for A1 DSS v.2**	**N.**
Compliant/ enables compliance with international regulations	3	static link is implemented in v.1	2nd version should enable real link to external DB	A
Enable assessment of residual life of components	3	wear-out models are static	2nd version should enable to download/ specify wear-out models, from external DBs	B
Capability of modelling the wear-out of different types of components	4	Idem	Idem	C
Adequacy of the modelling (true wear-out estimation)	5	Static in v.1	Idem. Will be ensured by adopting currently used models	D
Retrieve data from other dispositives (PDKM, ECU, RFIDs)	3	Link to PDKM is active	Link from PDKM to external DB is not.	E
Specify type of vehicles	5			F
Management of multiple vehicles	1	Not implemented	Not required	G
Identification of vehicle and components history (production, owners, substitution...)	1	Not implemented	Required to resolve problems of incoherency	H
Present summary of data (dynamic, static)	1	Not implemented	Required	I
Export data in .txt	1	Not implemented	Required	J
Access and modify some of data, with credentials	1	Not implemented	Required to resolve problems of incoherency	K
Support to operational dismantling	3			L
Support to recycling, remanufacturing, reuse	5			M
Back up data storing solution	1	No electronic or paper back up (e.g. print list of actions)	Required	N
Security and reliability (protected access)	5			O
Extendability (Capability of extending the number of relevant handled objects)	-	Still to be assessed in next version	Required	P
High processing capability	-	Still to be assessed in next version	Required	Q
Other				R
Attributes	**Evaluation of A1 DSS v1**	**Comment to A1 DSS v.1**	**Requirements for A1 DSS v.2**	**N.**
DSS cost of installation	-	Not assessable	Required in next version	I
DSS cost of maintenance	-	Not assessable	Required in next version	II
Accessibility via web	5			III
Simplicity of use	4			IV
Workability	5			V
Availability	3	Will be evaluated when implemented on-site		VI
Adaptability	1	Difficult to assess		VII
Usability	3			VIII
Other				IX
Evaluation. 1: not satisfactory; 5: highly satisfactory				

Table 1. Evaluation of the DSS versus expected functionalities

In conclusion , the solution seems to be on the right track, with a minimal version already existing (v.1). The functionalities that need to be refined are indicated in the last-but-one column, and regard principally:

- The link to an active PDKM (connected to external databases), to retrieve cost models, wear-out…
- Import/ export and back-up functionalities
- Summary, check and modification of data functionalities

On top of these, information regarding the total costs of the solution should be made available, in the framework of WPR8, WPI3 or WPA1.

4.2 End of Life: Heavy Equipment Decommissioning (A2)

This section contains the evaluation of the A2 DSS demonstrator delivered 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 make 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 V1 development and integrated to deliverable DR8.5 by month 24.

Figure 3 extracted from DR8.5 shows the decision tree specified at month 24.

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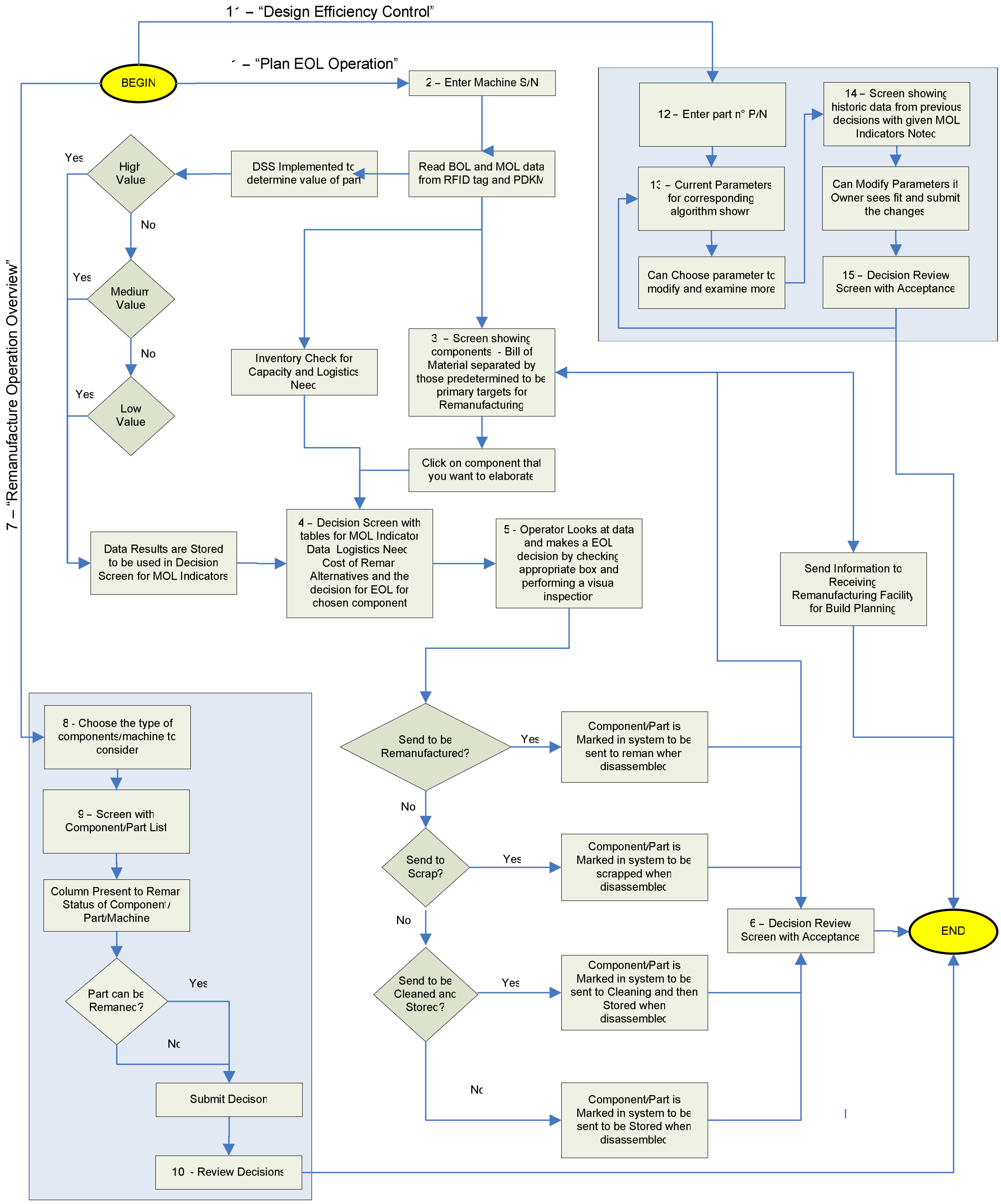

Figure 3: Decision flow chart for A2

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.

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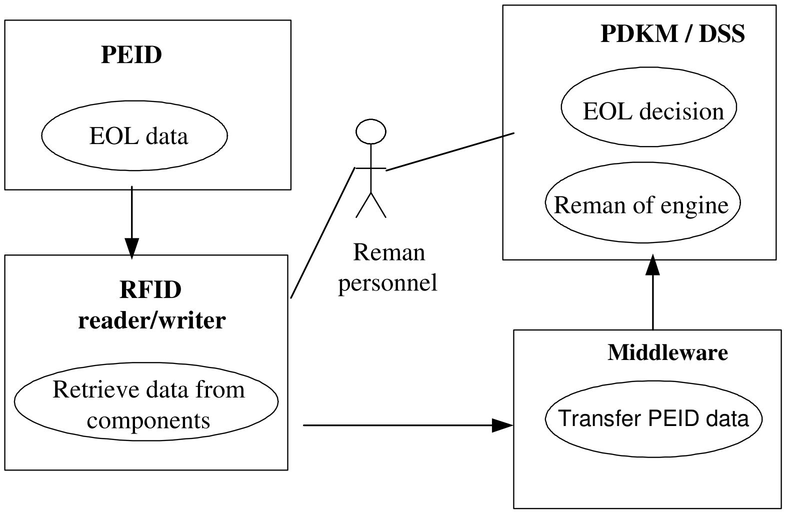

Figure 4: DSS use for A2

4.2.2 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 2 below, DSS V1 program and screen shots have been evaluated regarding the DSS functionalities primarily specified and the attributes characterized in DR8.7 chapter 3.1.1.2.

Functionalities	Evaluation score (DSS V1)	Comments on A2 DSS V1	Requirements for A2 DSS V2
Provide EOL decision for Engine Components	3	Only one component programmed in V1	GUI will allow EOL decisions for Promise enabled components and align with code
Support service reman EOL decisions	4	GUI interface with reman operator but Java code does not match GUI	
On whole engine core:			
- List of BOM available on engine core	1	Not currently available	Will be done in DSS/GUI or future DSS
- Depreciation level of parts	3	Depreciation is calculated but not shown	Integrated in DSS V2
- List of parts with alternate Reman options (landfilled, re-used, stored, re-maned)	3	Included in GUI but DSS V1 is component based	integrated in DSS V2 for 3 components (cyl head, cyl block & crankshaft)
- Engine type is a parameter	2	Not available (only one engine type considered)	Integrated in DSS V2 (truck or heavy vehicle)
Reman inspection results are entered in DSS to inform on DSS model correlation	1	Not currently available	To be integrated in further DSS version
Graphical Results	1	Not currently available	Will be in done in DSS/GUI v2
Attributes	**Evaluation score** (DSS V1)	**Comments on A2 DSS V1**	**Requirements for A2 DSS V2**
DSS cost of installation	-	not estimated	
DSS cost of maintenance	-	not estimated	
Accessibility via Web	3	Could not access till M28	GUI alignment with Java Code
Simplicity of use	3	OK	depends on new code
Workability	2	impossible to assess	
Availability	2	impossible to assess	
Adaptability	2	should be adaptable (java program)	to be evaluated when DSS/GUI are aligned
Usability	4	OK	
Utility	3	current estimated remaining lifetime	integrate with v2 parameters
Evaluation 1: not satisfactory, 5: highly satisfactory			

Table 2: Basic evaluation of the DSS versus expected functionalities

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Unfortunately, the DSS interface that has been programmed supports the specification for the GUI, but there are misalignments with the specification and the DSS java code. This issue will be addressed in the next version of the DSS and GUI development.

The current 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, but this can only be further evaluated in version 2 when the GUI will be more aligned with the DSS underlying code.

Conclusion

Considering the more complete DSS specifications, the first 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 information to make a EOL decision based on the DSS outputs;
- A more complex and comprehensive algorithm to estimate remaining lifetime depending identified parameters should be programmed in the next version;
- From GUI and the DSS java code, the next evaluation should be performed on the real DSS, where both are aligned for a true evaluation;
- 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).

4.3 End of Life: Tracking and 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.

4.3.2 Evaluation and requirements of the solution

Functionality	Evaluation[4]	Comment	Requirements for v2
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	3		Data to be further examined
Make movement decision after Production	5		
Configure RFID data for tag replacement for Outgoing Goods	3		Data to be further examined
Make movement decision for Outgoing Goods	5		
Retrieve container RFID/PEID data via PDKM	2	Interface available	To be integrated with PDKM
Retrieve item tag data via PDKM	2	Interface available	To be integrated with PDKM
Retrieve position information via PDKM	2	Interface available	To be integrated with PDKM
Write process instruction into container RFID/PEID	2	Interface available	To be integrated with PDKM
Save process information into PDKM	2	Interface available	To be integrated with PDKM
Instruct WMS to get goods	2	Interface available	To be integrated with WMS
Attributes	**Evaluation**	**Comment**	**Requirements for v2**
DSS cost of installation		not assessable	Required in next version
DSS cost of maintenance		not assessable	Required in next version
Accessibility via web	5		
Simplicity of use	4		
Workability	5		
Adaptability	3	Process oriented	
Usability	4		

Table 3: Basic evaluation of the DSS versus expected functionalities

Summary

In conclusion, the current solution has implemented all the desired scenarios in A3 demonstration. The further work should focus on the integration of the DSS, PDKM and other system.

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.

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

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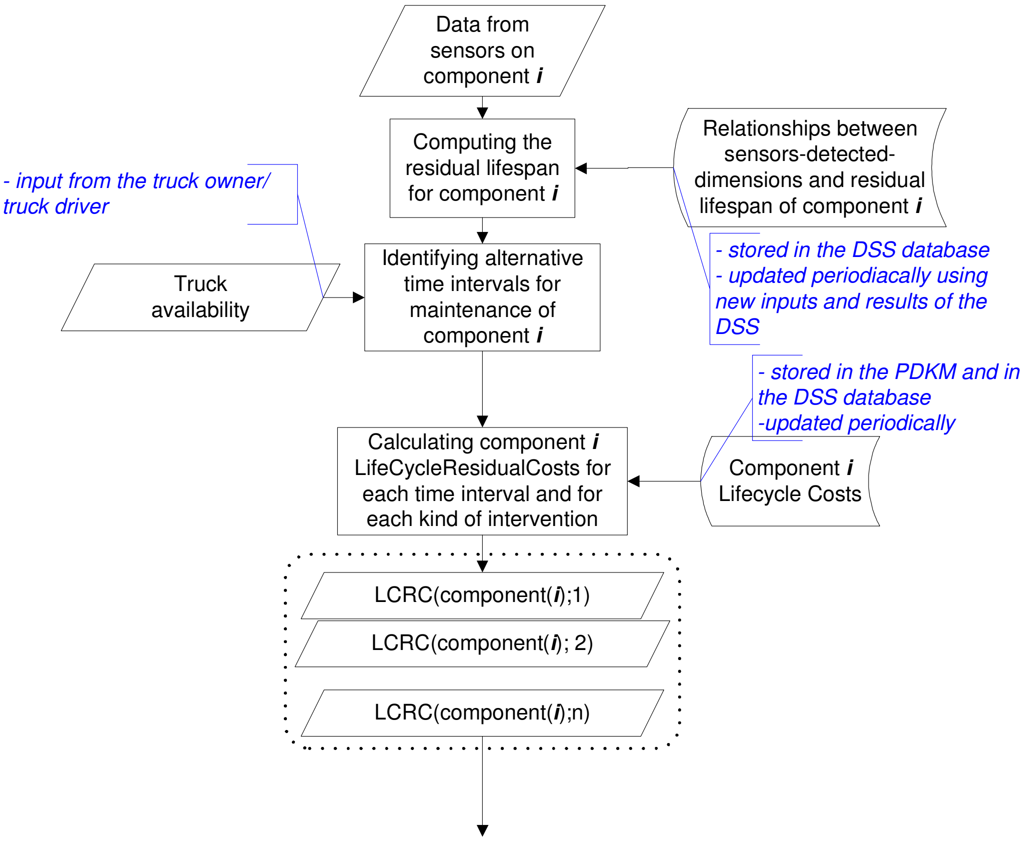
Closing the information loop using the Demonstrator "Information management for predictive maintenance" will improve the knowledge about the customer habits and the mission profile of the vehicle and finally enable to:

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

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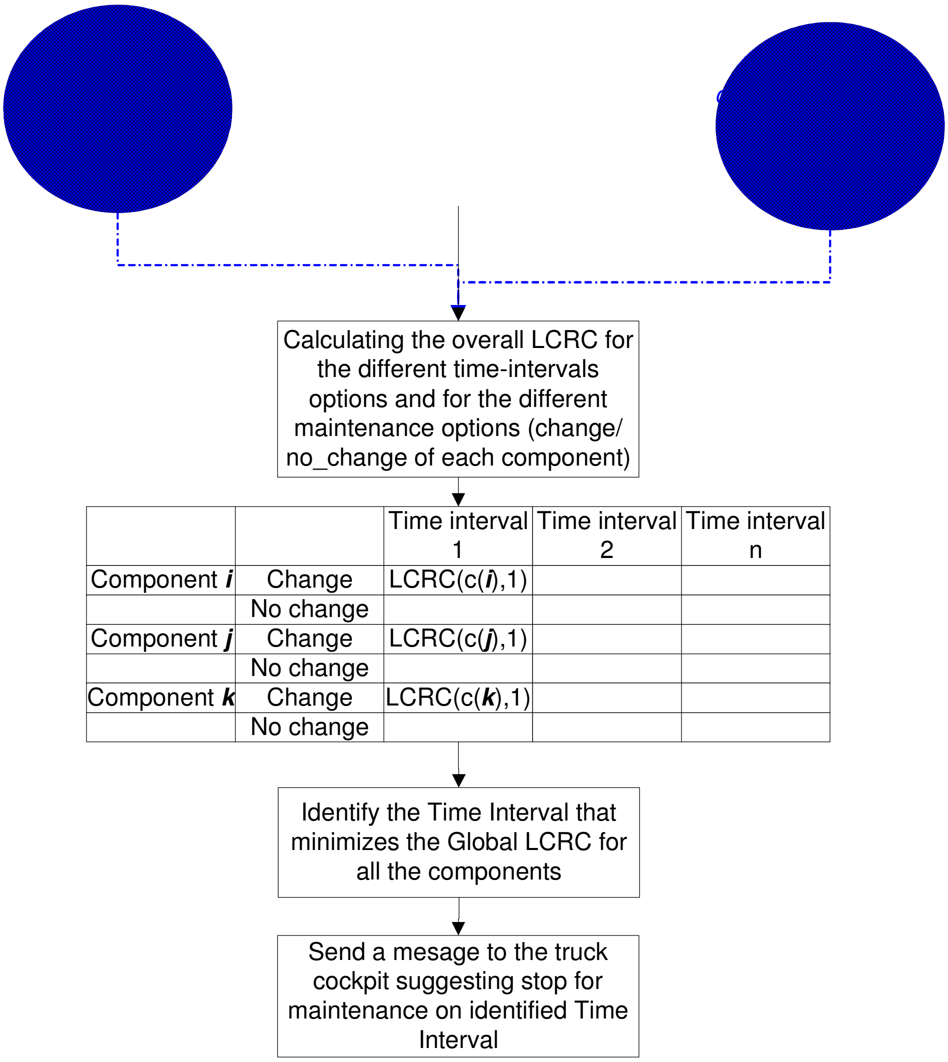

		Time interval 1	Time interval 2	Time interval n
Component ***i***	Change	LCRC(c(***i***),1)		
	No change			
Component ***j***	Change	LCRC(c(***j***),1)		
	No change			
Component ***k***	Change	LCRC(c(***k***),1)		
	No change			

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

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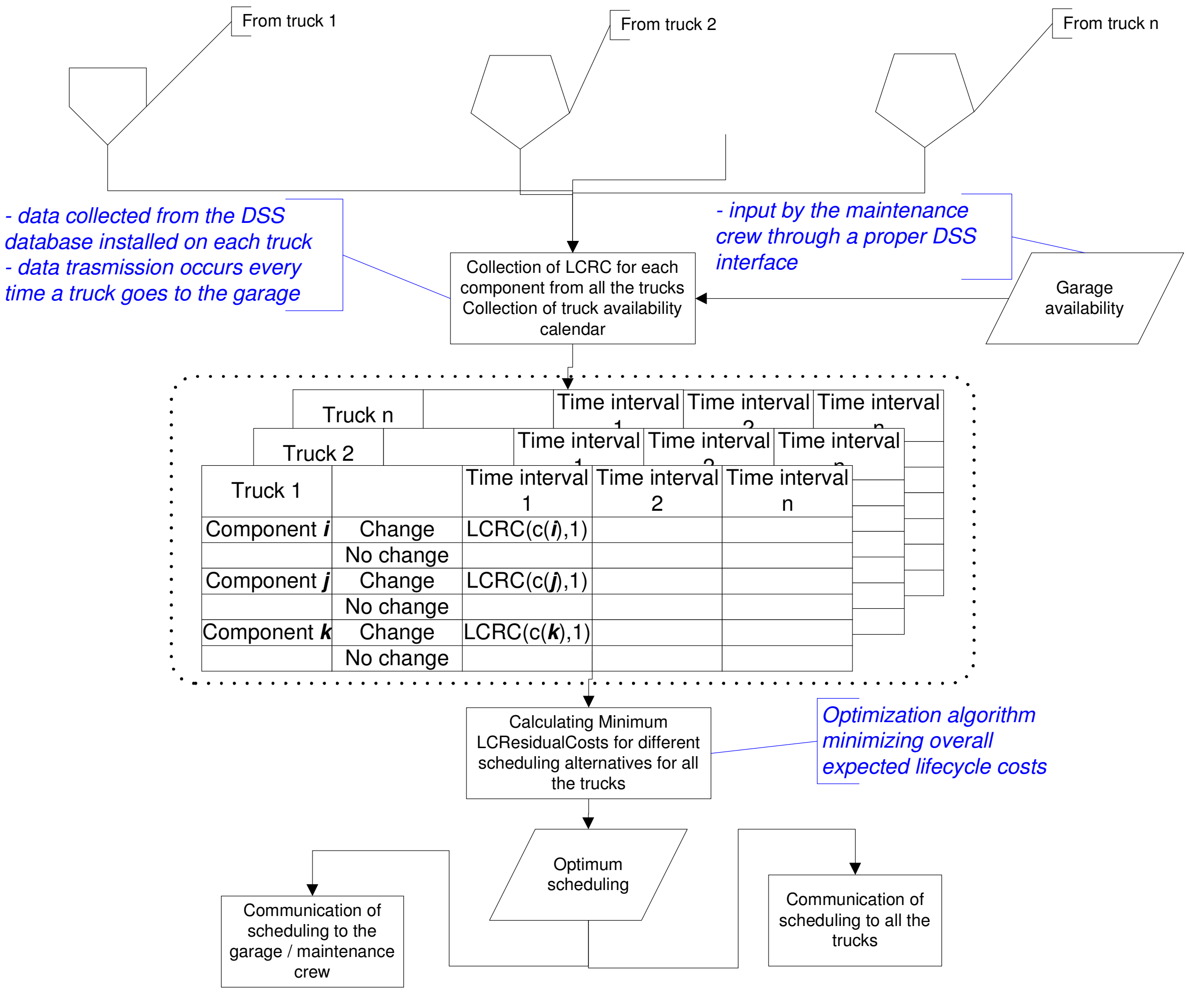

Data of the different trucks belonging to the same fleet are here grouped and optimization for the fleet is performed

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

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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				
Functionality	**Evaluation of A4 DSS v1**	**Comment to A4 DSS v.1**	**Requirements for A4 DSS v.2**	**N.**
Compliant/ enables compliance with internal procedures	3			A
Enable visualisation of maintenance plan	4			B
Enable manual modification of maintenance plan	2		To be included	C
Specify type of vehicles	5			D
Management of multiple fleets	1	Not implemented	Not required	E
Export data in .txt	1	Not implemented	Not essential	F
Security and reliability (protected access)	3	Not assessable	Very important	G
Extendability (Capability of extending the number of relevant handled objects)	-	Still to be assessed in next version	Required	H
High processing capability	-	Still to be assessed in next version	Required	I
Other				J
Attributes	**Evaluation of A4 DSS v1**	**Comment to A4 DSS v.1**	**Requirements for A4 DSS v.2**	**N.**
DSS cost of installation	-	Not assessable	Required in next version	I
DSS cost of maintenance	-	Not assessable	Required in next version	II
Accessibility via web	5			III
Simplicity of use	3			IV
Workability	4			V
Availability	2	Will be evaluated when implemented on-site		VI
Adaptability	1	Difficult to assess		VII
Usability	3			VIII
Other				IX
Evaluation. 1: not satisfactory; 5: highly satisfactory				

Table 4. Evaluation of the DSS versus expected functionalities

As it has not been possible to test all functionalities, the overall impression is anyhow good. The functionalities that need to be refined are indicated in the last-but-one column, and regard principally:

- The link to an active PDKM (connected to external databases)
- Import/ export and back-up functionalities
- Summary, check and modification of data functionalities

On top of these, information regarding the total costs of the solution should be made available, in the framework of WPR8, WPI3 or WPA1.

4.5 Middle of Life: Estimation of heavy vehicle lifespan (A5)

This section contains the evaluation of the A5 DSS demonstrator 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:

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- 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.

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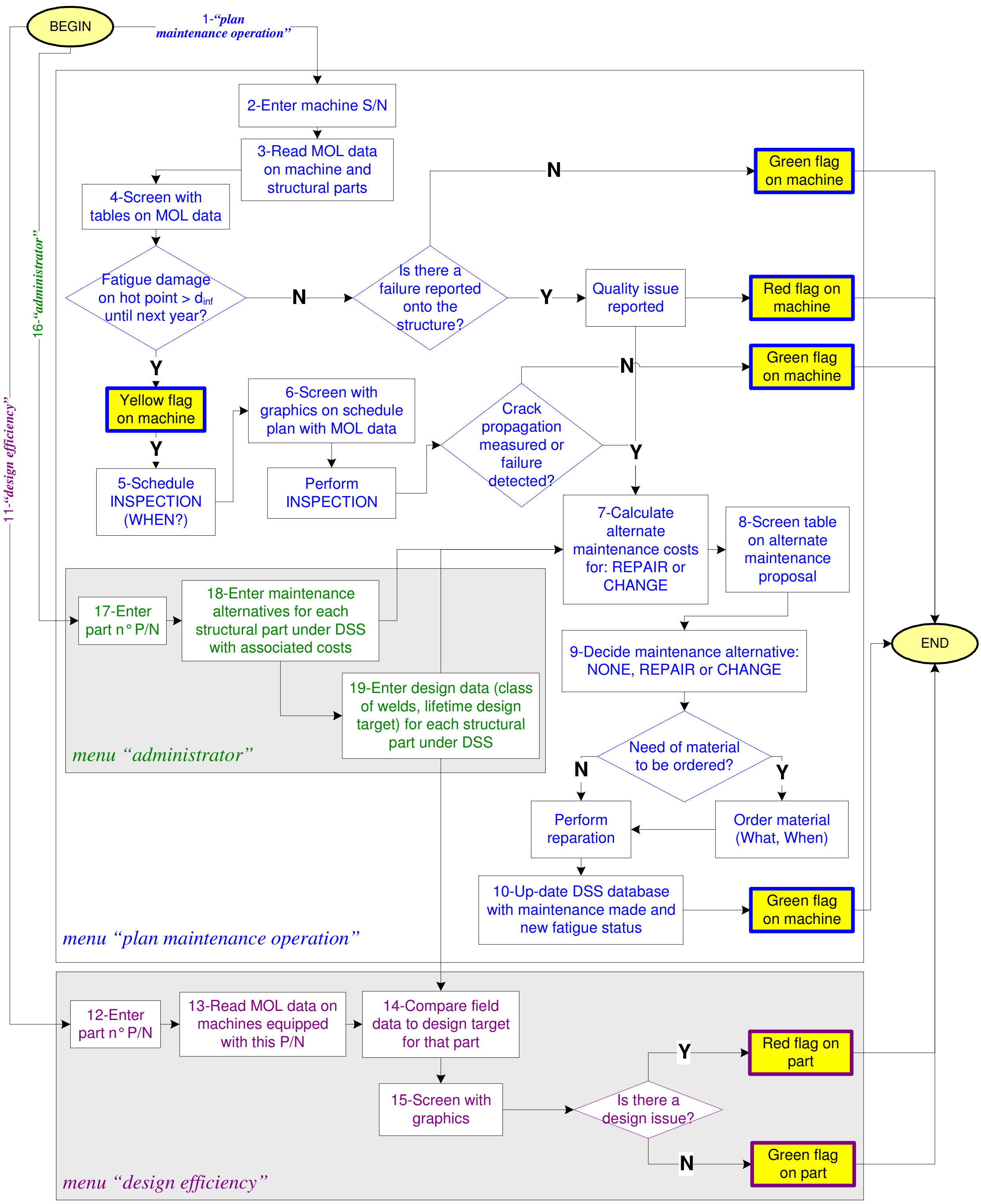

Figure 5: Decision flow chart for A5

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.

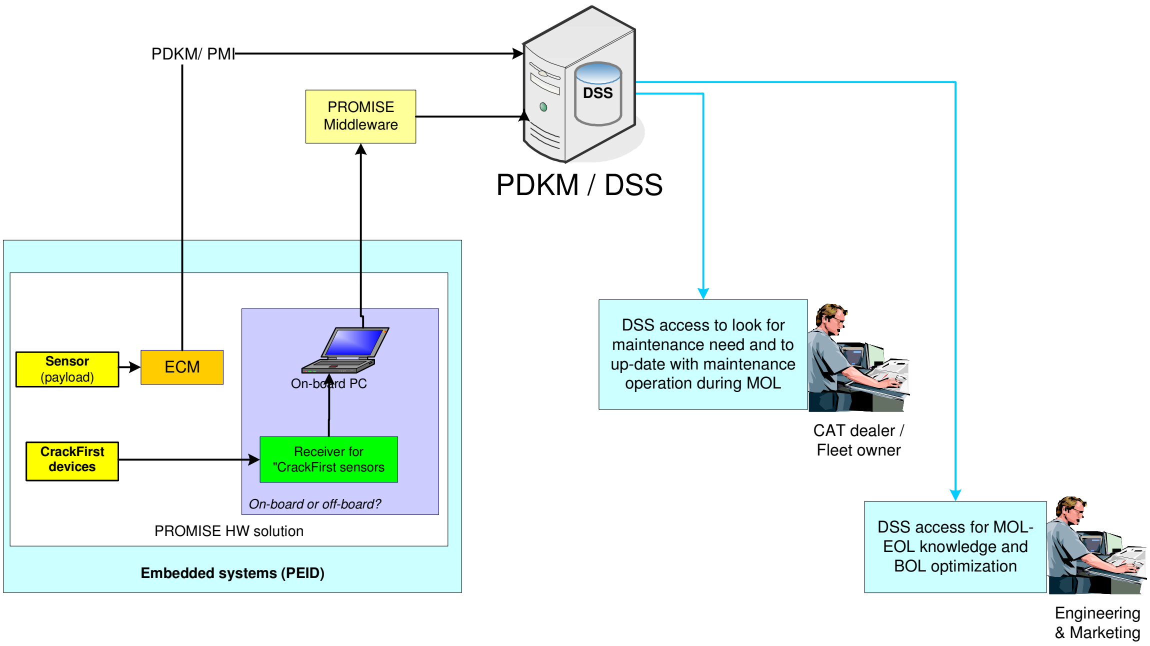

Figure 6: DSS use for A5

4.5.2 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 the table below, DSS V1 program and screen shots have been evaluated regarding the DSS functionalities primarily specified and the attributes characterized in DR8.7 chapter 3.1.1.2.

Unfortunately, at month 29, the A5 DSS V1 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

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

Table 5: Evaluation of the DSS versus expected functionalities

Conclusion

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

- A predictive maintenance model has been programmed using fatigue damage data 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) should be programmed in version 2;
- From screen shots provided, the DSS attributes should be appreciated, but next evaluation should be performed on real DSS GUI to be able to make a real assessment;
- 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;
- 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)

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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

Periodic diagnostic tests on the milling machine provide indicators on the "health state" of its mechanical components. The A6 DSS is made of two components: the aging module that provides the residual life of the mechanical monitored components and the maintenance cost management module that provides a list of suggested interventions that can be performed on the machine tool when the residual life of that mechanical components of the axes is under a certain fixed threshold. Residual lifespan of each axis is provided by the DSS aging module running on each CNC on board the milling machine. The DSS maintenance cost management module is centralized on the central server at FIDIA service.

4.6.2 Evaluation and requirements of the solution

FIDIA has developed a first PROMISE A6 DSS prototype for predictive maintenance purposes. In this first version the approach to a real industrial environment has been pursued. 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 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:

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DSS Functionalities			
Functionality	**Evaluation of DSS v.1**	**Comments to DSS v.1**	**Requirements for DSS v.2**
Classification of maintenance action (do nothing, modify, replace)	4	The suggested action is adequate in most of the times	It will be adequate all times
Assessment of residual life of components	3	Most of times replacing a component brings to the replacement of other components of the same axis	Residual life will be evaluated for the whole axis
Assessment of residual life of axis	4	At present DSS is implemented only for the 3-axis standard configuration machine	It will be extended also to the 5-axis configuration machine
Adequacy of the modelling (true wear-out estimate)	4	Thresholds have been set based on the techincal service experience	Thresholds will be refined
Retrieve data from other devices (PDKM, RFIDs, CNC, etc.)	3	Link to PDKM is active	Link to CNC required
Management of multiple machines	3	DSS in running only on K221 and K165 models	DSS will be used for the whole milling machines fleet
Identification of machine and components history (production, owners, replacements, maintenance actions, etc.)	1	No access available to historical data	It will be provided access to historical data
Import residual life data from CNC	-	It was not in the initial specifications	The process will be automated
Support to predictive maintenance	4	See item n.1	See item n.1
Security and reliability	-	Not assessed	Probably DSS will be accessed by a user password
Other			
Attributes	**Evaluation of DSS v.1**	**Comments to DSS v.1**	**Requirements for DSS v.2**
DSS cost of installation	-	Not assessable	Required in the next version
DSS cost of maintenance	-	Not assessable	Required in the next version
Accessibility via web	4	Problems related to the browser program/version	Required access from I-Explorer v.7
Availability	-	Will be evaluated when implemented on-site	
Adaptability	-	Difficult to assess	
Usability	5	Easy to use	Easy to use
Other			
Evaluation. 1: not satisfactory; 5: high satisfactory			

Table 6: Evaluation of the DSS versus expected functionalities

The first DSS prototype seems to cover most of the functionalities required at the beginning. Due to lessons learned in this stage, minor changes will be required to the DSS v.2 to fit the A6 requirements.

The most important functionalities that need to be refined are indicated below:

- the link to an active PDKM (real data filled-in database), to retrieve cost elements, residual life, historical data, etc.
- import/export functionalities with the Computerized Numerical Control
- adequacy of the models by refinement of algorithms implemented
- DSS extension to a variable multiple-axis machine

The total costs of the solution should be quantified and made available to the DSS actors involved, in order to implement an adequate exploitation strategy.

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

The main purpose of WRAP 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 1a and 1b, 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 7a), accessible via internet, but it could also be installed locally (Fig 7b), 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.

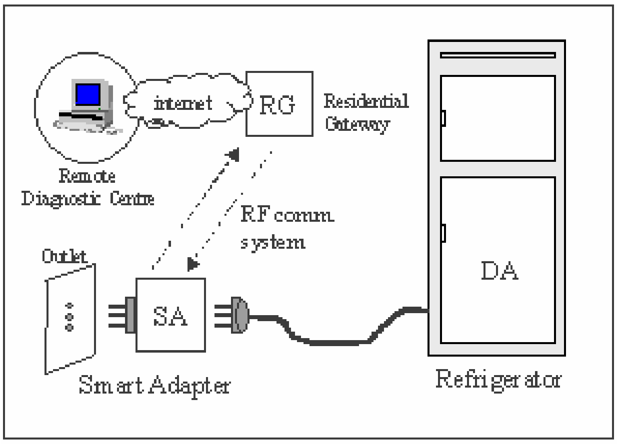

Figure 7a

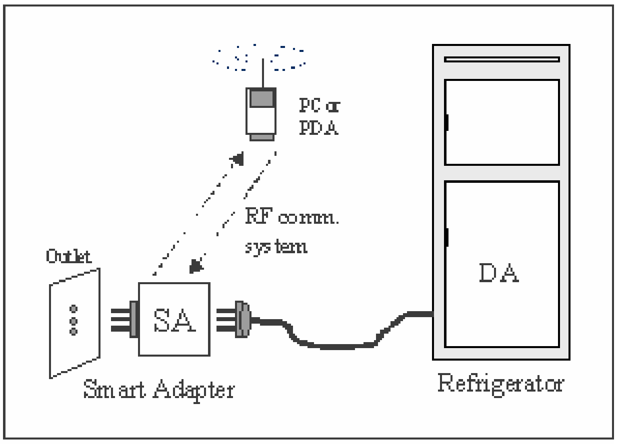

Figure 7b.

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 said price problems, 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 WRAP 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.

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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.
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 analyze all the data of the refrigerator and provide 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**, that 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.

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DSS Functionalities			
Functionality	Evaluation of DSS v.1	Comments to DSS v.1	Requirements for DSS v.2
On site diagnostic	5	the diagnostic works well	-
Remote diagnostic	3	At present DSS is able to give an approximation of the aging of the thermal circuit.	It shoud give a more precise esteem. The DSS needs to be finetuned.
Adequacy of Aging DSS	4	Thresholds have been set based on the techincal service experience	Thresholds will be refined and improved
Exchange data from the refrigerator to the PDKM	-	This part has not been implemented yet	It is under implementation in collaboration with HUT who has already developed an interface with the SA.
Management of multiple machines	-	Defined into the GUI description, but not implemented yet.	SAP is going to implement it.
Identification of machine and components history (production, owners, replacements, maintenance actions, etc.)	-	Defined into the GUI description, but not implemented yet.	SAP is going to implement it.
Spare Parts Management	-	Defined into the GUI description, but not implemented yet.	SAP is going to implement it.
Security and reliability	-	Not assessed	Probably DSS will be accessed by a user password
Other			
Attributes	**Evaluation of DSS v.1**	**Comments to DSS v.1**	**Requirements for DSS v.2**
DSS cost of installation	-	Not assessable	Required in the next version
DSS cost of maintenance	-	Not assessable	Required in the next version
Accessibility via web	-	This functionality is not available till now, since the GUI is still under development	Required in the next version
Adaptability	4	The diagnostic DSS is easily adaptable	All the system needs to be assessed
Usability	3	Till now the diagnostic DSS is quite easy to be used, but is not easily accessible since is not integrated within the whole system.	It has to be easy to use
Other			
Evaluation. 1: not satisfactory; 5: high satisfactory			

Table 7: Evaluation of the DSS versus expected functionalities

The DSS has not being completely implemented till now and the GUI is not available.

The first tests did on the two diagnostic modules provided good results. The modules estimated correctly the aging of the analyzed products.

In the next months a wider testing of the diagnostic module will be done; then the usage of the GUI will be tested and the whole solution effectiveness will be evaluated.

Concluding the diagnostic modules proposed achieved their aim, and the proposed GUI seems to achieve the desired functionalities, but a complete evaluation of the application case can be done only at the end of the implementation of the GUI.

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

This section contains the evaluation of the A9 DSS demonstrator.

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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 8.

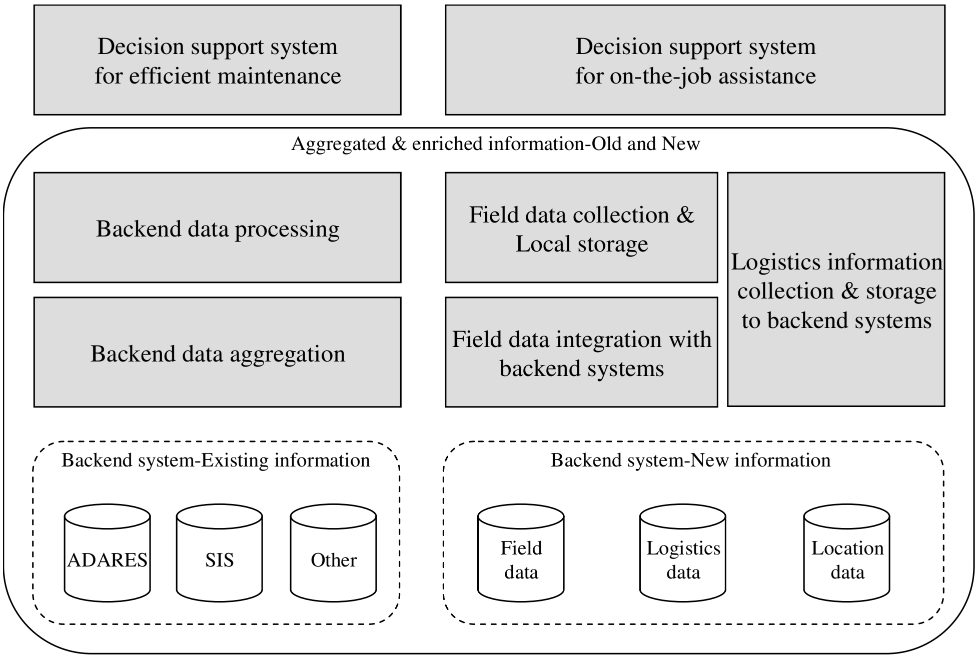

Figure 8: Functional modules in A9

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.

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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 9.

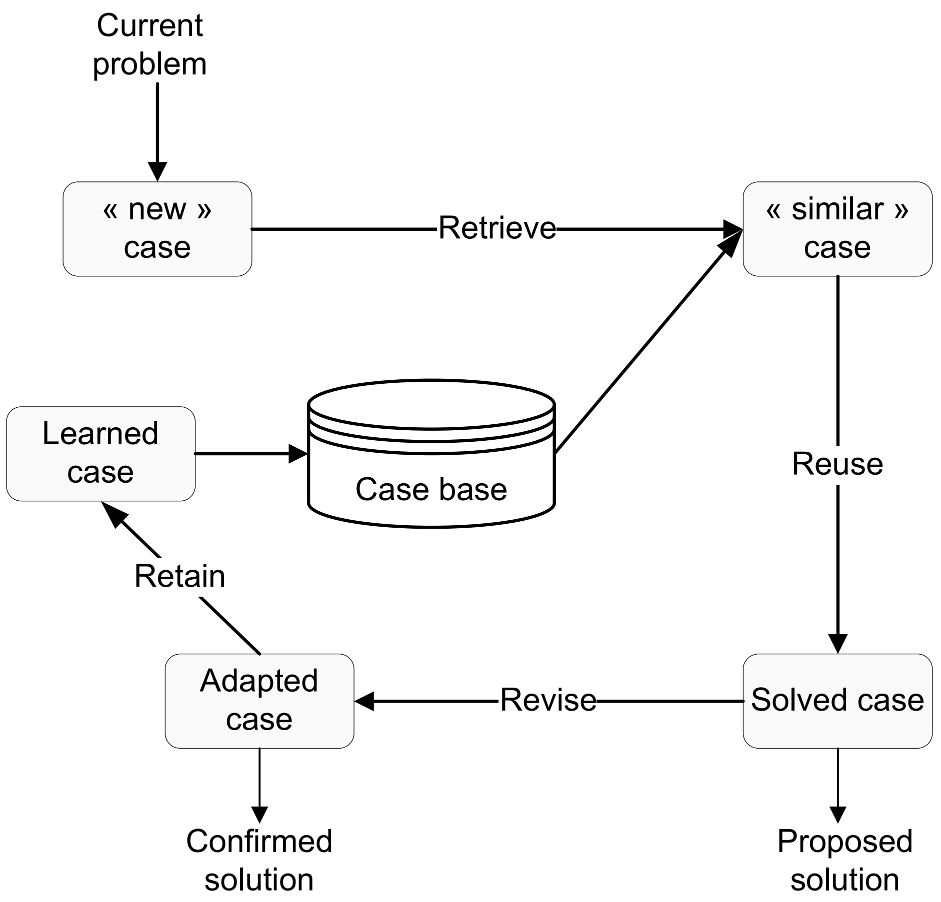

Figure 9: Case-Based Reasoning cycle developed by Aamodt (Schmidt et al., 2001)

4.8.2 Evaluation and requirements of the solution

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

The following table presents the results of the evaluation performed regarding the DSS v.1 functionalities.

DSS Functionalities			
Functionality	**Evaluation of A9 DSS v.1**	**Comments on A9 DSS v.1**	**Requirements for A9 DSS v.2**
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 if necessary	1	Not available	
- Capability to retain the new solution as part of a new case	3	Ok	
- Representation of cases	3	ok. Need to evaluate with real data	
- Similarity measurement	4	All "similarity"parameters included in algorithm	
Online customers problem solving: online "troubleshooting" solutions (to frequent well-defined problems)	1	Not implemented	Need for "User Profile" with rights to "Reduced" version of DSS. Potential creation of "Customer-oriented Solutions" in DSS data??
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. No PEID data available YET	
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.1**	**Comments on A9 DSS v.1**	**Requirements for A9 DSS v.2**
DSS cost of installation	-	No estimated	
DSS cost of mantainance	-	No estimated	
Accessibility via Web	3	Only interface planned is WEB??	Need for "User Profile" with rights to "Reduced" version of DSS. Potential creation of "Customer-oriented Solutions" in DSS data??
Simplicity of use	3	NOT tested with data	
Workability	-		
Availability	-		
Adaptability	4	JAVA based WEB interface gets a 4	
Usability	-		
Utility	3	Assume solution will be found	
Other			
Evaluation 1: not satisfactoty, 5: highly satisfactory			

Table 8. Evaluation of the DSS versus expected functionalities

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4.9 Begin of Life: DfX knowledge generation (A10)

It is worth to mention that the decision strategy described here is the one implemented in the first prototype of the A10 DSS. This decision strategy is parameter based i.e. the user has to select one parameter and all the analysis is made around this parameter and is suitable in the case where the user wants to focus on one specific parameter e.g. MTBF and when the number of data objects is relatively small.

Another important case is when the user has no specific knowledge about the significant parameters in the beginning of the analysis. So he may consider all the parameters at the same time and find out the significant parameters using the DSS.

To deal with this case another technique will be implemented in the second version of A10 DSS.

4.9.1 Objective of the A10 DSS demonstrator[5]

The main objective of the decision strategy of the DfX demonstrator is to provide decision methods and algorithms that allow transforming product lifecycle data into DfX knowledge where "X" stands for:

- RAM/LCC (reliability, availability, maintainability / life cycle cost);
- Safety;
- Environment.

The DfX decision strategy implemented in the first prototype of A10 DSS 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 is the component/subsystem/system performing with respect to the design aspect considered 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 aspect considered in order to aid designers in improving the next generation of locomotives from the point of view of the design aspect considered.

Several restrictions are considered while defining this first-version DfX decision strategy:

- the decision strategy relates to RAM/LCC design aspect;
- considers only "Main circuit breaker";
- considers only two parameters "MTBF" (Mean time between failures) and "DPN" (Degradation priority number);
- for factor analysis, it considers only two factors:
  - "Class" which is a non ordinal qualitative factor, and
  - "Mileage" which is a quantitative factor.
- for factor impact analysis, only one factor is considered at the same time;
- for Pareto analysis, only one type of categorization is considered;
- for Pareto analysis, only non weighting or weighting with respect to repair time are considered.

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

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A general view of the DfX decision strategy is shown in the flowchart of Figure 10.

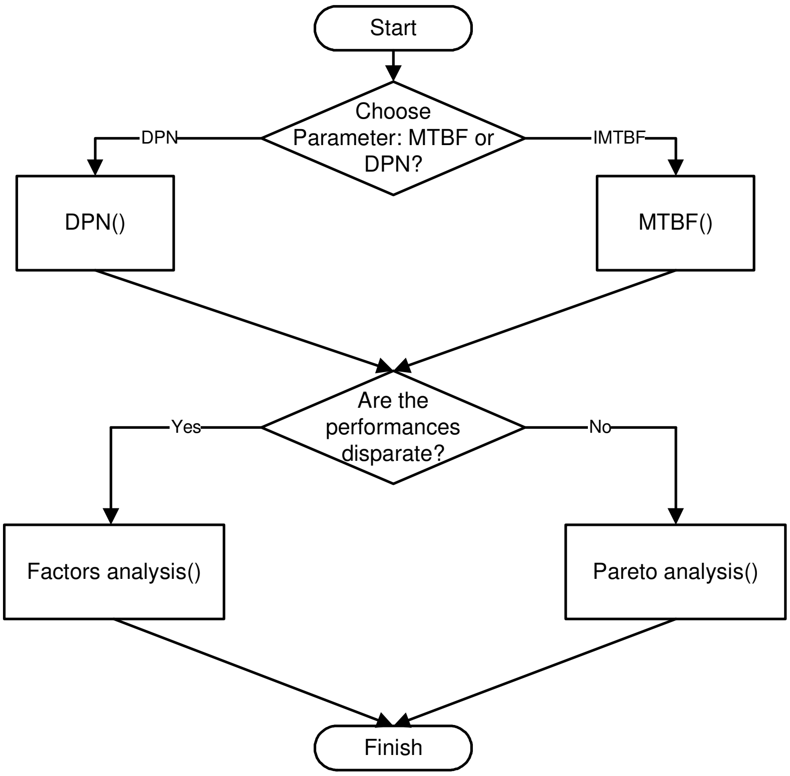

Figure 10. Flowchart for the DfX decision strategy

Information generation

The only parameters available within the (first version) DfX decision strategy for illustrating the transformation product field data into knowledge are MTBF and DPN.

The information generation involves two main steps:

1. Calculation of the selected parameter for each locomotive and over all locomotives in addition to the min, max and mean values.
2. Comparison of the levels of performance with respect to the selected parameter of each locomotive in order to determine whether or not the different levels of performance are disparate.

The DPN is a kind of index value which shows how product loses its reliability as time goes. To estimate product reliability with constant interval during product lifecycle, DPN calculates the failure ratio at every period with failure number and total failure number. Then, the failure rates show reliability change over the time. See Table 1 as an example.

Targeted		Failure number				
product	Product life time	1 year	2 year	3 year	4 year	5 year

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	ID					
Product i	i-0001	0	0	1	1	0
	i-0002	0	1	0	2	1
	i-0003	0	0	1	0	3
	i-0004	1	2	0	0	1
Failure distribution		1	3	2	3	4
Failure rate		1/13	3/13	2/13	3/13	4/13

Table 9. Reliability change over time: example for DPN

However, the same reliability at early stage and late stage of product does not have the same meaning. As time goes, the reliability has more importance since there is more possibility that the product fails in relation to the reliability. Therefore, the weight factor based on MTBF is multiplied by the reliability.

The performances with respect to the selected parameter (e.g. MTBF), calculated from field data do not provide any information regarding how well the component/subsystem/system is performing regarding the aspect under consideration. To obtain this information the calculated performances should be compared between each other and/or with existing values such as predicted values of the parameter if they exist otherwise the involved experts should make a judgment about whether the calculated values correspond to a satisfactory level of performance or not.

Knowledge generation

As can be seen from Figure1, if the performances are disparate factor impact analysis is pursued and if the performances are not disparate Pareto analysis is pursued.

In the case of disparate performances, the disparity may be caused by one or more factors such as operating conditions, environmental conditions, etc. The objective of factor impact analysis is to investigate whether or not there are one or more factors that have an impact on the level of performance.

Factor impact analysis is composed of the following steps:

- Selection of a factor for which the impact on the level of performance will be investigated;
- Definition of clusters representing different levels of performance of the parameter;
- Calculation of the homogeneity and heterogeneity indexes. The homogeneity index accounts for the extent to which the corresponding values of the factor are similar within clusters and the heterogeneity index accounts for the extent to which the corresponding values of the factor are different between different clusters.

Factors are those elements that have an influence on one or more parameters used to measure a certain type of performance. Various categories of factors can be considered:

- Operating factors such as mileage, operative hours, number of trips, etc.,
- Environmental factors such as temperature, humidity, pressure, etc.,

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- Maintenance/repair factors such as skills of maintenance staff, maintenance/repair solution, etc.
- Etc.

In case of non disparate performances, a Pareto analysis is suitable. The fact that different locomotives working in different environments and under different conditions have similar performances suggests that may be some intrinsic causes (design, manufacturing, etc.) are behind the level of performance achieved. The main objective of Pareto analysis is to investigate whether or not the design category of failures is among the main categories of failure and in the positive case what are the related causes.

Pareto analysis is composed of the following steps:

- Selection of a type of categorization of failures e.g. on the basis of their source: design, manufacturing, operation, maintenance, etc.[6];
- Accounting for severity of failures e.g. by considering a weighting factor such as repair time, repair cost, etc.;
- Sorting the (weighted) frequencies of categories of failure from the highest to lowest;
- Determining the main categories of failures e.g. those accounting for more than a certain percentage (e.g. 80%);
- Determining whether the design category is among the main failure categories and if yes what the related causes of failure are.

4.9.2 Evaluation and requirements of the solution

Basically we think that the compiled algorithms for DfX knowledge generation in the document "Deliverable DR8.3: Implementation of PROMISE DSS prototype" described a good basis for the A10 DSS.

In the future versions of the DSS the following points must be considered. It should be possible to consider all parameters relevant for the aspect to analyse, at the same time. Some requirements regarding the selection of inputs and functional extensions are provided below:

Selection of inputs:

- It should be possible to invent the input of a selectable time interval for the consideration of failure events (FAM) of the data objects (like from 1.1.2002 to 31.12.2004)
- it should be possible to invent a selectable time span for the consideration of attributes per failure event (like for each failure event of a data object a consideration of diagnostic data 5 h backwards and 0,5 h after the event).
- For the case where more than 3 attributes are considered, it should be possible to force a graphical presentation by choosing 3 parameters after the calculation

[6] Note: in many cases the knowledge about the categorization of failures is not available in the state of design definition (BOL). With further development of the DSS the finding of this categorization will be a supporting task of the DSS.)

Functional extensions:

- The objective of the current DfX decision strategy implemented in the first 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 one component which is the main circuit breaker. Further refinements and extensions are foreseen in order to develop a decision strategy that responds to all the needs of the DfX demonstrator.
- The ultimate goal of PROMISE DSS is to access data that is stored in PDKM however this is not possible currently since the integration between DSS prototype (Version 1) and PDKM is not achieved yet according to the description of work plans. Hence, a temporary database having similar features than those of PDKM which will be based on the SAP ECC database is developed.

To achieve these objectives, a variant of K-means clustering will be implemented in the next versions of A10 DSS. This technique allows considering all parameters at the same time and is suitable for large databases, which is the case of the Bombardier application scenario.

4.10 Begin of Life: Adaptive Production (A11)

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.

4.10.1 Objective of the A11 DSS demonstrator

Figure 11 represents the UML 2.0 Use Case Diagram related to the A11 DSS Demonstrator.

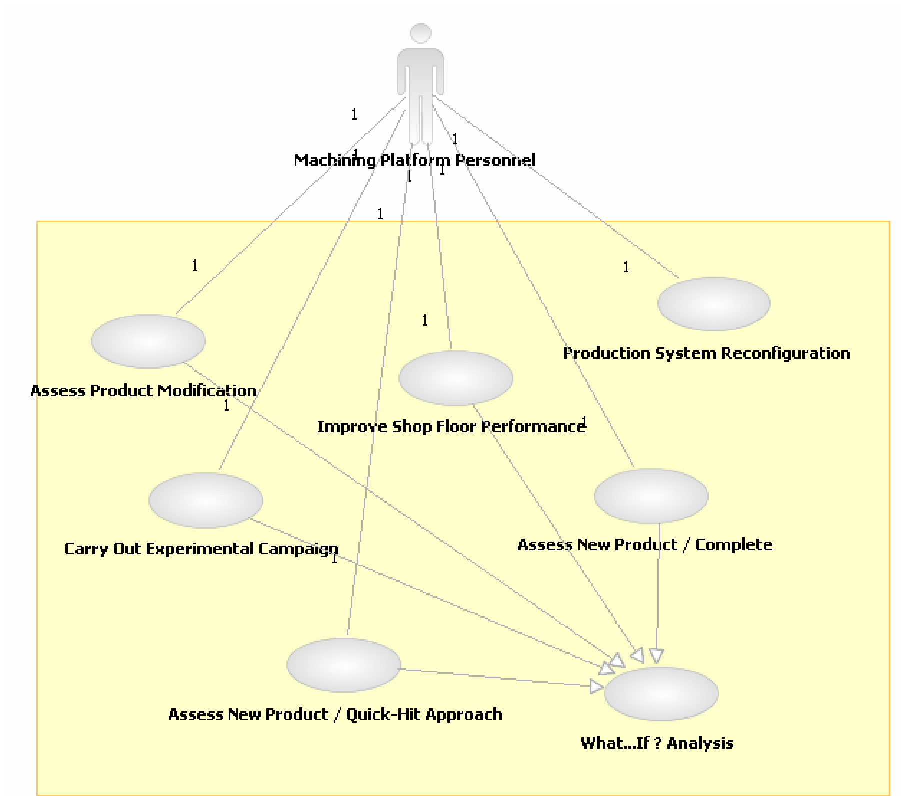

Figure 11: Use Case Diagram for the A11 DSS Demonstrator

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 11 (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

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A11 DSS Demonstrator), each of them can use the portion of the tool and of the related interface that corresponds to his competence.

The What…If? Analysis set of functionalities is represented inside the system by the following set:

- Assess Product Modification
- Assess New Product / Complete
- Assess New Product / Quick-Hit Approach
- Improve Shop Floor Performance
- Carry Out Experimental Campaign

In the M24 version of the A11 DSS demonstrator, only the “Assess Product Modification” functionality was developed. This functionality represents the most important “What..If? Analysis”, in the PROMISE viewpoint, and can be summarized as follows.

Given the following:

- a product currently in production;
- a set of modifications the customer (FIAT) wants to be implemented into the same product;
- the currently available configuration of the shop floor in terms of current process cycle and current production system layout;

the user must be able to:

- change something he wants to assess and evaluate in the process and/or in the system (directly starting from the existing ones), by actively using the GUI of the A11 DSS;
- save the defined alternatives;
- ask the system to make all the related evaluations in terms of economical (e.g. necessary investments and related operating costs) and physical (i.e. basically the system throughput) performance of the different solutions.

4.10.2 Evaluation and requirements of the solution

The test procedures followed was the following:

- Start the A11 DSS
- The user chooses the RPM (Request for Product Modification) document the user wants to investigate
- The user browses the details of the currently implemented process cycle and production system, and saves a certain number of alternatives of production systems and/or of production processes, which must be then evaluated.
- The A11 DSS performs the requested evaluations
- The user browses the results (and –eventually- saves them)
- Based on the previous steps, the user decides which modification of the production system has to be implemented

At the end of the test the users were asked to evaluate the PROMISE A11 DSS with respect to the framework provided by the table below:

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Functionality	Evaluation[7]	Comment	Requirements for v2
To lower sensibly down the lead time to decide how to adapt production system/process	4		
Profitability of the (adaptive production) solution proposed/suggested by the A11 DSS, with respect to the solution suggested by the currently available decision methodologies	-		Required
What … If? Analysis (overall)	-	Only one functionality available in v1	
What … If? Analysis/Assess Product Modification	3	Usability can be improved	
What … If? Analysis/Assess New Product (Complete)	-	Not available	
What … If? Analysis/Assess New Product (Quick-Hit Approach)	-	Not available	
What … If? Analysis/Improve Shop Floor Performance	-	Not available	
What … If? Analysis/Carry Out Experimental Campaign	-	Not available	
Production System Reconfiguration	-	Not available	Required
Attributes	**Evaluation**	**Comment**	**Requirements for v2**
DSS cost of installation	-	not assessable at the moment	Evaluation required
DSS cost of maintenance	-	not assessable at the moment	Evaluation required
Workability	5		
Availability	-	Not assessable at the moment	
Adaptability	3	For cases different than the Teksid Aluminum one, the framework of the A11 DSS remains the same, but many algorithms could have to be modified	
Usability	4	Only one functionality supported	New functionalities must be added according to the release plan as from DR8.5/"A11 DSS chapter"
Utility	5		

Table 10. Reliability change over time: example for DPN

In conclusion , the first version of the A11 DSS demo provided good results, but only concerning one of the many required decision support functionalities. The following M30 version will address

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

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the rest of the functionalities, as reported in the Release Plan at page 78 of the DR8.5 document. Moreover, the M30 version will start exploiting the PDKM component of the A11 demonstrator, while the current state only uses statically recorded data.

Particular attention will be paid, in the M30 version, to the Production System Reconfiguration functionality, with a first numerical solution to the problem implemented following a dynamic programming approach.

5 Conclusion

The evaluation through the potential users of the application has yielded that the DSS prototype (Version 2) is a good step into the right direction. The feedback of the users indicate the needed improvements that have to be added.