

# **Closed-Loop Product Life Cycle Management — Using Smart Embedded Systems**

Edited by Markus Frey  
PROMISE Interregional Coordinating Partner  
Bombardier Transportation



# *Closed-Loop Product Life Cycle Management— Using Smart Embedded Systems*

Copyright © 2011 by ISA—International Society of Automation

67 Alexander Drive  
P.O. Box 12277  
Research Triangle Park, NC 27709

All rights reserved.  
Printed in the United States of America.  
10 9 8 7 6 5 4 3 2

ISBN: 978-1-936007-61-5

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the publisher.

## Notice

The information presented in this publication is for the general education of the reader. Because neither the author nor the publisher has any control over the use of the information by the reader, both the author and the publisher disclaim any and all liability of any kind arising out of such use. The reader is expected to exercise sound professional judgment in using any of the information presented in a particular application. Additionally, neither the author nor the publisher have investigated or considered the effect of any patents on the ability of the reader to use any of the information in a particular application. The reader is responsible for reviewing any possible patents that may affect any particular use of the information presented.

Any references to commercial products in the work are cited as examples only. Neither the author nor the publisher endorses any referenced commercial product. Any trademarks or trade-names referenced belong to the respective owner of the mark or name. Neither the author nor the publisher makes any representation regarding the availability of any referenced commercial product at any time. The manufacturer's instructions on use of any commercial product must be followed at all times, even if in conflict with the information in this publication.

---

Library of Congress Cataloging-in-Publication Data in Process

# Preface

Developing a “Closed-Loop Product Life Cycle Management (PLM) using Smart Embedded Systems” was the challenging mission for the IMS Project PROMISE (Product Life Cycle Management and Information Tracking using Smart Embedded Systems), which successfully concluded in 2008.

PROMISE developed a new type of closed-loop PLM based on product embedded Information Devices (PEID), which allows product information to be tracked at all times and in any location around the world. This new PLM system enables product users, maintainers, and manufacturers to manage the life cycle information of their products seamlessly over all life cycle phases: beginning of life (BOL), middle of life (MOL), and end of life (EOL).

Over the next five chapters, this book will provide industrial users as well as the broad R&D community with an understanding of the principles behind the PROMISE technologies, their successful implementation in the PROMISE demonstrators, and their enormous potential across the industrial spectrum:

- Chapter 1. Introduction with overview on the IMS PROMISE project
- Chapter 2. Description of the PROMISE ‘Closed-Loop PLM’ approach
- Chapter 3. Explanation of principles and achievements for the main PROMISE technologies
- Chapter 4. Presentation of approach and results for various successfully developed demonstrators in different industrial areas
- Chapter 5. Highlights on benefits using PROMISE technologies and its applicability for broad industrial fields

The material for this book is taken from the PROMISE work and deliverables with contribution from all project partners.

## Acknowledgments

On behalf of the IMS PROMISE project consortium, I gratefully acknowledge the IMS organization and all regional funding organizations for their great support in carrying out the PROMISE project so successfully.

I extend our gratitude and appreciation to O<sup>3</sup>neida and especially to Allan

Martel and Susan Colwell for their invaluable support and efforts in making this book possible.

I would like to send special thanks to the various authors of the chapters in this book for their great efforts, as well as to the Regional Coordinating Partners for always keeping this large interregional project team on a successful track, and last—but not least—to all project partners for their collaboration and their contributions to this project.

Markus Frey

PROMISE Interregional Coordinating Partner

Bombardier Transportation

# Table of Contents

List of Figures ..... xvii

List of Tables ..... xxvi

<b>1</b>	<b>Introduction.....</b>	<b>1</b>
	The main objectives .....	1
	The PROMISE deliveries in brief .....	4
	Managing the PROMISE project .....	7
<b>2</b>	<b>Objectives, Principles, and Cornerstones.....</b>	<b>11</b>
	The PROMISE Challenge.....	11
	Addressing the Challenge: the PROMISE proposition....	15
	PROMISE PLM system architecture.....	16
	Who can benefit from PROMISE?.....	24
	Highlights of achievements .....	24
	The PROMISE demonstrators.....	27
	Conclusions.....	29
	References.....	30
<b>3</b>	<b>PROMISE Technologies.....</b>	<b>31</b>
<b>3.1</b>	<b>PROMISE System Architecture</b>	
	PROMISE architecture concepts.....	35
	Hardware layer .....	41
	Product embedded information device (PEID).....	42
	PROMISE Data Services .....	45
	PROMISE PDKM/DSS .....	67
<b>3.2</b>	<b>Product Embedded Information Device (PEID).....</b>	<b>69</b>
	Concept of PEID.....	69
	Definition of Core PAC .....	73
	Semantics of Core PAC interface.....	77
	Core PEID Prototype Implementation.....	83
	Summary .....	89

**3.3    Middleware.....91**  
    Locating information sources ..... 94  
    PROMISE messaging interface ..... 98  
    PMI implementation in Dialog..... 102  
    Conclusions..... 107  
    References..... 108

**3.4    Product Data and Knowledge Management (PDKM).....111**  
    Introduction ..... 112  
    Users and user roles..... 112  
    Functional requirements..... 114  
    Design criteria ..... 115  
    The PROMISE PDKM system..... 120  
    The PROMISE PDKM SOM..... 128  
    PDKM system prototypical implementation ..... 133  
    Concluding remarks..... 135  
    Acknowledgment ..... 135  
    References..... 136

**3.5    Decision Support System (DSS) .....139**  
    Abstract ..... 139  
    Introduction ..... 140  
    Previous work..... 141  
    A short history of DSS ..... 141  
    Main components of a DSS..... 142  
    DSS in PROMISE..... 145  
    The DSS platform PARASUITE..... 147  
    Architecture overview ..... 149  
    Data Exchange Interface ..... 151  
    Flow-based computation engine..... 152  
    Benefits ..... 153  
    Summary ..... 155  
    References..... 155

**3.6    Integrated Design Support .....157**  
    Outline ..... 157  
    Requirements analysis and real data evaluation ..... 158  
    Modelling and system framework for evaluation  
    of quality degradation..... 158  
    Reliability design method based on evaluation

of quality degradation.....	159
Maintenance planning for life cycle management .....	159
Product life cycle management using feedback of operational information .....	159
Prototyping and evaluation .....	159
Application examples.....	160
Maintenance planning for life cycle management .....	164
Product life cycle management using feedback of operational information .....	171
User preference.....	175
Supporting consumers in use and maintenance of HDD of their PCs .....	176
Summary .....	178
References.....	178
<b>3.7 Standardization .....</b>	<b>181</b>
Introduction .....	182
Scope of standardization for the PROMISE EU project.....	183
Hardware layer and Core PEID .....	184
Core PAC interface .....	185
PROMISE Data Services (middleware).....	186
PMI (PROMISE Middleware Interface) .....	187
PDKM .....	188
Conclusions and next steps .....	192
References.....	194
<b>3.8 Identifying and Evaluating the PROMISE Demonstrators' Business Effects .....</b>	<b>195</b>
Why focus on the Demonstrators' business effects? ....	195
Methodologies for assessment of business potential, targets, and effects.....	196
Methodology 1: Business Effect Evaluation Methodology (BEEM) .....	197
Methodology 2: Cost-benefit and sensitivity analyses.....	202
Work sessions/meetings at demonstrator owners' sites .....	205
General comments on the analyses of demonstrators business potential .....	207
Conclusion .....	208
Bibliography .....	208

- 4 PROMISE Demonstrators.....209
  - 4.1 Demonstrators Covering Multiple Life Cycle Phases.....213
    - 4.1.1 Product Quality Evaluation Based on Product Life Cycle Modelling with Disturbances .....215
      - Product life cycle modelling with disturbances..... 215
      - Product reliability design ..... 217
      - Product reliability based on product life cycle modelling ..... 218
      - Product life cycle modelling under disturbances ..... 222
      - Product functional modelling..... 226
      - Summary ..... 230
    - 4.1.2 Tracking of Material from Receipt, Processing to Storage and Shipping, Including Customer Claim Tracking .....233
      - Beginning Of Life (BOL)..... 234
      - Middle of Life (MOL) ..... 235
      - End of Life (EOL)..... 235
      - PLM for BOL management ..... 237
      - Conclusion ..... 242
  - 4.2 Beginning of Life Demonstrators.....243
    - 4.2.1 Transformation of Field Data into DfX Knowledge .....245
      - Introduction ..... 245
      - ‘Design for X’ application scenario..... 246
      - Characteristics of the BT DfX demonstrator ..... 248
      - Implementation of DfX demonstrator ..... 251
      - Analysis of obtained results ..... 254
      - Conclusions..... 261
      - References..... 262
    - 4.2.2 Adaptive Production.....263
      - Introduction ..... 263
      - Adaptive Production scenario ..... 264
      - Requirements for Adaptive Production ..... 267



Modification of the cylinder head and block .....	268
Modification of the car body .....	270
Adaptive Production in PROMISE.....	271
Algorithms.....	275
Physical Performance Evaluator.....	276
Economic Performance Evaluator.....	279
Optimal Buffer Space Allocation Algorithm .....	280
Conclusions.....	284
References.....	285
<b>4.3 Middle of Life Demonstrators .....</b>	<b>287</b>
<b>4.3.1 Predictive Maintenance for Trucks.....</b>	<b>289</b>
Overview of the application .....	289
Overview of maintenance strategies.....	290
Architecture and results .....	292
Innovation .....	295
<b>4.3.2 Predictive Maintenance for Machine Tools .....</b>	<b>297</b>
Introduction .....	297
State of the art in maintenance management .....	298
The proposed integrated approach to maintenance management .....	300
Description of the testing module .....	301
Description of the aging module .....	302
Cost maintenance management module .....	304
Conclusion .....	305
References.....	307
<b>4.3.3 Smart Bridge Health Monitoring and Diagnostics .....</b>	<b>309</b>
General methodology .....	310
Case study .....	312
Conclusion .....	320
Acknowledgment .....	320
References.....	321
<b>4.4 End of Life Demonstrators .....</b>	<b>325</b>

**4.4.1 Tracking and Tracing of Products for Recycling .....327**  
    Introduction..... 327  
    Specifics of the recycling sector ..... 329  
    Application scenario ..... 331  
    Implementation of the demonstrator..... 332  
    Analysis of results..... 339  
    Conclusions..... 339  
    References..... 340

**4.4.2 Recycling of Plastic Consumer Durable Products .....341**  
    Making decisions in plastic recycling ..... 341  
    Prediction of plastics volumes available for  
    recycling in automotive industry ..... 345  
    The effect of contamination on the properties of  
    engineering plastics..... 349  
    References..... 353

**5 Benefits of Using PROMISE Technologies .....355**  
    Key business benefits of PROMISE-based products..... 357  
    Coverage of broad industrial field and  
    whole product life cycle..... 358

# Introduction

## *Authors:*

Prof. Asbjorn Rolstadas (SINTEF/NTNU)

Markus Frey (Bombardier Transportation)

## **The main objectives**

The manufacturing sector has driven research and the implementation of new technology for decades. It is in a special position, providing end-user products for households, capital intensive products for national infrastructures and production facilities and machine tools for other industries. Its products are often highly complex, involving supply chains in several tiers.

Manufacturers employ advanced technology in both their products and their manufacturing processes. Products are frequently mechanical with embedded electronics and manufacturing equipment is often computer controlled.

But manufacturing is not simply a technological matter. It also has a substantial managerial component connected to planning, scheduling, logistics, quality assurance, as well as providing maintenance and service at individual plants and across supply chains. Lately, recycling has been added to the list.

Parts and product identification has always been important and it is essential for competitive products in today's market. Product classification systems were developed to control product variants early on. The bill of material at the top level could be extracted from the product identifier, which helped immensely in the development of cost-effective logistics, maintenance, and service. Classification codes were later developed for individual parts. This was necessary for au-