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A Collaborative Process of Product Lifecycle Management for Railway Signalling Infrastructure

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RATAHALLINTOKESKUS
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Key words: Product Lifecycle Management, PLM, collaboration management, rail infrastructure management, railway signalling maintenance

ABSTRACT

The purpose of this study is to define a collaborative process of Product Lifecycle Management (PLM) for railway signalling infrastructure.

In the theoretical part of the study different methods of Product Lifecycle Management and collaboration management and their principles are discussed as they provide a basis for the empirical part of the study, depending on which, a collaborative process of PLM for railway signalling infrastructure is created.

The collaborative process of PLM describes a set of methods of PLM, which the partners involved can utilize in order to facilitate the process of an optimal and continuously improvable railway signalling infrastructure management. The collaborative process of PLM facilitates railway signalling management at the Finnish Rail Administration (RHK). It highlights the collaboration between the rail infrastructure manager with the signalling suppliers, and railway signalling maintenance contractors and eventually improves the quality of the service of the railway signalling.

The study was conducted by having interactive interview sessions with chosen representatives of signalling suppliers and maintenance contractors. The sessions were led by the researcher and they sought after the areas of improvement and suitable practices to be utilized in the relations between the partners: the purchaser, the signalling supplier and the maintenance contractor.

The key insights from the interviewees are collected into the dozen performance indicators. Also based on the interviews and the inputs by the researcher, a collaborative process of PLM for rail signalling infrastructure is defined, which describes the main process steps, which the partners can schedule along the lifecycle of the installations.

By utilizing the results and the process presented in the study the partners can contribute to improving the punctuality of the train traffic. The results bear significant managerial implications in developing the practices of rail signalling infrastructure management at RHK. The results can be generalized in other industries with similar characteristics.

Härkönen, Aki: Tuotteen elinkaarenhallinnan yhteistoimintaprosessi rautateiden turvalaiteinfrastruktuurille. Ratahallintokeskus, Rataverkko-osasto. Helsinki 2008. Ratahallintokeskuksen julkaisuja A 13/2008. 93 sivua ja 5 liitettä. ISBN 978-952-445-245-8, ISBN 978-952-445-246-5 (pdf), ISSN 1455-2604, ISSN 1797-6995 (pdf)

Avainsanat: Tuotteen elinkaarenhallinta, PLM, yhteistoiminnan johtaminen, rautateiden infrastruktuurinhallinto, rautateiden turvalaitteiden kunnossapito

TIIVISTELMÄ

Tämän tutkimuksen tarkoituksena on määritellä tuotteen elinkaarenhallinnan yhteistoimintaprosessi rautateiden turvalaiteinfrastruktuurille.

Tutkimuksen teoreettisessa osassa käsitellään tuotteen elinkaarenhallinnan ja yhteistoiminnan johtamisen erilaisia menetelmiä ja periaatteita perustana tutkimuksen kokemusperäiselle osalle, josta riippuen on luotu elinkaarenhallinnan yhteistoimintaprosessi rautateiden turvalaitteille.

Tuotteen elinkaarenhallinnan yhteistoimintaprosessi kuvaa tuotteen elinkaarenhallinnan menettelyjä, joita mukanaolevat yhteistyökumppanit voivat hyödyntää pyrkiessään edistämään optimaalista ja jatkuvasti parantuvaa rautateiden turvalaitteiden infrastruktuurinhallintaa. Tuotteen elinkaarenhallinnan yhteistoimintaprosessi helpottaa turvalaitteiden infrastruktuurinhallinnan ohjausta Ratahallintokeskuksessa (RHK). Se korostaa rautatien infrastruktuurihallinnon, turvalaitetoimittajien ja kunnossapitourakoitsijoiden yhteistyötä ja lopulta parantaa rautateiden turvalaitteiden palvelunlaatua.

Tutkimus on toteutettu tutkijan ohjaamin vuorovaikutteisin haastatteluistunnoin rautateiden turvalaitetoimittajien ja -kunnossapitäjien valittujen edustajien kanssa etsien parannuskohteita ja soveltuvia käytänteitä, joita voidaan hyödyntää yhteistoimintakumppanien – hankkijan, rautateiden turvalaitetoimittajan ja -kunnossapitäjän – välisissä suhteissa.

Haastateltavilta kerätyt tärkeimmät oivallukset on koottu yhteen ja niihin ja tutkijan omaan panokseen perustuen on määritelty tuotteen elinkaarenhallinnan yhteistoimintaprosessi rautateiden turvalaiteinfrastruktuurille, joka kuvaa pääasialliset prosessiaskelmat, jotka kumppanit voivat ajoittaa asennusten elinkaarelle.

Hyödyntämällä tutkimuksen esittämiä tuloksia ja prosessia yhteistoimintakumppanit voivat osaltaan edesauttaa junaliikenteen täsmällisyyden parantamista. Tulokset sisältävät merkittäviä seuraamuksia RHK:n johdolle turvalaiteinfrastruktuurinhallinnon menettelyjen kehittämisessä. Tuloksia voidaan yleistää muille samankaltaisille teollisuuden aloille.

Härkönen, Aki: Samarbetsprocessen för produktlivscykelförvaltning för järnvägarnas infrastruktur av signal- och säkerhetsanläggningar. Banförvaltningscentralen, Bannätsavdelningen. Helsingfors 2008. Banförvaltningscentralens publikationer A 13/2008. 93 sidor och 5 bilagor. ISBN 978-952-445-245-8, ISBN 978-952-445-246-5 (pdf), ISSN 1455-2604, ISSN 1797-6995 (pdf)

Nyckelord: Produktlivscykelförvaltning, PLM, ledning av samarbete, järnvägarnas infrastrukturförvaltning, underhåll av järnvägarnas signal- och säkerhetsanläggningar

SAMMANDRAG

Avsikten med denna undersökning är att definiera samarbetsprocessen för produktlivscykelförvaltning för järnvägarnas infrastrukturförvaltning av signal- och säkerhetsanläggningar.

I undersökningens teoretiska del behandlas olika metoder och principer för produktlivscykelförvaltning och ledning av samarbetet som grund för den empiriska delen, som utgjorde grunden för skapandet av en samarbetsprocess för produktlivscykelförvaltning för signal- och säkerhetsanläggningar vid järnvägarna.

Samarbetsprocessen för produktlivscykelförvaltning beskriver de metoder som används för hantering av produktlivscykel som de deltagande samarbetspartnerna kan utnyttja då de strävar efter att främja den optimala och kontinuerligt förbättrade förvaltningen av infrastrukturen för signal- och säkerhetsanläggningar vid järnvägarna. Samarbetsprocessen kring produktlivscykelförvaltning underlättar infrastrukturförvaltningen av signal- och säkerhetsanläggningar på Banförvaltningscentralen (RHK). Den betonar samarbetet mellan järnvägarnas infrastrukturförvaltning, produktleverantörer och underhållsentreprenörer och förbättrar i slutändan kvaliteten på servicen av järnvägarnas signal- och säkerhetsanläggningar.

Undersökningen har genomförts genom interaktiva intervjusessioner ledda av forskaren med utvalda representanter för leverantörer och underhållare av signal- och säkerhetsanläggningar för järnvägarna. Vid sessionerna har man försökt hitta objekt för förbättringar och lämplig praxis, som kan utnyttjas i relationerna mellan samarbetspartner – inköparen, samt leverantören och underhållaren av signal- och säkerhetsanläggningar.

De viktigaste av de insamlade idéerna från intervjuerna har sammanställts och med stöd i dessa och forskarens egen insats har en samarbetsprocess för produktlivscykelförvaltning för infrastrukturen för signal- och säkerhetsanläggningar vid järnvägarna definierats. Denna beskriver de huvudsakliga processteg som parterna kan fördela över livscykeln av installationer.

Genom att utnyttja de resultat som undersökningen ger och processen kan samarbetsparterna för sin del främja förbättringen av punktlighet i järnvägstrafiken. Resultaten inkluderar betydande följder för RHK:s ledning vid utvecklingen av metoderna för förvaltningen av infrastrukturen för signal- och säkerhetsanläggningar. Resultaten kan generaliseras att gälla andra liknande industrier.

PREFACE

This is a Master's Theses at Stadia Helsinki Polytechnic, degree programme Master of Engineering (Industrial Management). The author of the theses is Mr. Aki Härkönen, the manager of the Rail Data Unit at the Rail Network Department of Finnish Rail Administration (RHK).

The instructor of the thesis was Mr. Markku Nummelin, Technical Director of Finnish Rail Administration (RHK). The supervisor was Ms. Satu Teerikangas, Doctor of Science (Technology).

The thesis represents the viewpoints of the researcher and is as such not an official or binding policy of RHK.

Helsinki, September 2008

Finnish Rail Administration
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ACRONYMS

3D	Three-dimensional
ALM	Asset Lifecycle Management
ATP	Automatic Train Protection
BOM	Bill of Material
BOO	Build-Operate-Own
BOT	Build-Operate-Transfer
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CALM	Collaborative Asset Lifecycle Management
CLV	Customer Lifetime Value
CM	Configuration Management
CMS	Content Management System
CMMS	Computerized Maintenance Management System
cPDM	Collaborative Product Data Management
CPD	Collaborative Product Development
CRM	Customer Relationship Management
CTC	Centralized Traffic Control
DFA	Design for All
DFM	Design for Manufacturability
DIN	German Institute for Standardization (Deutsches Institut für Normung)
DOE	Department of Energy, a government body in the USA
EAM	Enterprise Asset Management
ECM	Engineering Change Management
EDB	Engineering Data Base
EDM	Engineering Data Management
EIM	European Rail Infrastructure Managers
ERA	European Railway Agency
ERP	Enterprise Resource Planning
ERTMS	European Rail Traffic Management System
GTKB	Ganz Transelektro Közlekedési Berendezéseket Gyártó Kft. (a company in Hungary)
ICT	Information and Communications Technology
IM	Infrastructure Manager
ISO 9 000	Quality mgmt standards of International Organization for Standardization
ISO 10 007	Guidelines for configuration management of ISO
ISO 14 000	Environmental management standards of ISO
LCA	Life Cycle Assessment
MINTC	Ministry of Transport and Communications of Finland
MSA	Maintenance Support Agreement
MTBF	Mean Time between Failures
MTTR	Mean Time to Repair
NAO	National Audit Office of Finland
NPI	New Product Introduction
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PDM	Product Data Management
PKM	Product Knowledge Management

PLM	Product Lifecycle Management
PPP	Public Private Partnership
QFD	Quality Function Deployment
RAMS	Reliability, Availability, Maintainability and Safety
RCM	Reliability Centred Maintenance
RHK	Finnish Rail Administration (Ratahallintokeskus)
SAP	A software product and a company, originally named *"Systeme, Anwendungen und Produkte in der Datenverarbeitung"*
SCM	Supply Chain Management
TCO	Total Cost of Ownership
TOC	Train Operating Company
UIC	International Union of Railways (Union Internationale des Chemins de Fer)
VMI	Vendor Managed Inventory

1 INTRODUCTION

1.1 Background to the Study

This study deals with a collaborative process of Product Lifecycle Management (PLM) for railway signalling infrastructure.

The study has been conducted for the Finnish Rail Administration (RHK). RHK is a government authority and a rail infrastructure manager (IM) under the Ministry of Transport and Communications of Finland and it has as its task to manage the state-owned rail network in Finland. With activities pertaining to the planning, construction, maintenance and traffic control, RHK ensures the rail infrastructure on which the train traffic can continuously operate with reliability and safety. (RHK 2007)

The focus of the study is to improve the collaboration of RHK and its signalling infrastructure suppliers and its maintenance contractors by introducing a collaborative process for PLM, which the parties can utilize. The improved PLM and the methodical approach to collaboration are keys to manage better the use and maintenance of the existing installed base of signalling infrastructure and the network of suppliers and maintenance contractors of the Finnish rail system. By improving the process of collaboration and PLM, the quality of the service of the signalling infrastructure can be improved and train operation can become more punctual and the end-customers of the train operating companies more satisfied.

The railway signalling infrastructure is a system controlling railway traffic safely and ultimately preventing trains from colliding. The railway signalling infrastructure provides technical means enabling trains to operate at high speeds above the sighting distance of the driver. The functionality and the level of automation of the railway signalling infrastructure products have been increasing, adding to the complication of the systems and their maintenance.

The technological transition in railway signalling infrastructure has transformed traditionally relay-based systems into modern computer-based automation systems with remarkably shorter lifecycles in comparison to relay technology. Multi-supplier environment and increasing outsourcing within each supplier add to the need of taking better control of the products and their lifecycles. The outsourcing of maintenance and changes in maintenance contractors require clearly defined practices between the partners. Shorter lifecycles of the signalling system components demand an increased attention on keeping a sufficient level of spare parts stockpiled and also minding the provisions for emergencies. In the following, the key concepts necessary to tackle the amounting complexity are introduced.

Product Lifecycle Management (PLM) is a strategic concept for managing various engineering tasks of a product during its lifecycle. Computer-based technology has short lifecycles and products are produced sourcing from the global electronics industry, which emphasizes the need of an organized way of dealing with the task at hand. The supplying companies have varying ways of recording product related information starting from conceptualization of a product idea, to the detailed planning, through the manufacturing and distributing of the product until removing the product from the product palette being offered. Each change in product design complicates the management of the product and as the time passes by, product variations may become an obstacle in servicing the product during its lifecycle and a burden for the customers. PLM seeks ways to manage crucial factors affecting the long term utilization of the product. The systematic methods of PLM help the supplier as it tries to serve its customers in keeping the products and the services they render in production. Methods of PLM can be applied in signalling infrastructure as an answer to the demand of sustainable management of the systems during their lifecycle.

Management is a process of working with people and resources to achieve an organizational task. Management has two main components: the efficiency and the effectiveness, both of which must be applied to the basic management principles: planning, organizing, leading and controlling. (Bateman 2007: 16)

Collaboration management relates to collaboration, working together with partners towards common targets. It requires leadership and management in order to create processes and practices that are sufficient in achieving the task at hand but not overly bureaucratic or rigid in forms and methods. Collaboration management refers to the practices, which help in creating the infrastructure and framework for collaboration so that collaboration can take place effectively and efficiently. In order to enable the partners to collaborate, the processes, which are used in the collaboration, must be planned and executed systematically, still creating space for spontaneous and creative problem solution.

Signalling infrastructure management is dependent on collaboration of the partners working within the signalling supplier companies or within the signalling maintenance contractor companies. Better collaboration between the partners is an answer to the demands of improved management of the systems during their lifecycle.

1.2 Research Question

The objective of this Master's Thesis is to study the methods of Product Lifecycle Management (PLM) and their applicability to the collaborative relationships between the purchaser RHK and its signalling infrastructure suppliers and its signalling maintenance contractors.

To reach the objective of the study, the following research problem has been set:
- *How can the methods of PLM and collaboration management be applied to the relationships between the purchaser RHK, its signalling infrastructure suppliers and its signalling maintenance contractors?*

To reply to this research problem, the following questions are raised:

1) How could collaboration and PLM ultimately improve the quality of the service of railway signalling and the punctuality of rail traffic?
2) How could the collaborative process of PLM facilitate signalling maintenance management and improve collaboration between the rail infrastructure manager, the signalling suppliers, and the maintenance contractors?

3) What methods of PLM could the partners utilize in order to achieve an optimal and continuously improvable railway signalling maintenance?
4) What would be the practical application of collaborative processes of PLM, which could be utilized between RHK, its signalling suppliers and its maintenance contractors?

The current railway infrastructure administration in Finland has the characteristics that the government authority RHK in charge of the rail infrastructure management has totally outsourced the rail signalling maintenance. Two companies, namely Eltel Networks Ltd. and VR-Track Ltd. divide the signalling maintenance market, the latter being currently the dominant player. The rail signalling infrastructure has several suppliers. The maintenance of the modern computer-based signalling infrastructure is also dependent on the competence and support of the original signalling suppliers, which retain the source codes of the system and deeper knowledge of the applications. The effective and efficient rail signalling infrastructure management requires collaboration between those partners.

The collaboration of the partners can be illustrated using the following figure:

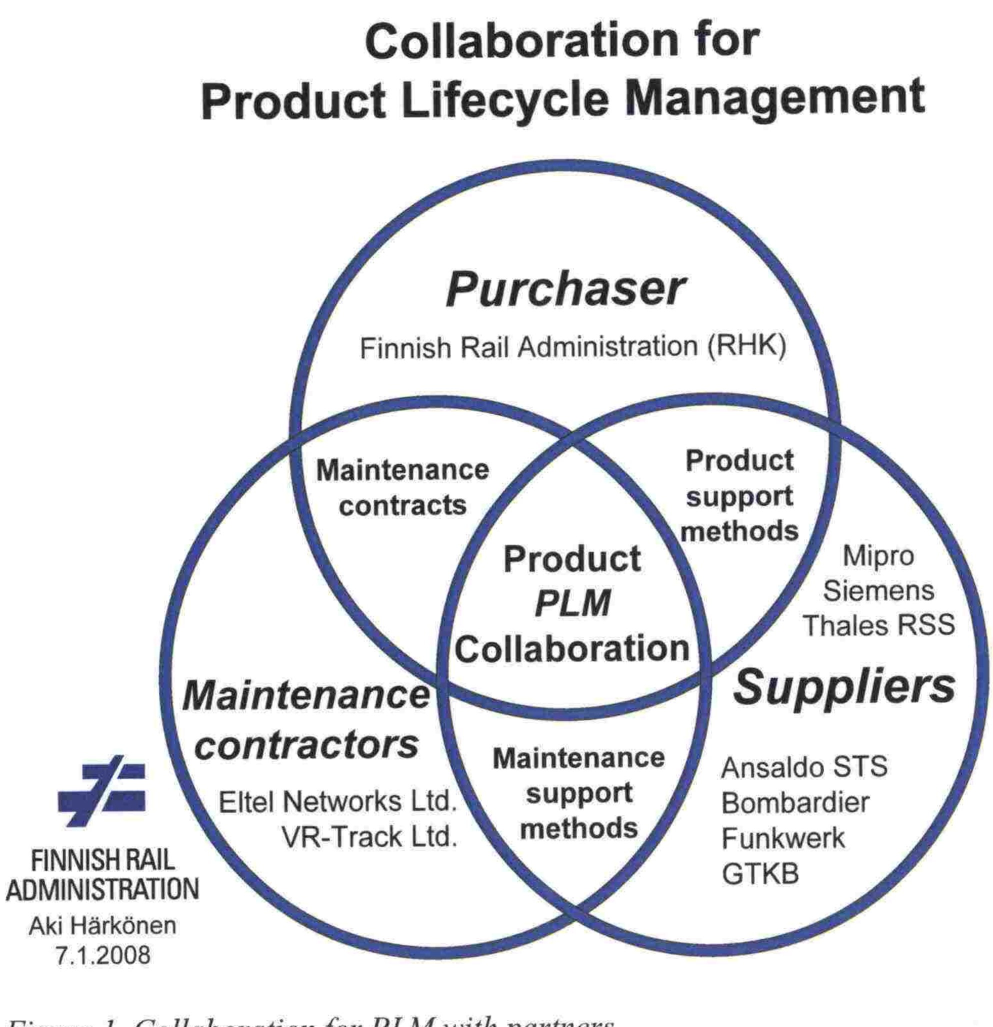

Figure 1. Collaboration for PLM with partners

In Figure 1 the three partners are described in the intersecting circles; the purchaser RHK, the signalling infrastructure suppliers and the maintenance contractors. The partners focus on the product, PLM and collaboration. The maintenance contracts and various support methods for maintenance and product are means in achieving the goal. The partners need clearly defined and easy to use methods, so that they can be adopted as practical tools in managing the tasks between the partners.

1.3 Scope of Study

The study has been limited to the suppliers Ansaldo STS Sweden AB, Bombardier Transportation Finland Oy, Funkwerk Information Technologies Malmö AB, GTKB, Mipro Oy, Siemens Osakeyhtiö, Thales Rail Signalling Solutions GmbH and the maintenance contractors Eltel Networks Ltd. and VR-Track Ltd. The study focuses on their applicable products and services in use on the Finnish rail network and on features of PLM, which those companies are capable to practice in collaboration with the purchaser and its maintenance contractor.

The scope of the collaborative process of PLM is limited to the most important subset of the railway signalling, the interlocking products, and to a few selected signalling suppliers. The process is described, but no ICT applications are defined. The scope is limited to the vision and practical instructions for the collaborative process of PLM, but the execution is out of the scope of the study.

1.4 Research Approach

The research has been conducted based on the ideas derived from the literature and with the approach of interviewing PLM specialists of the chosen rail signalling suppliers of RHK and the managers of the rail signalling maintenance contractors. The expertise and the experiences of the partners are utilized as a source of gaining insights and in collecting the set of practicable processes. The work flow of the study follows the diagram below.

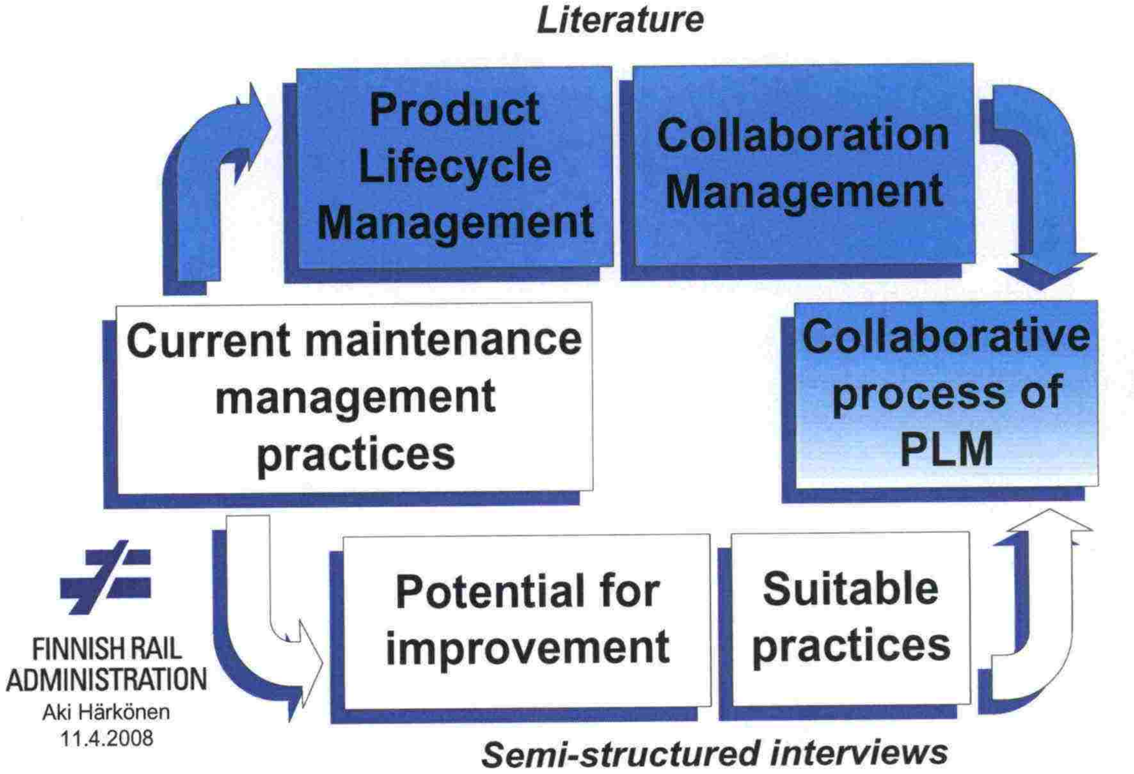

Figure 2. Work flow of the study

The current maintenance management practices of the supplier are as the starting point illustrated on the left hand middle section of the Figure 2. They were discussed with the experts of each individual company during the interviews. The potential for improvement and suitable practices for implementation were then analyzed based on the interviews. The developed processes are put under the framework of PLM and collaboration management schemes. The collaborative procedure will result in a proposed collaborative process of PLM for railway signalling infrastructure that meets the presented expectations of the involved parties.

1.5 Research Method

The research has been conducted using the method of semi-structured interviews, where a conversational and two-way communication method to the subject has been sought after. The interviewees, who gave input to the study, represented seven (7) signalling infrastructure suppliers and two (2) maintenance contractors, as listed in Appendix E.

A rigid questionnaire has been knowingly avoided, but rather a loose list of subjects to be covered has been presented to the interviewees before the interview with the research question to provoke thoughts and mentally prepare the interviewees for the coming communication (Appendix D). The purpose of the method has been to uncover relevant issues not known or not sufficiently understood before and to gain a range of insights on the subject at hand.

The list of subjects covers the theme, a collaborative process of PLM for the rail signalling infrastructure, and invites interviewees to focus on issues they feel are most critical. The method helps in concentrating on relevant themes bypassing the lesser issues.

The semi-structured interviews were conducted in sessions, where the author of the study interviewed one partner at the time. The number of interviewees in the room ranged from one to four. Typically the interviews started with few persons, who gave their input and a diminished group of attendees continued with a more detailed discussion. The time spent for each discussion was typically a few hours and with some partners the discussions were repeated for added hindsight in the presence of more participants.

The method of interviewing and recording the insights may suffer from a bias, as the author is the representative of the purchaser, and the interviewees may be reluctant to strongly point to the weaknesses of the purchaser or to their own neglects. Generally the maintenance contractor is willing to point to the weaknesses of the suppliers and vice versa. That brings a balanced view to the two partners, but the purchaser may be spared from direct criticism, even if that would have been deserved and necessary.

The notes from the communicative interactions were written down by the researcher. In the thesis the sources of ideas and the products are masked, and the insights are presented in general terms without identifying the signalling infrastructure supplier, product or the signalling maintenance organization in question due to confidentiality reasons.

The separate ideas derived from the interviewees have been analyzed and collected under relevant PLM concepts to form tangible results. Based on the research, a collaborative process of PLM for signalling infrastructure has been formulated. The professional perspective of the researcher has been significant in categorizing and analyzing the results in the rail signalling context. As the researcher has an experience of eight years in the business of rail signalling infrastructure management, the processing and the development of the ideas collected from the interviewees has notably relied on the vision of the author.

1.6 Structure of the Study

The study starts with a literature review covering PLM and collaboration management, given the relevance to the problems under study. It continues with the description of the context of the study i.e. the Finnish railway signalling infrastructure management. The results of the study are presented in two ways. Firstly, results are presented as distilled key insights from the interviews, which are arranged into a dozen performance indicators for measuring the state of PLM in the rail signalling context. Secondly results of the study are used to develop a collaborative process of PLM for the railway signalling infrastructure. In the conclusions section the applicability of the results is discussed. In the end of the study, there is a summary.

2 LITERATURE REVIEW

In this section the current practices and principles of Product Lifecycle Management (PLM) are studied. The trends and methods of collaboration management are also researched based on available literature.

2.1 Product Lifecycle Management (PLM)

PLM is a set of engineering practices, which are of current interest as product lifecycles shorten and the outsourcing of different tasks around a product increases. In the following, an introduction, some definitions, selected concepts, the development and the utilization of PLM are presented.

2.1.1 Introduction to PLM

The product lifecycle typically consist of the five phases: 1) imagining the concept of the product, 2) defining the specifications of the product, 3) realizing the product, 4) using or supporting the product and 5) disposing or retiring the product. The figure below illustrates the phases. (Stark 2006: 421)

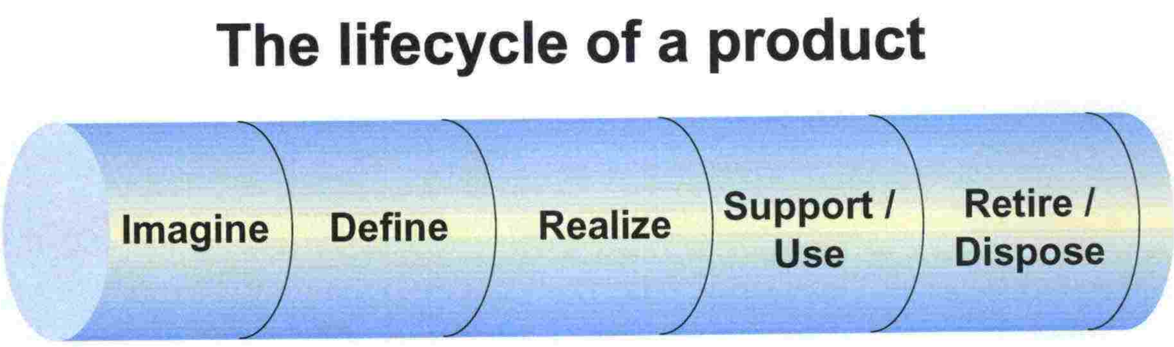

Figure 3. Lifecycle of a product (Stark 2005: 421)

Stark's model in Figure 3 sees the lifecycle of a product from the perspective of the product and stresses the development and utilization of the product. The lifecycle phases of developing the product before product delivery are important. Products require support during their use and when using the product the supplier and customer have differing views on it.

Sääksvuori's model of lifecycle phases stresses the business performance metrics of the products and especially the perspective of cash flow having the phases: planning, introduction, growth, maturity, decline and retirement. The product lifecycle model with the featured s-curve is the classical one with an emphasis on cash flow. The product is seen as the generator of cash flow. The illustration below describes the lifecycle phases. (Sääksvuori 2004: 181-182)

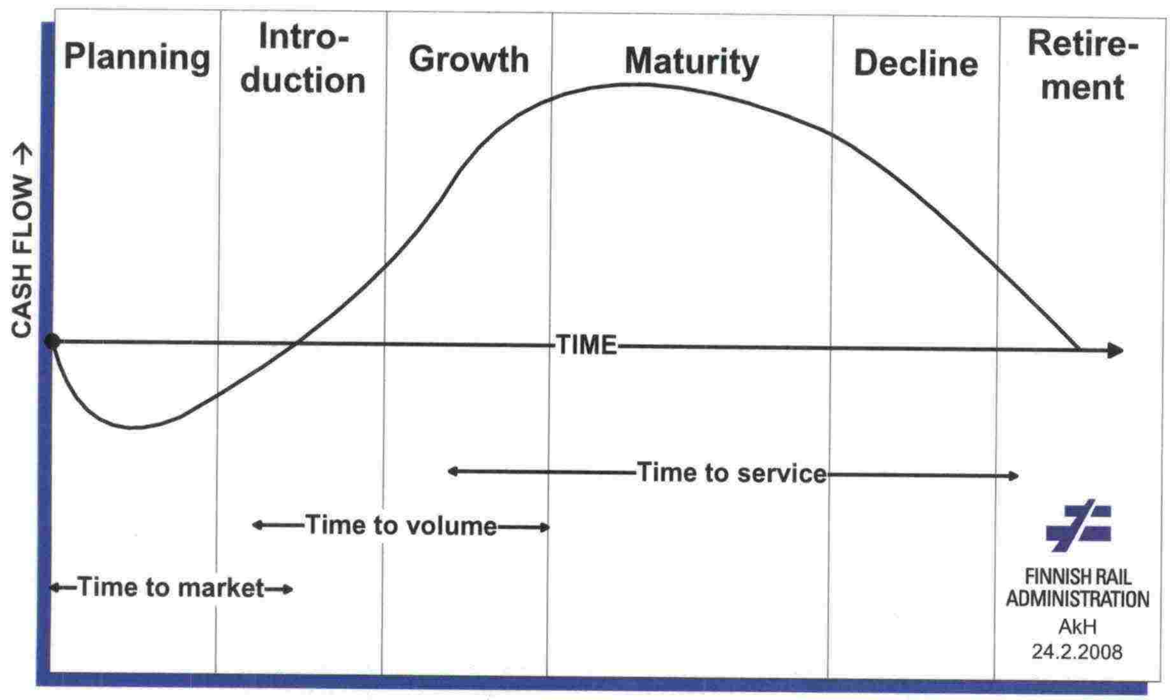

Figure 4. Cash flow of the lifecycle as a function of time (Sääksvuori 2004: 182)

In Figure 4 the lifecycle of a product begins with the planning phase of the product, during which there is a negative cash flow and it takes time to bring the product to the market. When the product has been introduced to the market, the cash flow becomes positive and growth continues until the volume has reached its peak and the product has reached its maturity phase. When the sales decline, so does the cash flow, until the production ceases and cash flow becomes zero and the lifecycle ends. The service time starts after the introduction and continues till the end of the lifecycle.

Another significant point of view to PLM is reliability and its changes during the lifecycle. Reliability is the probability that a product performs its function without failure for a stated period of time. In reliability engineering the classical bathtub curve describes the typical characteristics of the lifecycle, where the pattern of failure or hazard rate resembles a bathtub. When a new installation has been put into service, the failures of weak items start from the high level and is dubbed as “infant mortality”. The phenomenon has as its background the physical characteristics of electronics. The initial usage in production reveals hidden problems in weak items only after the usage has properly warmed up the components and they have been under the field conditions. When the weak items are replaced, infant mortality ends. Towards the end of the lifecycle, the wear out of the well served items increase the hazard rate again and the rising slope forms the other end of the bathtub. The illustration below shows the patterns of the bathtub curve. (O’Connor 2004: 2, 11).

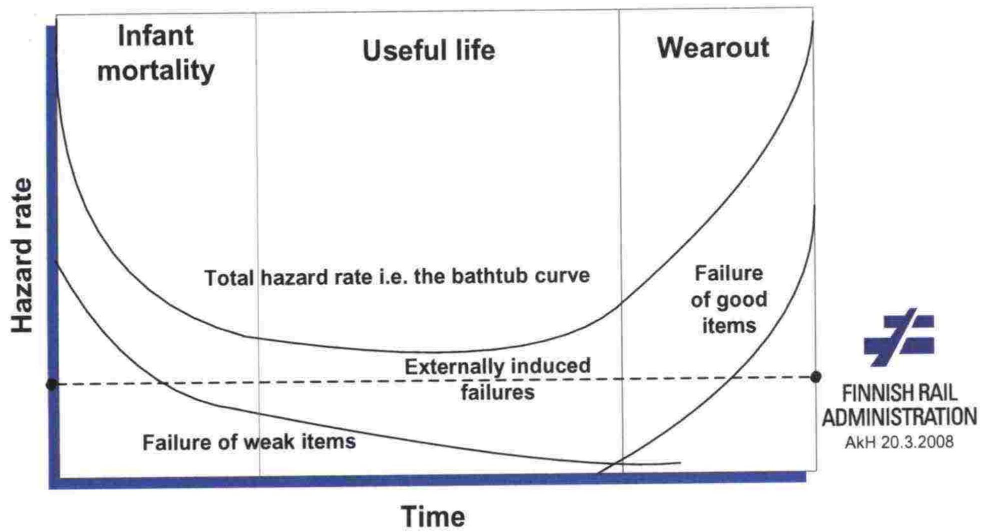

Figure 5. Hazard rate as a function of time, the bathtub curve (O'Connor 2004: 11)

In Figure 5 the bathtub curve divides the lifecycle timeline of the product into three stages, where the hazard rate initially during the infant mortality stage is high and evens out during the useful life. When the useful life ends and the wear out takes its toll, the hazard rate increases again.

In reliability engineering the pursuit of high reliability and quality of service requires actions, which improve the quality of service. Those actions or reliability programs induce costs, which must be weighed against the value of increased reliability. Tradition has it that if the failure costs are to be totally abolished, the quality program costs increase exponentially towards 100 % reliability. Somewhere below that optimal failure rate lays a tolerable failure rate, which due cost reasons must be endured. The Figure 6 below pictorially describes the traditional view (O'Connor 2004: 17)

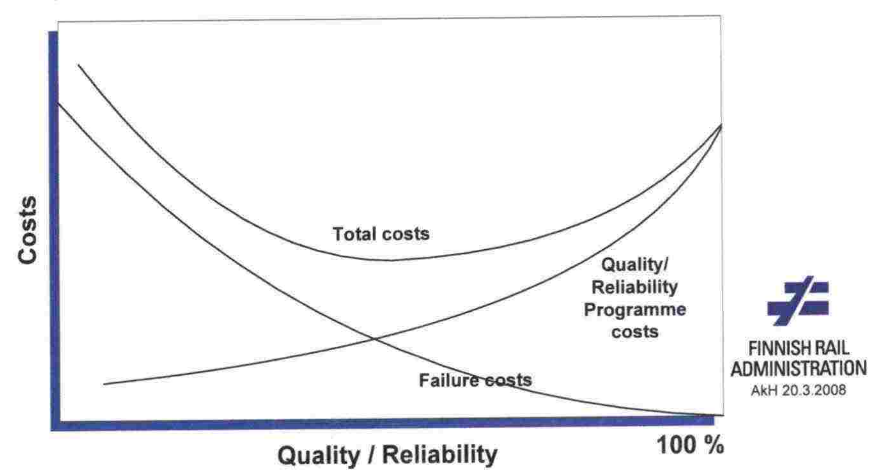

Figure 6. Traditional view of reliability and lifecycle costs (O'Connor 2004:17)

In order to abolish the failures and get the failure rate to zero, ever increasing costs of quality programs are caused and the total costs increase as the target of 100 % reliability is approached as shown in Figure 6.

In modern thinking the belief has it that reliability can be endlessly increased without increasing total cost. On the contrary the failure costs are the main cost drivers, not the development costs caused by the pursuit of abolishing the failures. Creating reliable products is seen as a management task, which must concentrate on intrinsically reliable products and effective testing during the development phase. Continuous improvements in the design phase of a product are the most effective ones. The illustration below describes the phenomenon. (O'Connor 2004: 18-19)

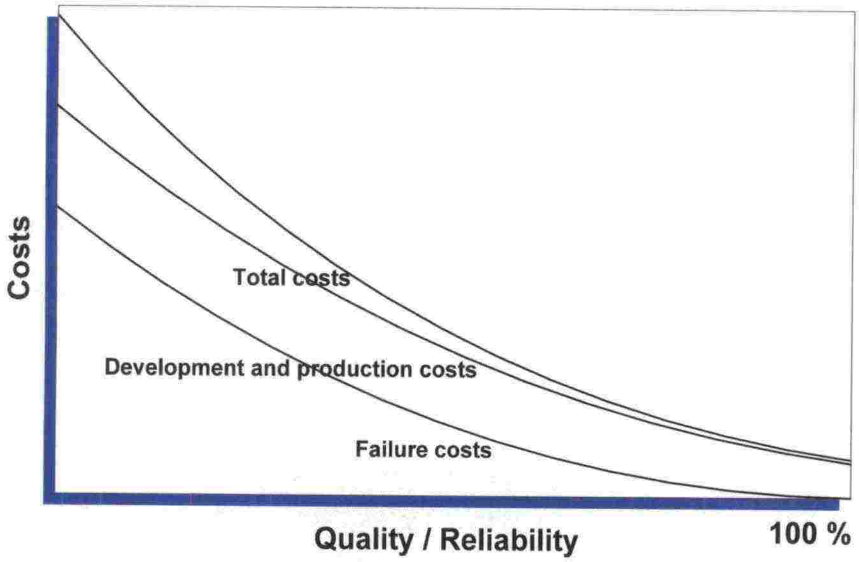

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Figure 7. Modern view of reliability and lifecycle costs (O'Connor 2004: 18)

Figure 7 illustrates failure costs as the main cost drivers. By constantly investing in development and production in order to minimize failures, total costs can be minimized. This view emphasizes the need for constant actions and endless pursuit for better quality. Contrary to the traditional view, the extra costs invested in improvements in the product development and in the production processes can lower the failure costs and ultimately reduce the failure costs to zero. Reliability can be increased by utilizing products that have been developed with the aspiration to high quality and reliability.

In the business of the railway signalling infrastructure management, PLM can be used as a point of view highlighting the problems encountered during the entire lifecycle of the systems. PLM is a broad set of engineering practices. The emphasis of PLM and the main point of view on it in this master's thesis is the user's or customer's point of view as RHK is the user and the customer for rail signalling products it has purchased. The most critical phase of the product lifecycle and the focus of attention is therefore the phase of using and supporting the product in service. The illustration below describes the product and order-delivery processes and their sub-processes (Sääksvuori 2004: 3).

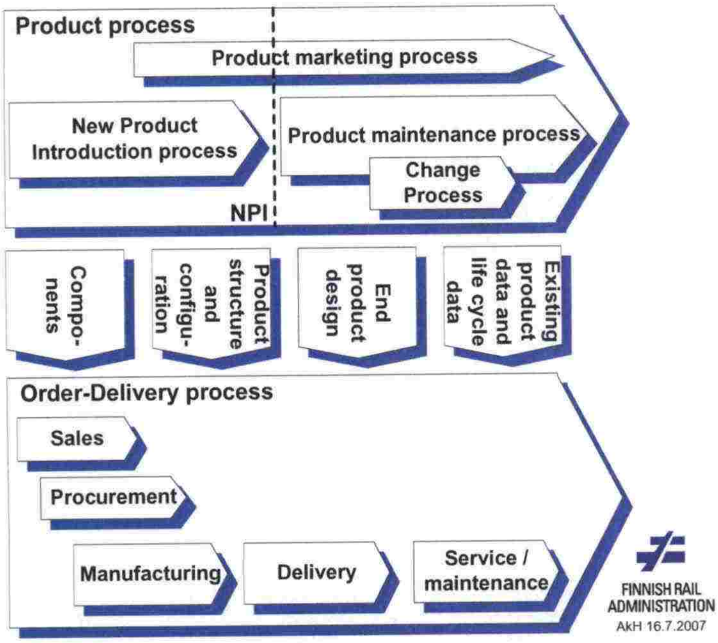

Figure 8. Product and order-delivery processes (Sääksvuori 2004: 3)

Figure 8 illustrates the product and order-delivery processes and their relationships, and distinguishes the New Product Introduction (NPI) with a dotted line, after which the product maintenance process and change processes take over. Similarly, in the order-delivery process, service and maintenance processes take over after a completed and successful delivery. After a successful delivery, when a new product has been introduced to the Finnish rail network, the product maintenance process, change process and service processes must take care of the continuous functionality of the product and the business operations of the railway undertakings i.e. train operating companies (TOCs) it is supporting.

PLM has been growing in importance in rail signalling infrastructure management. The main driver for the increased attention on PLM has been the technological transition from mechanical, electro-mechanical and relay-based interlockings to computer- and electronics-based interlockings.

Computer-based interlockings are technologically constructed with components and circuits, which have been sourced from the global market place of the electronics industry. The original supplier is in charge of the software programming and the integration of the hardware components. The original supplier is on the other hand dependent on a multitude of sources and subcontractors, which provide it with different parts of the installation.

A systematic approach on PLM is required in order to manage the usage phase of the lifecycle economically and ensuring the requirements of the target production i.e. the operation of the trains by the railway undertakings on Finnish rail network. In this Master's thesis, such a PLM process is described. PLM has many dimensions and in the following the main definitions in the literature are discussed.

2.1.2 Definitions and Features of PLM

Product Lifecycle Management can be defined in various ways. Below there are the few important ones published in recent literature on PLM.

Grieves (2006: 39) sees PLM as 'an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment and maintenance – culminating in the product's removal from service and final disposal. By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of lean thinking'. According to Grieves, PLM deals with maintenance and lean thinking.

Lean thinking refers to the avoidance of waste. Under the Japanese term "muda", the waste, there are different kinds of waste: the human efforts that add no value, the errors that must be corrected, the useless items produced, the unnecessary phases of processing, the movements of people and goods in vain, the excessive waiting due the bottlenecks of the production and the unsatisfactory products and services. Lean thinking is an antidote against waste and seeks continuously ways to do more with less. (Womack 1998: 15)

Affuso (2005: 5) emphasizes PLM as 'a powerful enterprise initiative that creates a digital backbone to supply interconnected authoring, analysis/validation, prototyping, simulation, and support capabilities. In this digital environment every authorized lifecycle participant – from engineering to manufacturing, finance, marketing, sales and service groups – can share and exchange product knowledge, enabling companies to proactively solve strategic issues that influence the success of a product's lifecycle from beginning to end.' Evidently PLM includes exchanging the product knowledge and solving strategic issues.

Cook (2004: 15) defines PLM as 'helping manufacturers meet the new challenges for collaboration and information sharing introduced by decisions to outsource or decentralize design and manufacturing. Through PLM, manufacturers can realize significant increase in productivity by saving time through eliminating the need for face-to-face meetings, travel time and schedules, and reductions in cost by identifying changes and corrections at the earliest.' In conclusion PLM relates to collaboration and productivity.

Scheer (2006: 13) describes the goal of PLM as 'the optimal design of the processes, especially the product development processes, and the preparation of the needed information on the product over its whole lifecycle. The requirements of the integrated business processes and the availability of the information grow both within a company and also in collaboration with the partners, suppliers and customers.' Obviously, PLM involves optimizing of processes and availability of information.

Stark (2006: 420-421) summarizes PLM as 'the business activity of managing a company's products all the way across their lifecycles in the most effective way. PLM helps a company get its product faster to market, provide better support for their use, and manage end-of-life better. PLM brings together products, services, structures, activities, processes, people, skills, application systems, data, information, knowledge, techniques, practices and standards.' In summary, PLM emphasizes support services for the products and various other business activities.

Sääksvuori (2004: 3) introduces PLM as 'a systematic, controlled concept for managing and developing products and product related information. PLM offers management and control of the product (product development, productizing and product marketing) process and the order-delivery process, the control of product related information throughout the product life cycle, from the initial idea to the scrap yard. Almost without exception, the PDM (Product Data Management) and PLM abbreviations also refer to information systems developed to manage the product lifecycle and product related data'. In a nutshell, PLM forms a controlled concept utilizing information systems.

In his latest publication, Stark (2007: 115) redefines the use of PLM as 'implying that the activity of managing products across the lifecycle is clearly-defined, well-documented, proactive, and carried out according to a particular design to meet specific objectives of increasing product revenues, reducing product-related costs, and maximizing the value of the product portfolio. The focus on the product is important as a company's products are what the customer buys.' In other words, PLM increases clarity by meeting particular demands.

Arnold (2005: 278) describes PLM as 'a paradigm, which supports holistic, structural and consistent administration and organization of all the information, data, documents and processes, which are produced during the development of the new or modification of the existing products'. Based on Arnold, PLM introduces a holistic paradigm for administration.

Feldhusen (2008: 20) describes PLM as 'a knowledge-based corporate strategy, which affects all the processes and methods of product development from the product idea to the recycling of the product'. Feldhusen emphasizes the all-encompassing and strategic approach of PLM.

The definitions described above each have a slightly different angle to PLM, but together they shed light to its different facets and help in forming the whole picture.
Regardless of the individual nuances of the different definitions, PLM represents the newest wave of productivity and it is aimed at eliminating waste and inefficiency. PLM utilizes the power of information and inexpensive methods of sharing, distributing and transferring information as a means of reducing the need of other costly resources like labour, services and tangible assets. (Grieves 2006: 2)

The power of PLM lays in its capability to offer managers visibility and real information of the product over its lifecycle thus enabling them to base their decisions on solid ground of information. PLM is an answer for coping with changes in the marketplace and responding to the drivers of change. The changes that can affect the product during its lifecycle are for example outsourcing, the multi-cultural environment, the evolution of information systems, product traceability, knowledge management, regulatory requirements and accidents. (Stark 2005: 2, 55)

PLM is not a software application, but a way of managing the product. PLM is always applied in a company- and customer-specific way and it cannot be bought as a ready software package or ICT solution. PLM is not single computer software or method, but rather a set of practices and processes around the product and product related information. (Sääksvuori 2004: 9)

As the definitions of PLM vary greatly, the industry has tried to create a consensus definition of it. The so called "Liebenstein's theses" are an attempt to generally define PLM. These ware adopted in 2004 in Germany. Liebenstein's theses are:

1. PLM is a concept, but no system or application.
2. For the realization of a PLM concept, some application components are needed. Those are CAD, CAE, CAM, Virtual Reality (VR) and PDM and other applications through the product development process.
3. Also interfaces to other application areas such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM) are components of a PLM concept.
4. PLM providers offer components or services for the implementing of a PLM concept. (TU Clausthal 2007)

Liebenstein's theses see PLM not as a system or application even if in its implementation the ICT components are utilized. The theses emphasize the interfacing of the systems and the role of PLM service provider in charge of customizing a company-specific application.

Due to the fact that products differ immensely from each other and the industrial environments around similar product can vary significantly, the attempts of defining a multi-faceted concept of PLM in a unified manner are not going to be very successful. Rather than attempting to reach unanimity on a definition it is more fruitful to make clear what one means with the concept of PLM and how it is practically utilized.

Based on the literature review above, PLM can be defined as an engineering discipline for efficient and effective way of managing a product during its whole lifecycle. A collection of general features gives a glimpse of PLM, but is not all-encompassing or exhaustive, but rather limited to a certain point of view. The emphasized items of PLM can be collected as illustrated below.

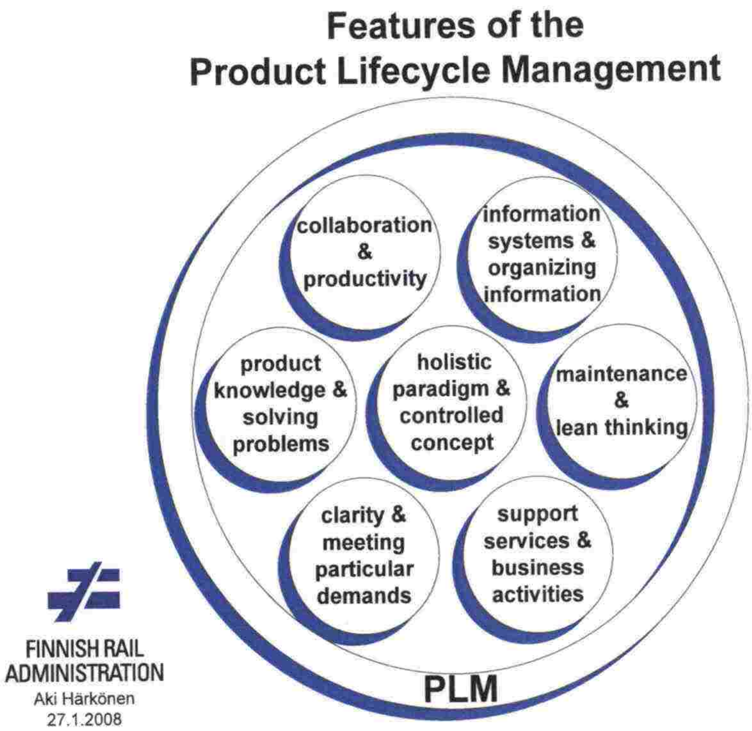

Figure 9. Features of PLM

PLM and its main features and ideas are illustrated in the Figure 9.

As Figure 9 shows PLM is a holistic paradigm and controlled concept, which affects all areas of the product lifecycle. A central theme in play is the idea of fostering collaboration within the supply chain of the product and towards the customers of the product. Such collaboration increases productivity as the over-all effectiveness of the partners and their product-related operations increase. Information systems and ways of organizing information are essential enablers of PLM and they possess a crucial supporting role. PLM empowers maintenance with information and promotes lean thinking minimizing waste. It can help in focusing on the most important support services and business activities, which are needed during the lifecycle of the product. By applying it, the clarity of needed actions and focusing on items to be taken care of, can be magnified and the particular demands set by the specific nature of the product can be met. PLM also brings attention to the product knowledge and helps in solving product-related problems.

These features emphasize the adjusted and customized nature of the practised PLM application and the concentration not on an ICT system or a software product, but rather on a mutual agreement of the parties involved. In the end the practiced PLM application must pass the cost-benefit-analysis and the sharing of incurred costs must be agreed upon.

PLM is a multidimensional concept, which has several features. The focus can be placed on a strategic concept, on processes or on ICT systems, but no matter which features are put on the foreground, the product and managing its lifecycle are at the centre of attention. Out of the spectrum of PLM features there are some, which are especially interesting. They will be introduced in the following.

2.1.3 Selected Concepts Related to PLM

The central concepts of PLM, which are especially of interest from the point of view of this thesis, are Configuration Management (CM), Product Data Management (PDM), Engineering Change Management (ECM), Product Knowledge Management (PKM), Enterprise Asset Management (EAM) and Customer Relationship Management (CRM). They are discussed below.

2.1.3.1 Configuration management

Configuration management (CM) is an integral part of PLM and records the information on the composition of the product and creates traceability of the individual product. Each individual item i.e. identified part or component of a product, must in a sufficient accuracy be traced back to an assembly of a product delivered to a customer's location. Creating CM, which is capable in managing the variance of the products and locating an individual component in a customer's installation, is a task, which requires integration of information out of several sources. The benefit of CM lies in improved risk management, which comes with the ability to efficiently and effectively retrieve and replace a substandard lot of components, if the need arises. The information typically exists within the supplier, but it needs collecting in a sufficiently unified system of information, in which the searching is possible. In the illustration, below the spectrum of the traceability information is described.
(Sääksvuori 2004: 130-133)

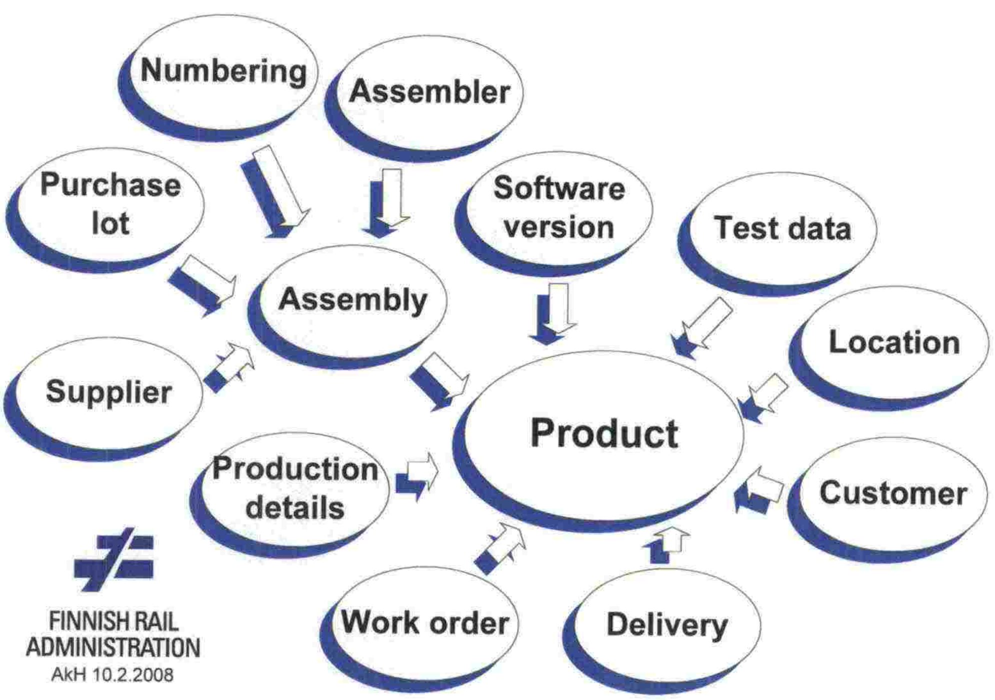

Figure 10. Information on traceability of the product (Sääksvuori 2004: 132)

Figure 10 illustrates how CM can achieve traceability by storing product related information so that the product and its assembly can be traced back to the supplier, purchase lot and assembler among others.

A comprehensive CM of a product enables the different information pertaining to various aspects of the product to be connected to an individual part. It is the higher level of item management, where not only the items within a product, but also the origins and the process information of the items are known and traceably stored. Well kept and comprehensive traceability information increases the administrative overhead costs. But benefits of advanced abilities to act quickly and trace the products, which must be replaced, soon proves to be worthwhile. When the collection of the information concerning the CM is done along the way, the extra costs are not high in comparison to the enhanced abilities of lifecycle management.

The CM is the method of continuously securing that the product fulfils the requirements and that the functional and performance characteristics are within the allowed ranges. CM applies both to the hardware and to the software of the product and enables the transparency and traceability of the current configuration of the product during its lifecycle. The guidelines of CM are described in ISO 10 007 and they contain configuration identification, change control, configuration status accounting and configuration audit. (Arnold 2005: 74-75)

The term mechatronics refers to the trinity of product characteristics; its mechanical, electrical and software technical engineering. Each aspect of the mechatronics of the product must be sufficiently addressed in CM so that the product as a whole is managed. The three are interdependent and any changes in one of the aspects may cause changes in the other. (Feldhusen 2008: 43-44)

Commercial software capable of CM functionality such as the PLM application of SAP utilizes specialized data models i.e. configuration folders to cohesively collect information like item lists over the lifecycle. The construction and configuration of the delivered products may vary during the lifecycle so that CM must manage the different product lifecycle phases: as-planned, as-engineered, as-sold, as-build, as-maintained. The configuration folder can consistently preserve the relevant information with different versions and baselines and record the history of the installation as it evolves during the lifecycle. (Hartmann 2004: 316-318)

CM brings with it abilities to know the exact status of the product in each individual installation location and it is an essential item of well-managed product lifecycle. It is not sufficient alone, but other methods are needed as well.

2.1.3.2 Product Data Management

Product Data Management (PDM) is another critically important concept of PLM, which is required for comprehensive coverage of the subject. Product data is information about product with different points of view. It can be definition data specifying the product details, lifecycle data obtained along the use and maintenance of the product or metadata describing the available data of the product. (Sääksvuori 2004: 7)

The right information in correct documents in sufficient quality must be available when and where needed. The documentation of the information can be in an electronic or paper format. According to the DIN 6789 standard for product documentation, the information on product is divided into three parts; technical, commercial and quality information. The product neutral information like norms is an additional information type. In the illustration below the types of information are highlighted. (Arnold 2005: 86)

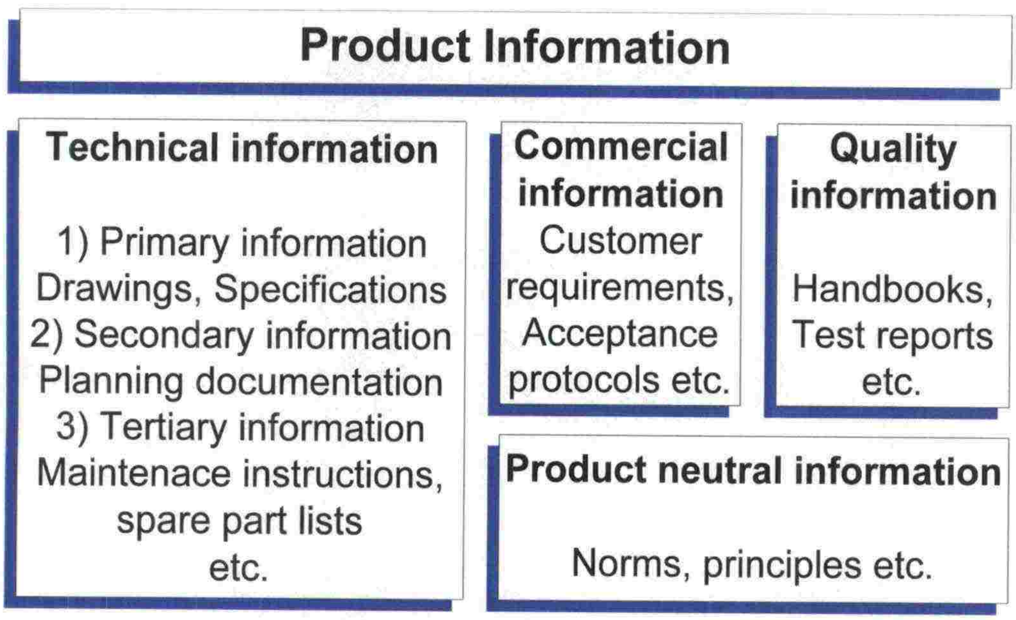

Figure 11. Types of product information based on DIN 6789 (Arnold 2005: 86)

The different types of product information illustrated in Figure 11 must be safely collected and archived during the product lifecycle in order to be able to refer to the needed documentation in the maintenance or change processes. Where and how the archiving is done is not crucial as long as retrieving of information is reliable and fast and the upkeep of the archives is not fortuitous. The retrieval of the information is needed whenever engineering changes are at hand.

2.1.3.3 Engineering Change Management

Engineering Change Management (ECM) is also a central task, which must be taken care of during the lifecycle of the product. The ECM forms the basis for documentation and traceability of the changes and adjustments of the product during its lifecycle. It involves planning, controlling and methodical execution of the engineering changes. The ECM collects the change requests and problem reports and according to the company processes the changes are planned, simulated, scheduled, executed and documented. Historical changes can be traced back. (Hartmann 2004: 299-300)

ECM requires structural procedures, which include detailed documentation of the changes itself and description of the change processes on the other hand. The changes are caused by many reasons; quality improvements, technological advances, marketing needs etc. and changes can thus be quite frequent. Often the changes are made under time pressure from company internal and external stakeholders. Change management process has its distinctive phases adding to the complexity: reasoning for the changes, decision of scope, validation process and the decision of acceptance or rejection and the execution of the changes. Especially when changes involve several companies and organizations, ECM is a demanding task. (Steinbrecher 2006: 40-41)

ECM can get overly bureaucratic, complex and paper-intensive. If the processing of the proposed changes takes a long time and the approval and implementation drag on, the problems may accumulate as products with unwanted designs and characteristics are further used and even continually delivered to the market. If the change processes are very time and cost-intensive, they may be totally avoided and the changes are neglected altogether or the changes are done with a non-standard procedure cutting the edges. (Stark 2007: 42)

ECM is a knowledge intensive activity during the lifecycle of the product and requires thorough practices, which ensures that the changes made are executed in a controlled and safe way and the RAMS requirements are met. As the installed base of infrastructure grows old and the technology is not any more of the latest generation, the management of the knowledge becomes a more central theme of PLM.

2.1.3.4 Product Knowledge Management

Product Knowledge Management (PKM) grows in importance as the variety of the technical installations and the organizational structures increases. The upkeep of the sufficient level of knowledge within the outsourced organizations providing services for using, maintaining and supporting maintenance must be managed to achieve optimal levels of services and costs and ensuring the continuous availability of knowledge.

People who work with the infrastructure during its lifecycle are a major source of effectiveness and efficiency. PKM must ensure the retention of the knowledge with training, skill transfer, improvement initiatives, career development etc. Also the beliefs, cultures and roles, which may empower the use of the knowledge, can be influenced. The hire and fire practices of the companies are an essential element of PKM. (Stark 2005: 153)

PKM has several application and focus areas; knowledge about customers' organizations and procedures, knowledge data bases containing best practices, knowledge retention schemes allowing the collection of working methods, education plans and software enabling efficient product training etc. (Stark 2007: 137)

Continuously running systems require a knowledge support strategy to fill in the knowledge in severe problem situations ensuring high availability of the systems. The users may have the knowledge to be able to do minor maintenance tasks with the self help. The maintenance contractor must be knowledgeable enough to fulfil its task of fast repair of the functionality. The knowledge support strategy may also include second level support provided by the specialists of the Original Equipment Manufacturer (OEM). (Reuvid 2005: 15-18)

The most economical ways of providing failure corrections are the methods minimizing human interventions and human costs altogether and thus the self heal by the system is the most desirable form of the failure correction. The self heal of the system i.e. the automated avoidance of the failures is an ideal, which is unfortunately rare in today's technology. As the number of needed human resources increases, the costs related to them grow along with them. By utilizing a Shift Left Strategy, more knowledge is transferred to the users and maintenance people in order to minimize the need of the first line maintenance and especially the second line OEM support. By shifting the emphasis to the left, also the downtime is reduced and the Overall Equipment Effectiveness (OEE) is increased. The illustration below describes the Shift Left Strategy. (Reuvid 2005: 15-18)

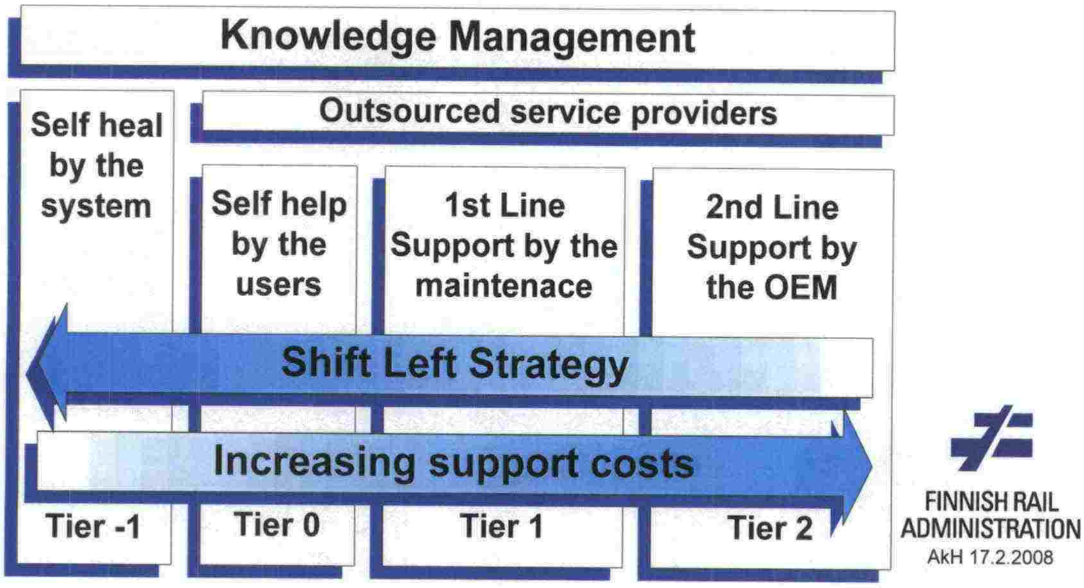

Figure 12. Reducing costs with knowledge management (Reuvid 2005: 17)

In Figure 12 the lowest tier of support i.e. the self heal of the system (tier -1) is the most cost effective as it requires no human costs. When it comes to self help by the users (tier 0) or first line support by maintenance (tier 1) and the second line support by the OEM (tier 2), the costs increase. Knowledge management efforts, which enable the lowest tiers to act and fix the most problems, are cost efficient, if they can help to reduce total costs by reducing the costs of OEM support.

An essential enabler of efficient PKM is the knowledge sharing infrastructure, which allows document collaboration for common document types in use. The ease of use and openness across the organizations can make such Content Management Systems (CMS) developing sources of accurate and up-to-date information. Discussion boards and collaborative authoring software i.e. wiki-systems would also enhance the knowledge sharing capabilities and thus improve the knowledge management. (Binder 2007: 206)
PKM faces special challenges when its object is knowledge about aging products. A central question is how to retain knowledge as “unique key knowledge holders” of the product retire and leave the workforce. Identifying those valuable key knowledge holders in time and utilizing tandem staffing arrangements, job rotation and transferring the knowledge can help safeguarding the knowledge of the product to the next generation of specialists. (Strack 2008: 121)

An effective PKM ensures that knowledge is available, no matter in which organization. Even as the installed base of infrastructure ages and reaches the end of the lifecycle, enough knowledge is there as long as needed, so that the infrastructure assets can be fully and economically utilized without untimely replacements.

2.1.3.5 Enterprise Asset Management

Enterprise Asset Management (EAM) sees the lifecycle of the product out of the customer's or purchaser's point of view in terms of costs. It combines asset management, maintenance, servicing and spare parts catalogues, and bills of material (BOM) and the other cost drivers of the product lifecycle. Technical data concerning places, equipment, components and connections of the objects are also managed. A Computerized Maintenance Management System (CMMS) ensures that the co-ordination of the maintenance tasks for failure correction, preventive maintenance and the human resources tied to the asset management are taken care of in a systematic manner and the MTBF values of the products are calculated. (Hartmann 2004: 31-32)

As the number of asset management stakeholders increases, the solutions that extend the EAM capabilities with the collaborative functions that enable the collaboration across organizations are emerging. A true collaborative EAM includes systems, which allow a global computerized interconnection of the stakeholders. It also have a common data model in which the states of the assets are saved in a unified manner and visibility services, which allow access to the information over the organizational borders. Analysis services make a common view of the state of the assets possible. Business process management tools make it possible to share resources of asset management like spare parts, best practices, knowledge and people. When the collaborative EAM is put under the framework of Asset Lifecycle Management (ALM), the term Collaborative Asset Lifecycle Management (CALM) can be coined. (ARC Advisory Group 2004: 14-19)

The EAM methods can keep track of maintenance and activities pertaining to removal and replacing of the equipment, execution of individual tasks, cost planning, realized costs and deviations, and the equipment in technical locations etc. (Hartmann 2004: 532)

EAM is one of the key functions, which must be taken care of in order to effectively manage the installations during its service lifecycle. The assets must be maintained in an orderly matter taking into account the often very high equipment replacement value (ERV), even though the exact ERV is sometimes difficult to calculate. (Kelly 2006: 86). The EAM can utilize the principles of Total Cost of Ownership (TCO) as it collects the costs attached to the assets such as investment, commissioning, maintenance and supporting costs. The TCO can be adjusted with the different levels Service Level Agreements (SLA) so that by lowering the availability requirements and other service characteristics, the TCO can be lowered. (Feldhusen 2008: 263-265)

As the customer utilizes EAM for her assets in an effort to minimize the costs attached and maximizing the value of the assets in use, she cannot do without having some kind of contact to the OEM and these contacts need an effective and efficient management during the service-life of the assets, typically under a MSA contract.

2.1.3.6 Customer Relationship Management

Customer Relationship Management (CRM) is another viewpoint to PLM. The CRM has the task of managing information, requests, requirements, experiences and problems of the customer. The CRM activities have the focus on customer, not the product, but the maintenance of the supplier-purchaser relationships during the lifecycle of the product is an important function. (Stark 2007: 106-118)

The supplier has customers, to whom product has been delivered and who require services over the lifecycle of the product. In order to meet the customer requirements, the supplier may have internal methods and processes under the framework of the CRM. Additionally, the supplier must take care of its sources, so the systematic approach to the Supplier Chain Management (SCM) is needed to ensure continuous supply of parts among other things. CRM starts in the design phase of the product lifecycle, where the potential customer may have a say on specifications. CRM reaches the high point, when the production and distribution to the customer at their most active phase. After the production ends, CRM continues in aftermarket service, until the product is retired as obsolete. The illustration below describes the relationships between CRM, SCM and PLM. (Görg 2004: 11-12)

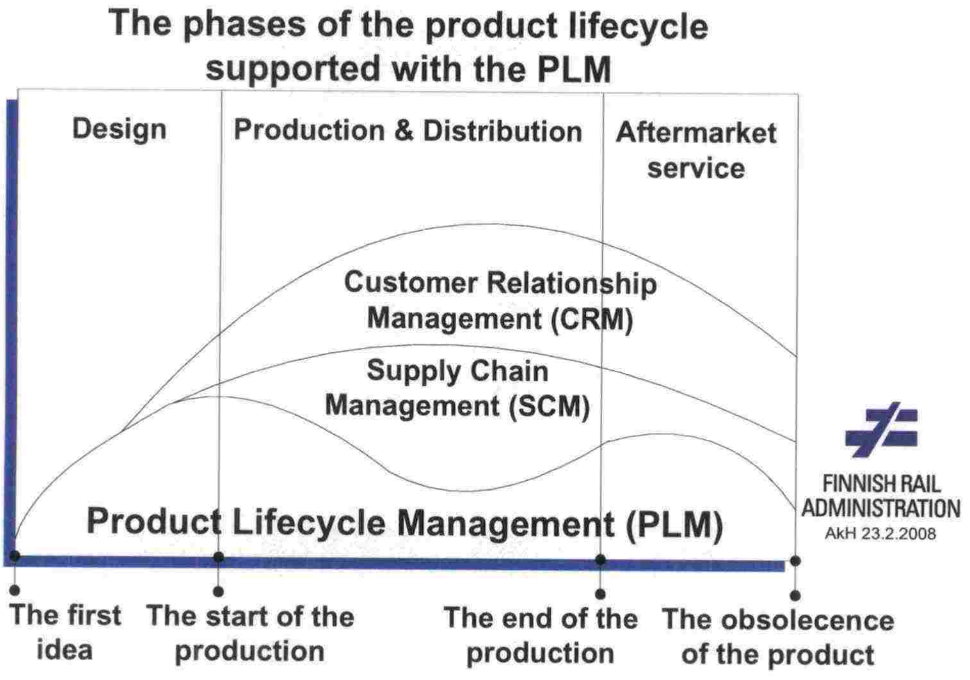

Figure 13. Phases of the product lifecycle supported with PLM (Görg 2004: 12)

In Figure 13 PLM starts with the first idea and reaches a high point at the start of the production. Again at the end of the production towards the time, when the product will become obsolete and removed, PLM activity increases. The internal SCM processes of the supplier are there all along the way and CRM is the process, which ensures the needed interaction with the customer.

CRM can utilize specialized ICT systems, which are typically sales-oriented. Such systems incur costs and may result in race between revenue and cost, where the costs must be out weighted by the additional revenue. The methods of CRM are not necessarily supported by the costly systems. (Grieves 2006: 123)

CRM is needed as a means of managing the customer's needs during the lifecycle of the deliveries. In the increasingly competitive marketplace the supplier cannot be sure that the existing customers will continue their custom with repurchases, but instead the supplier must tend the relationship by keeping the customer aware of the product's lifecycle and its implication to the available services to the product. The supplier may also take into account the Customer Lifetime Value (CLV), when tailoring service offerings so that the once profitable customers are better taken care of. (Zellner 2008: 36)

2.1.3.7 Summarizing the Selected Concepts of PLM

The selected concepts of PLM each carry an important task in ensuring the efficient management of the product during its lifecycle. CM practices ensure that the characteristics of the product, which may vary during time the product is produced, is continuously kept in valid version and traceably recorded so that any discrepancies in the system versions or information on them do not adversely affect to the functionality, performance or maintainability of the product. PDM affects the various types of information on the product. It ensures that the data is kept in a way, which ensures the reliable and fast recovery of the necessary data on product when needed. ECM defines the methods utilized, when the product is changed and ensures that the changes do not adversely affect the RAMS of the system. PKM helps in maintaining the sufficient level of knowledge on the product during the lifecycle of the installations. EAM seeks ways to maximize the value of the products and minimizing the costs attached to the utilization of the products. CRM addresses the customer's contacts needed to the OEM of the product. The illustration below highlights the selected concepts of PLM.

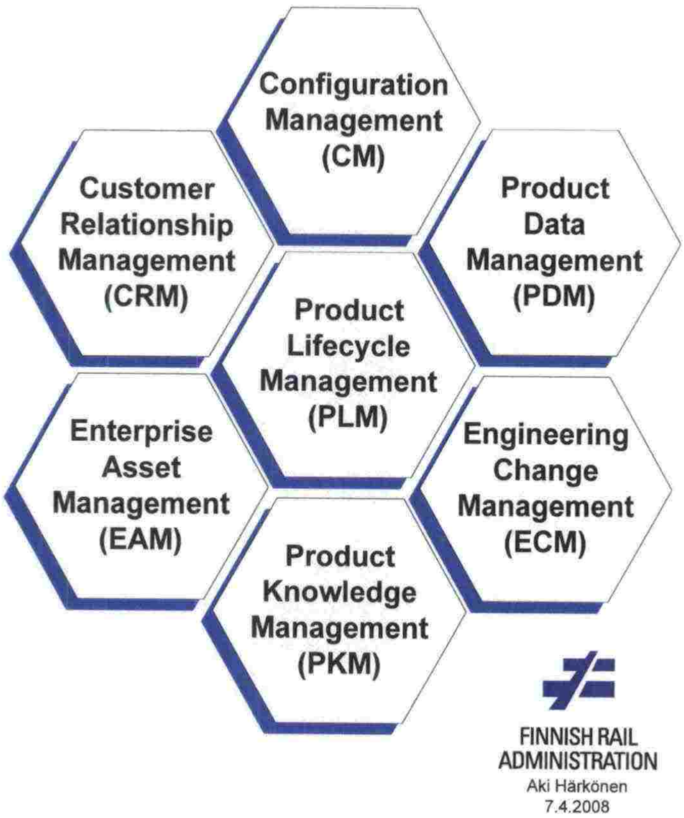

Figure 14. Selected concepts of PLM

Figure 14 collects the selected concepts of PLM. A better execution of CM, PDM, ECM, PKM, EAM and CRM over the lifecycle of the product can alleviate most everyday problems the field engineers, specialists and managers face.

2.1.4 Developments of PLM

The concept of product lifecycle has its origins in the marketing management of the 1960's as the stages of the product lifecycle were recognized to be the market development, the market growth, the market maturity and the market decline. Understanding the general pattern of product lifecycle has helped managers to effectively employ their strategies for the existing and the new products alike. (Levitt 1965: 2-8)

The continued attention for the product lifecycles in the 1980's was focused to the product marketing theories, where the marketing of the product and the typical characteristics of its lifecycle were studied. The marketing mix (product, place, promotion and price) varies during the product lifecycle and its phases: introduction, growth, maturation and decline. The marketing was managed accordingly. (Onkvisit 1989: 103)

The engineering aspect of managing the product lifecycle and the history of PLM systems as we know them in the first decade of the 21st Century starts in 1990's when Engineering Data Base (EDB) systems were utilized to house the product data. The second generation of the systems were called Engineering Data Management (EDM) systems and they had a more structural and consistent way of storing the information. Still further developed, the systems were focusing more on version management, acceptance and release processes and introduced with the name Product Data Management (PDM). As the practise of collaboration over the company and national borders increased, the name Collaborative Product Data Management (cPDM) emphasised the systems capable of multi-company use. (Görg 2006: 7-8)

Another family line of PLM is Computer Aided Design (CAD), which refer to the various math-based descriptions of the products. When CAD systems evolved to be able to handle three-dimensional (3D) pictures, the systems became more important as paper printouts were not anymore sufficiently representing the designs. The advent of the 3D enabled the Computer Aided Engineering (CAE), which perform various tasks pertaining to analysis, simulation and testing. (Grieves 2005: 46-48)

In Stark's "Product Lifecycle Management – 21st Century Paradigm for Product Realisation" systems have different scope; from one component to holistic approach. They also have a different span; from one department or function to across the product lifecycle. The CAD systems attached to the Computer Aided Manufacture (CAM) bring together several functions. Likewise is the case for Design for All (DFA) and Design for Manufacturability (DFM), even if they can be applied to the one component. Collaborative Product Development (CPD) and Quality Function Deployment (QFD) involve several functions and components. Even wider span has the Life Cycle Assessment (LCA) and ISO 9 000 and ISO 14 000 standards. PLM brings together various aspects of product such as product development and support, systems like CAD, PDM and Enterprise Resource Planning (ERP), developers and customers. PLM is holistic and across the product lifecycle and thus it has a wider scope and span than other approaches. The figure below puts the scope and span of the systems pictorially in perspective. (Stark 2005: 430-431)

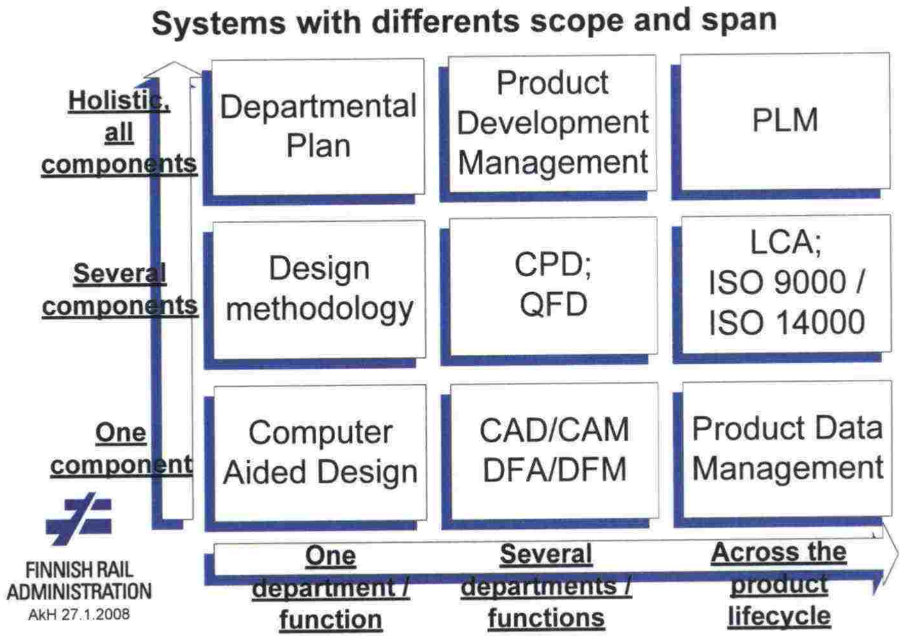

Figure 15. Systems with different scope and span (Stark 2005: 430)

PLM was initially piloted in the industries with complex manufactured products with wide spread outsourcing i.e. the automotive and aerospace industries. Also electronics industry was an early adaptor of PLM. Other industries have since followed and will increasingly follow the adaptation of PLM in their quality management processes. (Grieves 2005: 1)

The future development of PLM will evolve along with the technological and societal changes. The models and standards of PLM will be developed so that the exchanging of information between PLM systems will be easier. The companies are held responsible for their products in many ways and this will be a motive to take a better control or the product lifecycle. As PLM processes get standardized, the audits of PLM will be more commonplace. (Stark 2005: 417-419)

In the future, when products are increasingly connected to the internet, the systems will automatically send intelligent feedback to the producer and thus enable the producer to collect and utilize the information in improving the maintainability of the product and in further development of the product. (Görg 2006: 8)

The web will be the platform for the product-related lifecycle services, which will grow in economical significance. The products will be serviced and the product information will be collected bi-directionally over the web. (Stark 2007: 208).

The development of PLM has been closely tied to the general technical development and especially to the advancement of the computer aided methods of product planning and design. As the globalization and off-shoring increase, the products will have more diverse origins and the ability of taking a better control over the lifecycle becomes a crucial success factor. The internet will more and more be used as a tool to support the product during its lifecycle.

2.1.5 PLM Literature Review in Summary

PLM distinguishes the phases of a product's lifecycle and sets methods and practices, which facilitate the management of a product over its lifespan.

The earliest applications of PLM concept were in the marketing management of products, where the identification of the stages of the product lifecycle gave a new tool for improving the marketing strategy of product portfolio. The engineering aspect of PLM has been growing in importance in tandem with the ability of ICT systems to manage information. Since the 1990's computer technology has on the other hand created a growing complexity of the products with a challenging PLM task and on the other hand the same ICT capabilities enable a methodical PLM.

PLM is an engineering discipline for efficient and effective management of a product during its whole lifespan. It fosters collaboration and productivity together with the stakeholders of the product. It forms a holistic paradigm for organizing information. It supports maintenance and lean thinking. It facilitates exchanging product knowledge and solving strategic issues. It provides support services for the products and other business activities. It is a controlled concept utilizing ICT. It aims for increased clarity and meeting particular demands.

The products, which are a part of a business process and whose outputs render a mission critical service, are much more valuable in use, than the mere equipment replacement value of the product or corrective maintenance costs as such indicates. PLM has powerful methods summarized below, which can be utilized to improve the living with a product thus enabling the mission critical services to function with high reliability, availability, maintainability and safety (RAMS).

- Configuration Management (CM) records the status of the products in individual installations. CM answers to the question: "*How is the product set up and how can we keep track of it in the years ahead?*"
- Product Data Management (PDM) is a method of cohesively collecting the data on product during the lifecycle and ensuring the right data in right place. PDM answers to the question: "*What information of the product do we have and how we can manage this information during the lifecycle?*"
- Engineering Change Management (ECM) handles the changes of the product and enables an efficient method of executing changes without jeopardizing the quality of the service. ECM answers to the question: "*How can we change the set up of the product and what is our path of changes in the future?*"
- Product Knowledge Management (PKM) helps to guarantee the availability of the sufficient knowledge during the lifespan of the product. PKM answers to the question: "*Who is knowledgeable enough to manage the product and its services and how can we utilize their knowledge in the future?*"
- Enterprise Asset Management (EAM) emphasizes the products as assets and manages costs *drivers* and costs incurring during the lifecycle of the product. EAM answers to the question: "*Which costs do we have in managing the product and how can we optimize those costs?*"
- Customer Relationship Management (CRM) is needed in order to systematically interact with the customer or the purchaser of the product in order to help the purchaser to maintain the product and its services during its lifespan. CRM answers to the question: "*How can we - the supplier and the purchaser - together manage the product and its services during the lifecycle?*"

Answering the above questions can in due course result in savings of time and cost. PLM is not a philosopher's stone, which easily and miraculously turns the management of the product into gold, but rather a set of methods, which help the stakeholders of the product to systematically keep track of the essential factors affecting to the lifecycle management of the product. It can help opening the eyes of the managers not to neglect the long term view and prepare them to be better equipped to the challenges ahead.

PLM cannot be performed in a vacuum, but rather it calls for a joint effort of the stakeholders of the product. It requires collaboration between the supplier, purchaser, the maintenance contractor among others and timely insertion of updated information in the system. Such collaboration requires management and therefore in the subsection below discusses the aspects of the effective and efficient collaboration management.

2.2 Collaboration Management

In this section the characteristics of the successful collaboration, the process of collaboration and the traits of mass collaboration are studied.

The word collaboration is here used in the positive meaning of working together with partners to achieve a common goal. And even if the business partners like purchaser and supplier sometimes tend to compete fiercely against one another in seeking extra benefits for themselves, such an "enemy" is worth collaborating with for the common interests. The idea of collaboration is based on the ground that only mutual efforts and shared benefits can bring long term success for all partners. Seeking short term one-sided benefits will not be profitable in the long run.

2.2.1 Characteristics of Successful Collaboration

Collaboration can be defined as a process in which the partners involve in a joint problem solving and decision making. The process has five critical characteristics:

1. The partners are interdependent.
2. Differences are handled in a constructive way to achieve practical solutions.
3. Decisions are mutually agreed upon.
4. Partners assume a collective responsibility for the future development.
5. The process is emergent and capable of utilizing an evolving, temporary and loose organization. (Gray 1989: 11)

If some of the critical characteristics are missing, the chances of a successful collaboration process are diminished. Especially, when collaboration includes partners with several organizations and potentially cultural and linguistic barriers, management is required to alleviate the process.
Fasel discusses six keys to successful collaboration or "partnering in action" i.e. alignment, ability, attention, acuity, attitude and adaptability. The essential ingredients of the partnering in action are pictorially illustrated below. (Fasel 2000: 12-13)

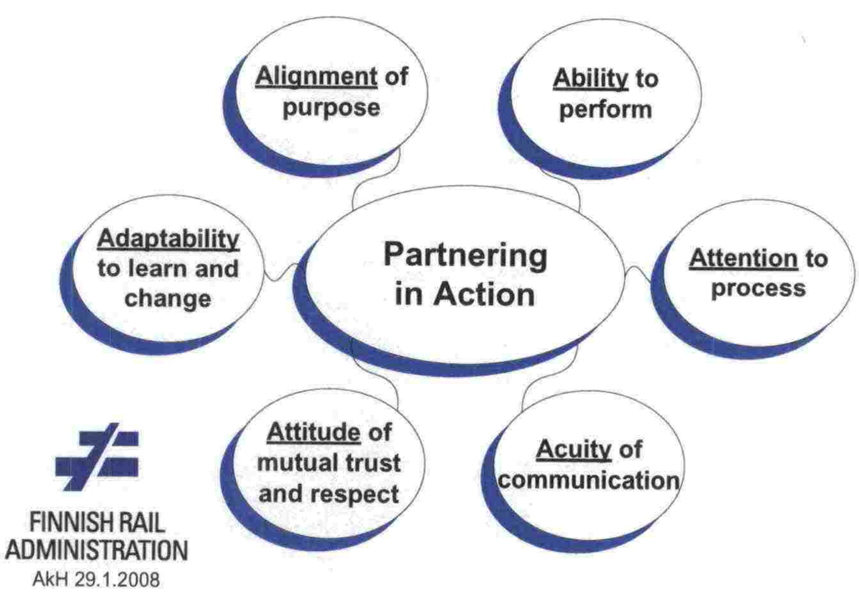

Figure 16. Partnering in action (Fasel 2000: 13)

Figure 16 emphasizes, that all collaborators need to have a common purpose, which positively affects their performance. Processes are in place and supporting the task. Communication must be precise and trust and respect need to be maintained. By actively learning and making changes when the experience shows that methods must be refined, the collaboration can be continuously improved. When one of six keys of successful collaboration is missing or mismanaged, the quality of the collaboration and its results suffer. When they can all be kept on a high level, the circumstances of the collaboration are fruitful to cause effective action.

Straus, who studied the principles of collaboration observed that managing a collaborative process includes defining the relevant partners, bringing the partners or information together and organizing the decision making process. (Straus 2002: 7)

Collaborative teams face several problems in their tasks, but also the collaboration itself and the set up of the team can suffer from negative characteristics. If the number of the participants is more than 20 the effectiveness of the co-operation tends to decrease. If the teams participate virtually via internet, the quality of the collaboration declines. If the people do not know each other, but instead collaborate with strangers and with diverse people, the willingness to share knowledge diminishes. A great proportion of highly educated specialists in a team can cause unproductive conflicts. (Gratton 2007: 103)

Gratton has identified characteristics, which have proven to create a positive effect for the success of the collaboration:
1. Highlighting the collaboration with visible investments.
2. Management as a role model for collaboration.
3. Promoting informal networking with mentoring and coaching.
4. Teaching essential collaboration skills to employees.
5. Building a sense of community.
6. Team leaders' orientation for task and relationship.
7. Avoiding building teams of strangers.
8. Roles are clearly defined, but there is leeway in methods of achieving the task. (Gratton 2007:104)

The complexity of the collaboration at hand is also an important factor determining the chances of success. Several factors add to the complexity of the task. If the task is not entirely in the power of the team, the difficulty increases. If the task requires the formation of a new team, the initiation takes time. If highly specialized individuals are needed or a large group (more than 20) of people are needed or the members of the team are geographically dispersed, the situation is more complex. If solving a problem requires prioritization, which need outside input or the problem solving is dependent on unpredictable events or the task is done under time pressure, the collaboration is complex. (Gratton 2007: 107)

The willingness to invest in improving the capabilities of collaboration is growing in importance as a source of competitive advantage. In-house excellence is not any more enough, instead the ability to utilize and integrate the skills of a global network of partners is crucial. Successful firms invest in people and development programs aimed at the collaborative skills. Another focus is to the processes of collaboration and continuous learning. The infrastructure platforms, such as tools for sharing information, require also attention. The fourth cornerstone in the blueprint of the successful collaboration is a coherent program, which supports the individual collaborations. (MacCormack 2008: 24-26)

Straus argues that the results of the collaboration are not the only measurement needed in defining a successful collaboration. Results are of course needed, but the quality of the process and the relationships are important dimensions as well. Even if the results can be deemed successful, but the process was irrational and haphazard or the results were achieved in a manner, which hurt the feelings of the participants and caused friction in the relationship, the overall quality of the collaboration was not sustainably successful. (Straus 2002: 116)

Patterson, who studied the influencers, has concluded that when trying to create collaborative arrangements with partners, one has to be able to answer to the two critical questions, if one tries to influence the behaviour of the people and change their thinking and behaviour. The critical questions are: "Will it be worth it?" and "Can I do it?" Unless those questions can be answered in a satisfactory manner with a positive outcome, the chances for successful collaboration are low. The efforts in creating collaborative schemes should be aimed at creating actual and vicarious experiences, which can positively prove that the collaboration is worthwhile and it can be done by the partners. Unless experiences can be arranged, a vivid story, which powerfully confirms the messages: "it is worthwhile" and "we can do it", can influence the minds of the listeners and cause desired action. (Patterson 2008: 63-65)

Successful collaboration has distinctive characteristics which can be seen as benchmarks or as tests, when evaluating the current state of a collaborative relationship and when initiating new collaborative schemes.

In seeking the ways of new collaborations, the proven recipes of success should be utilized, but it is as important to influence the partners, so that the mutual interest and benefits can be made understood and the motivation for collaboration created. Well-managed and thoroughly planned processes of collaboration succeed if they are co-negotiated and mutually applied with the partners. The processes of collaboration need a special attention.

2.2.2 Process of Collaboration

When collaboration takes place in an environment that combines members of different organizations and even across national and cultural borders, the preparations must be careful. In order to achieve effective and efficient collaboration, conditions must be right.

Fruitful collaboration causes action, which can be stimulated by creating the suitable conditions with an action framework, as suggested by Mankin. This framework can be divided into four phases as illustrated below. (Mankin 2004: 7)

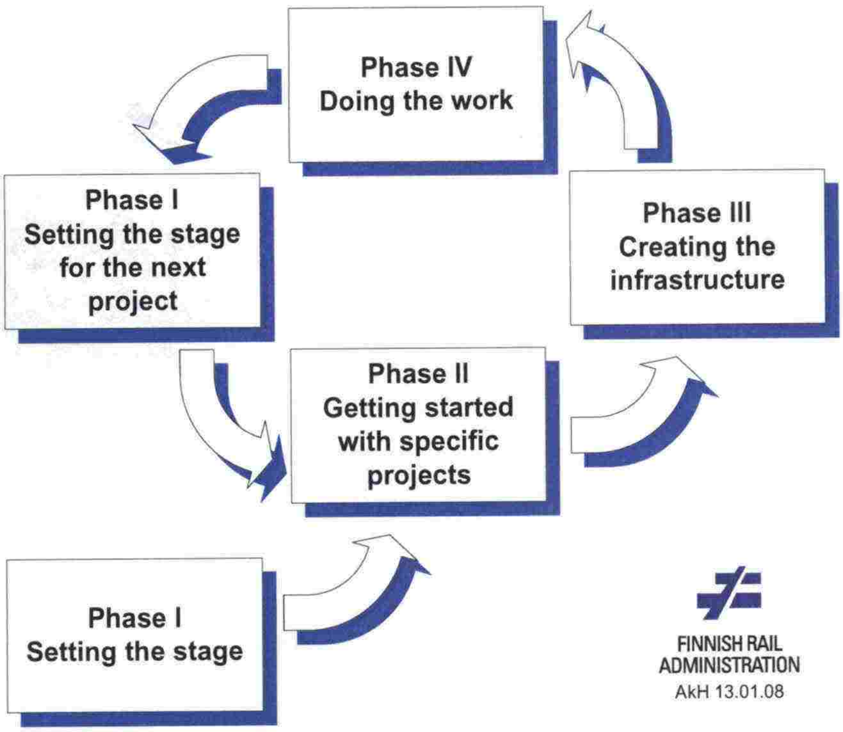

Figure 17. Four phases of the action framework (Mankin 2004: 7)

Down at the left bottom line of the Figure 17 there is the phase one, *setting the stage for collaborative action* including steps that prepare the people for the collaboration. The communication of the collaboration vision by the management and fostering of a collaborative culture are important ingredients during this initial phase. Effective communication means not only publicly articulating promotion, but also tangible examples by management. As collaboration requires people, developing collaboration skills in people and choosing right people are essential. The collaboration needs also continuous managerial support and reinforcement, especially in the early phases. (Mankin 2004: 162-172)

Getting started with specific projects requires identification of purpose, naming people with liaison roles and giving them opportunities for face-to-face interaction. After the collaborative project team has drafted a roadmap for collaboration, the management of the partners should reaffirm support, assign a sponsor and provide needed resources for the go-ahead of the project. (Mankin 2004: 176-185)

Creating the infrastructure for the collaboration involves general project management steps with building the project team and giving the project detailed structure and process. Overall governance of the project and expectations for the outcomes must be in place. Needed information and access to the systems and other resource needs must be identified and ensured. (Mankin 2004: 187-199)

Doing the work means executing the project and learning while doing. As conditions might change during the execution of the project, the goals, the structures and the processes must be revised accordingly. The complex collaboration produces information, which should also be disseminated to the management for continuous learning purposes. (Mankin 2004: 200-204)

The collaborative process starts with the problem setting where a mutual definition of the problem and a commitment to collaboration are reached. The stakeholders are identified and the convener of the meetings is named. The direction of the collaboration is set by agendas and rules and organizing needed groups and resources after the options have been explored and decisions reached. The implementation of the collaboration requires structure and support. The progress requires monitoring and controlling the compliance of the agreed process. (Gray 1989: 57)

In the process of collaboration, sometimes the mutual agreement cannot be reached, but a way to reach a decision is required. In those circumstances it might be possible to utilize the fallback i.e. to switch from a collaborative structure to a hierarchical or horizontal structure with a manager or a chairman in charge. Such fallbacks are illustrated below. (Straus 2002: 73-75)

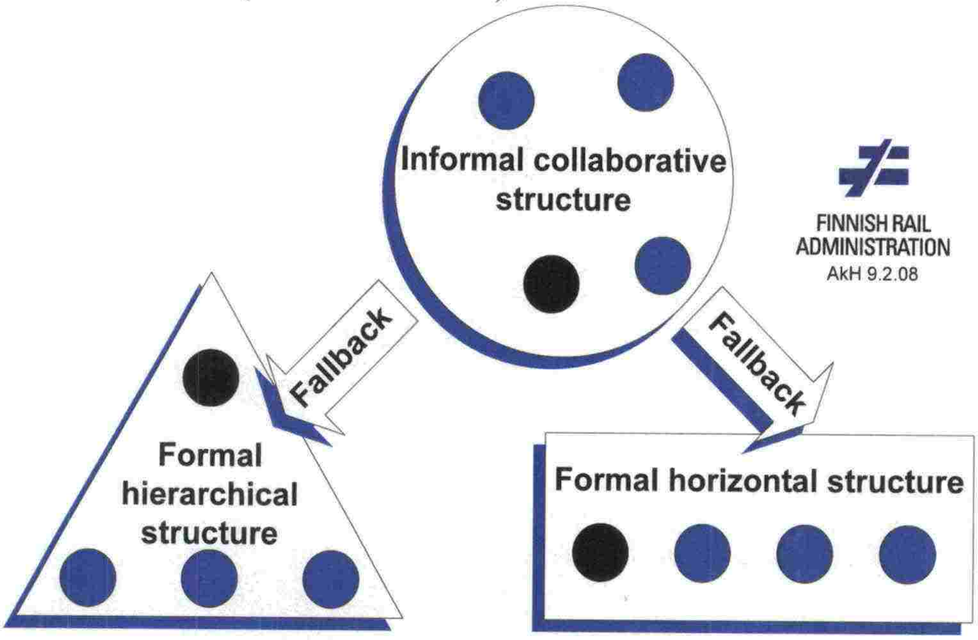

Figure 18. Fallback in a hierarchical or horizontal organization (Straus 2002: 75)

Figure 18 shows that the collaborative process with a strong consensus building ideology and an informal collaborative structure can be very effective in reaching decisions, but the possibility of a fallback in formal structures can enhance the productivity of the group and the threat of fallback can increase the pressure to reach a mutual agreement. In multi-organizational collaborations the fallback is a more complicated matter, but the same principle applies. (Straus 2002: 75-77)

Effective collaboration has carefully planned preparatory steps before executing the project. The process of planning and executing collaboration creates a circle of continuous learning and improving, which strengthens the individuals and managers involved in collaboration.

The process of collaboration is a balancing act between compliance of the agreed methods and the flexibility of the partners in learning and adapting the practices as experience and changing conditions indicate that new ways to collaborate are required. The internet technologies are bringing new possibilities for effective and efficient collaboration.

2.2.3 New wave of the Collaboration – the Mass Collaboration

In the modern production, the supply chains and networks are becoming more complex as off-shoring and outsourcing become more commonplace. The decentralized processes of planning and production of the goods makes collaboration a key success factor. The internet and especially the web 2.0 increasingly provide the professional communities and companies with powerful tools of mass collaboration. The internet promotes peering and participation in mass collaboration arrangements. The Linux operating system or Wikipedia dictionaries in several languages are famous products of mass collaboration. The tools of mass collaboration will be utilized increasingly in the business processes and the effective capability of collaboration will be one of the major sources of competitive advantage. (Tapscott 2006: 18-19)

The principles of wikinomics – openness, peering, sharing and acting globally – are the defining factors in the current competitive environment. Whereas in 20th century the businesses tended to be hierarchical, closed and secretive, those very characteristics which were strengths back then, are now weaknesses, when the global competitiveness requires agility, creativity and connectivity. Mass collaboration can rapidly change an entire industry. (Tapscott 2006: 30-31)

The idea of mass collaboration is that content is created in decentralized network of partners, which form an ecosystem of peers, exchanging knowledge and innovating together. The companies must embrace this open and collaborative way of business, if they want to benefit from the potential of their market partners. (Tapscott 2006: 290)

The computer tools of mass collaboration can be utilized in specialized networks of experts, who have a common task of supporting or utilizing of a product – depending on which company they are in. By using web-based portals and other collaboration tools the transaction costs of the collaboration can be significantly diminished.

The mass collaboration is a powerful example how utilizing the new technologies can create totally new possibilities for services and open ways of effective and efficient collaboration.

2.2.4 Summary of Collaboration Management

Collaboration management requires attention to the characteristics of successful collaboration. The collaboration can and must be managed taking into account the features, which have been proven to promote its success. By knowing the characteristics of successful collaboration managers can reproduce those advantageous conditions in their collaboration schemes.

The process of collaboration is also an object of managerial focus and it has typical phases. In the first preparatory step the stage is set. Then the collaboration is started with specific projects. The infrastructure of collaboration with agreed practices and methods must be in place. The execution of the collaboration can then follow. The process of collaboration can also be improved when doing produces learning.

The networks of mass collaboration and the computerized tools supporting the collaboration are becoming commonplace. The application of those powerful methods of collaboration will be the success factor in the future, which can revolutionize the ways in which the mutual problems are being solved.

2.3 Summary of the Literature Review

In this literature review the features of PLM and collaboration management were studied. Both of them are as such complex and multifaceted topics. PLM brings with it the different methods of technical management of the product over its lifecycle. PLM methods require, if they are to be implemented in an efficient and effective way, mutual efforts of the stakeholders and their collaboration. Collaboration management is therefore needed to build a framework to support those PLM efforts. In combination PLM and collaboration management are the essential ingredients in the collaborative process of product lifecycle management for railway signalling infrastructure.

The next section discusses the context of the study.

3 CONTEXT OF THE STUDY

In this section the context of the study, the Finnish rail signalling infrastructure and its managerial characteristics are described in general terms.

3.1 Features of the Rail Signalling Infrastructure in Finland

The rail signalling infrastructure consists of the technologies and application products, which have the task of technically enabling the rail traffic with high speeds above the sighting distance. The economy of the train traffic is based on the physical fact, that the friction between the steel rail and the steel wheel is low and thus it takes less energy to overcome the friction in comparison to rubber wheel vehicles. On the other hand the low friction between the rail and wheel means long braking distances. Without technological arrangements the speed should be limited to the sighting distance i.e. the distance, which can be seen by the driver so that she can brake and stop the train before an obstacle, but this would allow only speeds of up to 50 km/h or below.

An economical train operation requires sophisticated technologies of the rail signalling infrastructure to enable high speeds up to 220 km/h, which is currently the highest speed practicable on Finnish rail network and with Finnish rolling stock. The rail signalling infrastructure has functions like signals, block signalling, interlocking, remote control and automatic train protection systems (ATP).

In rail signalling infrastructure the interlocking has the central function of securing the train movements with route setting, so that signals and points can be logically so arranged, that the train movement can always take place with sufficient reliability, availability, maintainability and safety (RAMS).

The previous generations of interlockings, the mechanical, the electro-mechanical and relay interlocking, relayed in their functionality more on their mechanical construction and physical properties of the components. In the mechanical interlocking the mechanical parts lock the routes at signal box, so that arranging conflicting routes are mechanically prevented. In the electro-mechanical interlocking the electronic circuits are added to increase functions. The relay based interlocking functions totally electrically with complex relay circuits, which are arranged to perform the logical interlocking operations.

The interlocking technology has always followed the best available technologies of the times and the evolution of their technologies has been depending on the general advancement of the technology, somewhat lagging behind it. The technology is designed with the fail-safe principle i.e. even during the failure of the system the safe state of the system is technically ensured.

The need for increased automation and remote controlling in order to perform the train operation economically without wasting human resources has been the driver to improve the functionality and the level of automation of the rail signalling infrastructure.

Since the 1980's the technological focus of the rail signalling infrastructure has been on the computer based electronic interlockings. The electronic automation and its technologies have increasingly been introduced to the rail infrastructure and they have gradually been replacing the technologies of the previous generations. At today's stage the installed base of the Finnish rail signalling infrastructure is dominated by relay and computer based interlockings, and the latter one is increasing its installed base as the relay interlockings have been replaced by them since the 1990's.

The rail signalling infrastructure market has since 19th century been dominated by strong European national equipment manufacturers and in smaller nations like in Finland technologies of a dominant nation has been adapted. In Finland the rail signalling infrastructure has been following the German principles and practices with some adaptations according to the Finnish national specifications.

The European evolution of the rail signalling technology has led to the national development of signalling principles and practices and no uniform European set of signalling aspect or marker boards have been achieved in contrast to the road traffic, which have unified signs. Due to the national development of the signalling principles, no unified products can yet be produced to the European markets, but the products must be at least in some extent localized to the national specifications. The products are thus produced in relative small series and each dominant European manufacturer has relatively broad palette of products to cover various national markets. International efforts for more unified interlockings have been made within the UIC, but the projects have not so far produced commercial products.

3.2 On Finnish Rail Signalling Infrastructure and Maintenance Markets

In Finland the rail signalling infrastructure market has been relatively open to various suppliers, because no single dominant domestic supplier has existed. During the 1960's and the 1970's the German supplier Siemens dominated the Finnish market. But since the 1980's and especially since the formation of RHK in 1995, the Finnish market has been further opened also to other companies, like German, Hungarian and Swedish suppliers.

The Finnish rail signalling supplier market differs significantly from many European nations, where the market is dominated by a single supplier or a couple of national main suppliers, whereas in Finland the market has gradually been since early 1990's opened to a wider range of suppliers, which import and implement signalling equipment to Finland. This makes benchmarking between the various rail managers for example within the European Rail Infrastructure Managers (EIM) and their corresponding systems of PLM difficult, because PLM of a unified installed base differs remarkably from PLM of installed base with a wider variety of suppliers.

Currently the suppliers, which are significant on Finnish market, are Ansaldo STS Sweden AB, Bombardier Transportation Finland Oy, Siemens Osakeyhtiö, Mipro Oy and Thales Rail Signalling Solutions GmbH. The Hungarian company Ganz Transelektro Közlekedési Berendezéseket Gyártó Kft. (GTKB) and the Swedish company Funkwerk Information Technologies Malmö AB are also suppliers to the Finnish rail signalling infrastructure market.

The outsourcing of the maintenance has been realized organizationally in 1995, when the infrastructure manager RHK was established (the current organization, see Appendix C.). The historical state railway organization, which integrated the infrastructure management and the railway undertaking, came then to an end. Then also came into existence the railway undertaking VR Ltd. and the maintenance contractor VR-Track Ltd. The outsourced maintenance contractor had a monopoly until 2004, when it lost the maintenance of the permanent way, the electrification and the signalling in North Finland, due to submitting its offer late in the competitive bidding process.

The Finnish rail signalling infrastructure has a 100 % outsourced maintenance and a 100 % outsourced supplying of products, the management of rail signalling infrastructure is therefore management of contracts and contractual practices between the partners. The maintenance is supplied by the supplier independent third party maintenance contractors. The role of the OEM is managed through Maintenance Support Agreements (MSA), which regulate the quality of second line maintenance support, which the OEM gives to the local maintenance contractor in charge of the first line maintenance.

The opening of the Finnish rail signalling supply market has coincided with the technological transition to electronic interlockings. In order to manage the increasingly complex systems with the help of the OEM and allow competition between supplier independent maintenance contractors, MSA arrangements have been deemed strategically inevitable.

The MSAs have been negotiated since 2003 with the main signalling suppliers of RHK and they are composed of few key services facilitating the signalling infrastructure maintenance at the Finnish rail network. The signalling supplier arranges a hot-line phone support service, which is available to the maintenance contractors on regular office hours or even round the clock and which provide expert advice and support on product maintenance through phone. The signalling supplier surveys the premises with the maintenance contractor yearly or once in one and a half year and performs check-ups and gives advice. The software maintenance of the supplier ensures the up-keep of the software version and minor bug-fix updates and the administration like escrow arrangements for software storage. The remote connections are utilized to enable maintenance actions without travelling to the site. The reporting of the MSAs allows the signalling supplier to communicate significant phenomena concerning the technical state of the infrastructure or practises of the maintenance contractor etc. to the purchaser.

National Audit Office of Finland (NAO) has in its audit report in January 2008 slightly criticized RHK for its ways of measuring and controlling the rail maintenance, which concentrates mainly on the condition monitoring of the permanent way, leaving the electrical equipment and especially the rail signalling infrastructure to somewhat lesser attention. According to NAO, the rail signalling infrastructure and its quality of maintenance should have its own indicators. (Jatkola 2008: 73)

The rail signalling maintenance of RHK has great potential for improvements, but the scarcity of the resources restricts the possibilities for speedy revolutions and achieving significantly higher levels of quality of service on the short notice. The path to the improved quality of service must therefore be a continuous evolution of current practices and structural improvements taking place after the new installations.

The role of coherent practices of PLM is also essential in shaping the Finnish rail signalling infrastructure markets in the future. As more emphasis is put on PLM, the future development strengthens the companies, which are committed to the market and present on it in the long run and which are willing and capable in providing services related to the efforts aimed at the collaborative processes of PLM.

4 RESULTS AND ANALYSIS

This section presents the key insights from the study obtained through the semi-structured interviews. The results are divided into two subsets, the key insights and the collaborative process, which both are developed based on the interviews. The literature on PLM and on collaboration management is utilized as the foundation and as the theoretical background in formulating the empirical results. The key insights are the immediate results collected from the interviews, which can be utilized separately one by one. The collaborative process is a holistic approach attempting to facilitate the collaboration practices of the partners during the whole lifecycle of the systems.

4.1 Insights from Interactions between RHK and Partners

The communicative interactions between the representative of RHK i.e. the researcher and the signalling suppliers and maintenance contractors took place between January and March 2008 in Espoo, Helsinki, Mikkeli, Oulu and Tampere in Finland and in Stockholm and Malmö in Sweden and in Stuttgart in Germany (the interviewees, see Appendix E.).

The distillation of the collected insights is presented below. For each item a performance indicator is developed in order to give a practical metrics for evaluating the current state of the item in question. As the corrective maintenance must take place as soon as possible, in many items the time is a significant metrics in performance indicators.

4.1.1 Improvements of the Maintenance Support Agreements Practices

Maintenance Support Agreements (MSAs) are aimed at formalizing the interactions between the OEM supplier and the maintenance contractor and they consist of technical telephone support, online diagnostics of the systems, recurrent surveys of the technical premises, reporting of the state of the systems etc. actions needed to optimize the lifecycle of the system with OEM knowledge. The risk exists that the people in charge of the MSA activities can get so occupied with the daily business, that the ideas of improvements and measures aimed at increasing the reliability of the systems are neglected.

According to the insights derived from the interviewees, the improvements of the practices within MSAs are needed especially regarding the way requests for technical help are managed and feedback on actions is given to the maintenance contractor. Each individual incident or failure, which has caused delays for a significant number of trains to merit above-average amount of infrastructure sanctions, needs also sufficiently analysis in order to clarify the root causes of the failure and in order to achieve knowledge for continuous improvements. Only if the maintenance contractor is capable of technically analysing and reporting the failures to the supplier and when there is feedback from the supplier, can the state of the system be improved as the knowledge on pass failures is spread and corrective measures taken. Unless such loops of collecting and analysing failures and conducting necessary improvements are executed, the state of the system cannot be amended.

Efficient usage of the MSAs as a tool for improved quality of service requires effort from the maintenance contractor in analysing the failures and the state of the system before contacting the technical support provided by the supplier. Unless such analysis is conducted beforehand the learning of the failures remains at low levels and useful knowledge is not amounted to the maintenance contractor. The collaboration of the supplier and the maintenance contractor is crucial; both must bear their responsibilities in highlighting the reliability engineering items to be improved.

The contents of the MSAs and the capabilities of the signalling supplier in remote monitoring and remote measures of the signalling infrastructure must be better communicated and marketed to the field engineers and maintenance specialists of the maintenance contractor. The communication between the signalling supplier and the maintenance contractor must always take place before a remote measure by the supplier is executed in order to avoid miscommunication and its effects. Such constant communication increases the understanding of the common goal of improved quality of service.

The MSAs have potential for improvement especially in the written reporting of the state of the systems and in formulating the so called to-do-lists, which propose measures aimed at reliability engineering actions needed for the decreasing the current failure rate. Various proposals for increased quality of service can be costly to execute, but their cost-benefit-analysis should be at least attempted, so that the decisions can be made. Assuming that no money exists for reliability programs is counterproductive and hinders the efforts for increasing reliability.

The MSAs should continuously produce proposals for measures, which could reduce the failure costs within the maintenance and production and increase the reliability of the system. This area is the most significant based on both interviewees' and researcher's experiences.

A performance indicator for the quality of the MSA is: *the number of well-analyzed and closely-argued proposals and measures with a price tag for improving the quality of service of the system.*

4.1.2 Product Data Management of the Equipment

The second group of findings relates to the practical Product Data Management (PDM) of the equipment on the field. It encompasses the management of all the data, which is needed in maintaining the current functionality of the systems. The computerized systems contain various hardware and software objects, which are kept up-to-date by occasional upgrades. Keeping the data constantly available for reloading the systems if needed for preventive and corrective maintenance actions is an increasingly complicated task.

PDM requires that the software composition of the installations can be clearly understood and the necessary information is readily available for the corrective maintenance. The software includes the operating system platforms, and application programs with versioning, which all must be clear to the maintenance staff. A problem in deepening the software knowledge is the infrequency of occurrences, when such server side knowledge is in practice needed and the shortage of routine caused by the rare opportunities for training by doing. The software version description documents in the equipment room must be up-to-date and the maintenance staff must carry the latest versions with relevant information with them.

PDM of the equipment should be in such state that when entering an equipment room, the maintenance contractor can easily and speedy acquire all the maintenance relevant product data independent on how the storage of the data is arranged for the system in question.

A performance indicator for the PDM of the equipment is: *time necessary for the product data of any given object in the equipment room or on trackside to be identified and preparations for reloading the data for corrective maintenance purposes finished.*

4.1.3 Configuration Management of the Equipment

This group of findings was indicated especially by some representatives of the suppliers. Practical CM of the equipment means the different ways in which the current configuration of the system is made known in the equipment rooms on the field. The information, which makes it easy to know, which parameters and other possible variables are used, is needed in several maintained components.

CM is related to PDM, but whereas PDM concentrates on the data, CM has the focus of informing which data, settings, parameters etc. are needed for preventive and corrective maintenance purposes.

CM must be kept up-to-date and generally the software version and the other CM issues are stored in data base registers by the supplier and no access to the information is readily available to the purchaser or maintenance contractors, but listings may be provided as needed and asked for. When the supplier executes software upgrades and other measures, which require changes in CM, the relevant information is updated and information distributed according to the agreed processes. CM information is needed in the maintenance process when failures are such that reprogramming of the programmable logic units is necessary, but such events are relatively rare.

Reprogramming of the units of the interlocking requires specialized software tools, which may be difficult or expensive to install to a wider range of bearable computers. In such cases a smaller amount of specialized bearable computers may be available or the installation of them is managed through the MSA arrangements. If a document portal is available, the information of the current configuration may be accessible through it. Depending on the complexity and the rarity of the reprogramming task, it may be left to the supplier if it is not feasible to be taught to the staff of the maintenance contractor.

CM must be in a state, that the configuration needed for any given maintainable object is readily available and easy and fast to find, be it described in electronic or in paper documentation.

A performance indicator for CM is: *time necessary for the configuration of any given object in the equipment room or on trackside to be identified and the tools and the instructions prepared for the execution of the reconfiguration.*

4.1.4 Document Management of the Equipment

The issue of the documents available on site has been criticized by some representatives of the maintenance contractors even if corrective actions have been initiated recently. An effective PLM requires various documents of the equipment, which describe the product and contain instructions on maintenance and other issues relevant to the site in question.

Document management has also many items with need a further attention. The intellectual property rights of the maintenance instructions and especially their Finnish versions can be somewhat unclear and the availability of the documentation thus debatable. Typically the signalling supplier has the intellectual property rights for the required documentation. But the maintenance contractors also have documentation, which they may consider as their trade secrets to be kept out of public domain.

Finnish language versions of the maintenance documentation are essential enablers of efficient maintenance. Sometimes the translations are poor in quality, difficult to understand and even containing misleadingly expressed instructions. In order to allow the simultaneous use of the original language and the Finnish, the documentation should be kept bilingual so that the original language, typically English or German is kept in the same documentation so that both language versions can be read from the same double page of the binder. This would allow the usage of the original language if needed.

An internet tool for document management, a so called document portal, is an extranet service which can provide with the easy access the multitude of supplier documentation to the maintenance organizations. Creating and developing more such services is a future task for collaboration.

Keeping the documentation with possible supplements created by the partners on public domain and mutually accessible between the signalling supplier, maintenance contractor and the purchaser is important so that all the partners can share the latest and most accurate information and develop it together.

A document portal could help opening the eyes for the systematic and comprehensive storage of documentation in electronic format, remembering that the oldest installations have been in use since the 1960's and their documentation is not readily available electronically. Only partial current availability of documentation in electronic format is not an excuse for not developing the document portals and other means of ensuring the upkeep of documentation in the future.

A performance indicator for the document management of the equipment is: *the degree of completeness of the set of documentation available on site in comparison to the installed equipment on site and in comparison to the available documentation in electronic format.*

4.1.5 Management of Spare Parts in Mixed Environment

Efficient management of spare parts have been a concern for the maintenance contractors and suppliers alike and especially long delivery times and time pressures attached to the spare parts purchases has brought this issue into discussion.

Management of spare parts is a crucial driver of the effective maintenance. The spare parts are in today's situation delivered and stored in several locations, but the management of the whole inventory of spare parts has become increasingly difficult as the number of items and versions of individual electronic circuit boards have increased. The circuit boards even for the same purpose by the same supplier may vary according to the three aspects of mechatronics i.e. mechanically, electrically and in terms of software. The mechanical differences are typically used to highlight functional versioning in two other aspects. Nevertheless the variety of spare parts has become a challenge in the efficient PLM.

As the interlockings are geographically spread (see Appendix A.) the management of spare parts must be decentralized. Initially the spare parts are centrally stored in a warehouse, but they are then delivered to the locations of the interlockings to cover the geographical need of spare parts. The spare part batch becomes dispersed in several locations and the network wide management of them becomes more difficult. Also the maintenance areas and regional management areas (see Appendix B.) form artificial barriers for free flow of spare parts.

The spare parts should be kept in a common list with an actual inventory with the information on how many spare parts for each item there is and where the parts are located. A common list requires recurrent inventories to correct any deviations, which happens when the removed parts are not properly listed. Also processes at suppliers and at maintenance contractors aimed at continuously keeping the lists valid and up-to-date are necessary. A collection of the inventory of the installed base, which contains the list of hot parts in use, is a step, which brings the benefit of knowing how many components of a specific item are in use. By combining the knowledge of the installed base and the available spare parts together is a precondition to the capability of fast answering to the critical question: Do we have enough of this item stored as spare parts taking into account the availability and delivery times of the new spare parts?

The continuously up-to-date and readily available information on installed base parts and spare parts may in practice require an ICT application specialized for the task or a SAP system for supporting the management of the information. Even without such a system RHK should as the rail infrastructure manager have easily accessible information in order to be able to swiftly conduct targeted exchanges of parts if needed due to quality reasons. Such information would also allow fast and overall economically analyzed decisions on repurchasing of spare parts, when the availability of the parts is ending and so called "last stand by" purchases are required.

Spare part management can utilize different policies on cost and repurchasing responsibilities and risk sharing between the purchaser and the maintenance contractor and various arrangements with the suppliers, as the practice has been. The ideology of Vendor managed Inventory (VMI) of spare parts, where the supplier bears a greater responsibility of spare parts stockpiling at customer's premises is a future development and a so called "return and replace service" is a step towards that. In every spare part policy the capital value of the spare parts must be weighed against the costs of non-availability of spare parts and against the costs of the losses in production. Generally the waste in excessive stockpiling of spare parts is a lesser evil in comparison to the insufficient levels of storage and the problems caused by it.

Cost of the ICT and other administration related cost attachable to the spare parts must not be shied away from, because an effective management of spare parts is a guarantee for the speedy corrective maintenance. The costs of ICT solutions are marginal in comparison to the capital value of spare parts and the value of the production and the maintenance the spare parts are supporting.

A performance indicator for the management of spare parts is: *time necessary for an accurate assessment of the network wide availability of any given spare part item with the information of the current location of the spare part.*

4.1.6 Product Feedback Management with the Partners

This finding refers to the information derived from the maintenance of the systems and to the communication channels between the maintenance contractors and the signalling suppliers.

Practical product feedback means detailed information on the behaviour and the characteristics of the product, which are reported to the supplier. Product feedback management of the supplier gets inputs for example from the MSA, which have created opportunities for immediate feedback. The return and replacement service for spare parts, the surveys in the signalling infrastructure installations and communication on technical support issues, all give feedback to the supplier.

The maintenance contractor can provide systematic information on maintainability i.e. MTBF values, failure rates in locations and other maintenance issues, which causes maintenance costs. Such information is valuable and must be shared between the maintenance contractor, the supplier and the purchaser. When the quality of service is continuously reported and mutually understood between the partners, the questions about the corrective measures are also put to the agenda. The efforts for improved quality of service and for better maintainability of the systems must be under constant consideration, so that the measures can be planned and executed in due time.

The maintenance contractor sends to the supplier log files, which are files containing listed rows of system data. Those log files are analysed and information derived from them classified and possible future software upgrades are planned by the supplier based on the information received. Also answering back to the maintenance contractor needs to be arranged. A process of collecting feedback and giving responses is to be kept simple but the feedback is needed in order to motivate the maintenance contractor to send in such log files to be analyzed. Without any responses from the supplier the maintenance contractor may consider the efforts of acquiring and giving the feedback in vain.

The feedback can get too detailed or amounts of it excessive, but at least in the major maintenance issues a discussion of the root causes is necessary. The maintenance contractor and the supplier must identify the critical incidents after which the maintenance contractor should always contact the supplier with relevant information in order to share the knowledge. Also the product feedback by the maintenance contractor on system maintainability and its strengths and weaknesses are one source of wisdom to be used in future development.

Yet another source of feedback is the operators using the systems in their daily work. The meetings focusing on the feedback of the operators and on the relevant issues can be too problem-oriented and not giving sufficiently suggestions on future improvements unless the product knowledge of the systems is on a high level. The operators may be better equipped of giving realistic feedback when the technical expertise of the maintenance contractor or other stakeholders with high product knowledge supports such sessions. A representative group of people, which is formed out of respected and experienced operators, could be formed to collect such systematic feedback.

The operators i.e. the dispatchers at the Centralized Train Control (CTC) are less prone to give feedback unless directly requested. Systematic collection of feedback let it be negative or positive should be arranged so that the key operators – perhaps the ones involved in the education of others – are utilized as reference group gathering feedback information.

Product feedback management should aspire to a mode of practice, which enables a constant flow of product feedback sent to the supplier by the maintenance contractor and operators. The supplier on the other hand should analyse the feedback and based on results give instructions on improved maintenance and operating practices. The analysis of the feedback can also produce change requests for the development of the future versions of the products.

A performance indicator for product feedback is: *the number of well-prepared product feedback items both sent to the supplier by the maintenance contractor or the operator and after being analyzed replied to the sender by the supplier.*

4.1.7 Collection of Information to an International Knowledge Base

The systematic methods of international information collection from the users and the maintenance organizations are especially interesting out of maintenance contractor's point of view.

As the rail signalling infrastructure suppliers are typically multinational corporations active in several national markets with their products, the product related information could be gathered from those international users of the product and then spread back to individual national users, thus creating a knowledge base for the product.

Such a common knowledge base would mimic the practises within aviation industry, where the maintenance issues related to the aircraft are reported to a centralized knowledge base hosted by the aviation authorities. For example in the USA the Aviation Accident and Incident Reporting System (AAIRS) and the DOE Occurrence

Reporting Processing System (ORPS) are systems, which record incidents and occurrences with the technical backgrounds from various operators. If a technical phenomenon or problem is revealed, the companies operating the aircraft can be notified in common. (DOE 2005: 43)

Such practices are utilized by the rail signalling infrastructure suppliers in major occurrences, but they are not systematically used for gathering minor maintenance issues at least not openly to the maintenance contractors.

Setting up and operating a maintenance related knowledge base would require some investments from the supplier, but the system would be a valuable source of product feedback and become a competitive advantage as the maintenance contractors would bear the costs for their usage of the system when providing valuable information. Customers would probably appreciate and prefer the products, which they know are supported by such knowledge bases.

The suppliers may be reluctant to the culture of openness in the maintenance and feel that being open to their customers would jeopardize them, if their competitors on the other hand are keeping their maintenance issues hidden and out of sight. If the industry is not taking the initiative on the issue, it might be that the European railway bodies like the EIM will promote the idea to the European Railway Agency (ERA), located in Valencienne, France. The common knowledge base becomes more interesting as the traffic management systems used in Europe are being harmonized. In Europe, the European Rail Traffic Management System (ERTMS) is a strategic initiative, which aims at technical interoperability allowing the frictionless crossing of national borders for the train traffic. When the migration to the ERTMS is advanced, the demand for the knowledge bases is increased.

Regardless of the European development, the international knowledge bases would be powerful tools in managing maintenance issues and they would increase pressure for national maintenance contractors to systematically collect the information, so that it could be sent to the international knowledge base. The utilization of the international knowledge bases would not only enable international collaboration on maintenance, but also sharpen the national maintenance practices and allow benchmarking of the methods.

A performance indicator for international knowledge bases is: *the availability of an internet service by the supplier dedicated to gathering the maintenance incidents and information from its customers to form an international knowledge base aimed at improving maintenance knowledge.*

4.1.8 Requirements and Specifications for Engineering Change Management

This finding of the study is based on experiences of some suppliers, which have encountered the problem in processing of the requested changes. Sometimes unclear change management issues have surfaced at a late stage, even at the commissioning of the changes.

Requirements and specification are the basis for developing nationally localized versions of the generic interlocking products, which are suitable for the use for Finnish rail network. Requirements and specifications management is mainly taken care by the requirements issued in the tendering process and with the original specifications of the tender.

The specifications on electronic interlockings have been changed several times during the past 15 years, so the installed base of infrastructure contains small variations due to the different specifications applied at the time of the project. Such variations are typically geographically restricted to a certain area and to the certain interlocking products depending on their original delivery times and as such well managed. The communication of the specification used in the installation is not a major issue during the maintenance of the systems.

When engineering changes are conducted within an installation a dilemma might need to be solved; which requirements are valid after the change, the ones applied during the initial commissioning of the installation or the upgraded ones now valid. If the latter is chosen, the decision may cause more changes than just the ones concerning the original change of rail topography or other reasons of the change. The varying editions of the requirements allow different solutions and this might cause a source of uncertainty.

The validation and internal checks at the supplier ensure that no mixture of old and new requirements and specifications can occur in one system, so that accidentally two sets of requirements would be used simultaneously at one location.

When planning a functional change typically due to the change in controlled rail topography, the supplier must inform, which versions of the requirements are applied to the change so that any uncertainties in commissioning tests can be avoided and possible disputes on functionalities prevented.

A performance indicator for engineering changes is: *the quality of details of the description of the specifications and requirements to be used for the engineering change in the tendering documentation and the completeness of the supplier information of the specification status of the planned outcomes.*

4.1.9 Maintenance Management and Openness in Sharing Information

This group of findings is based on my experiences and on the capabilities of the maintenance contractors in reporting their maintenance activities. The issue of rightly dimensioned maintenance is also important to the suppliers as it affects the TCO of the systems delivered and the competitiveness of the supplier.

In the scope of maintenance management belongs the planning, executing and controlling of the required maintenance tasks, which help in achieving the objectives of the maintenance i.e. the up-keep of the integrity of the physical assets.

Maintenance management planning has as a main source of information the maintenance requirements of the supplier on the one hand and the maintenance requirements of the contracts between the purchaser and the maintenance contractor on the other hand. Any discrepancies between those requirements may cause excessive or insufficient planned maintenance and thus incur immediate or postponed extra maintenance costs i.e. the so called maintenance debt. The planning of the maintenance requires checkups, in order to ensure that the plans of the maintenance contractor are not without conscious decisions deviating from the requirements of the OEM supplier or the maintenance contracts.

Controlling of the maintenance is needed to ensure that the planning and the executing of the maintenance is in harmony with the requirements so that the planning covers the sufficient level of maintenance and the maintenance actions are executed according to the plans. Also the outcomes of the execution of the maintenance require a critical evaluation, which can lead to the conclusions, which demand changes to the current maintenance requirements. Either the number of the preventive maintenance actions need to be added or they can be reduced. The illustration below describes the flows of checkups and feedback.

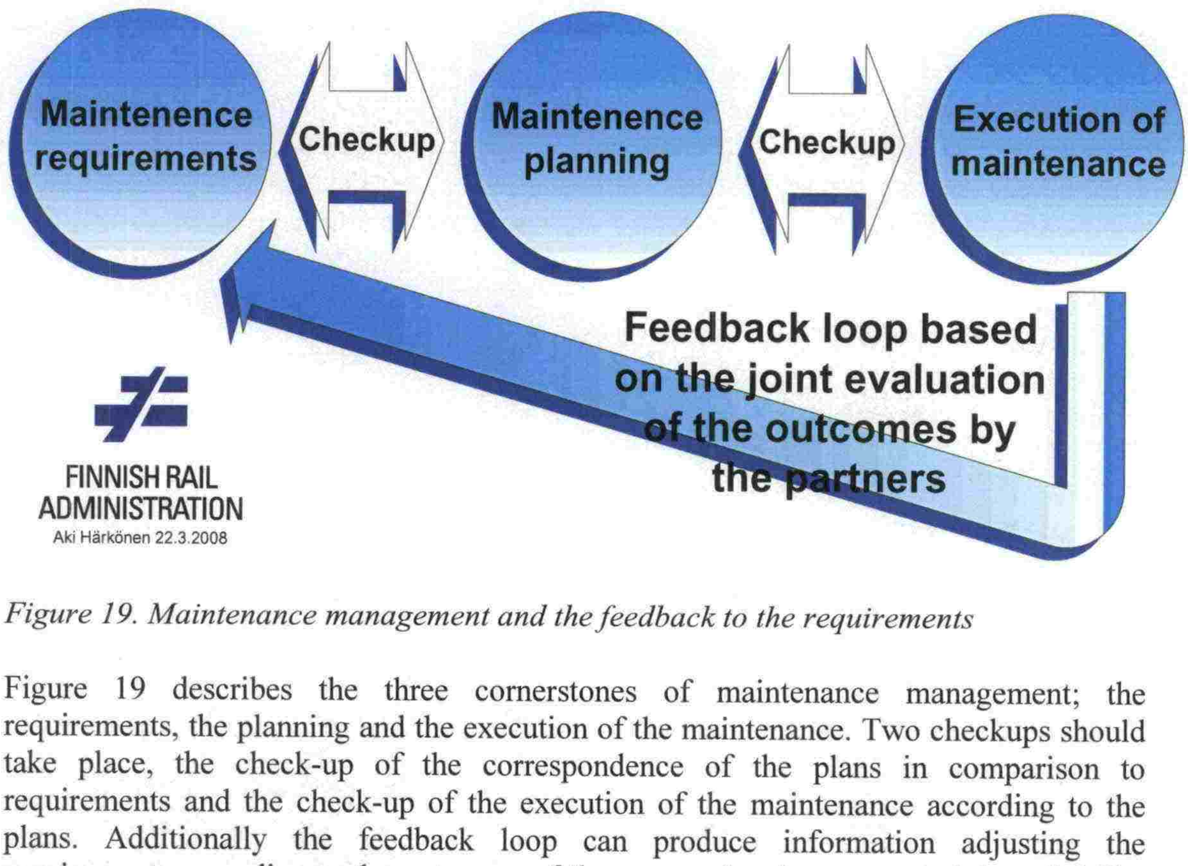

Figure 19. Maintenance management and the feedback to the requirements

Figure 19 describes the three cornerstones of maintenance management; the requirements, the planning and the execution of the maintenance. Two checkups should take place, the check-up of the correspondence of the plans in comparison to requirements and the check-up of the execution of the maintenance according to the plans. Additionally the feedback loop can produce information adjusting the requirements according to the outcomes of the executed maintenance and the reliability level achieved. Also the ratio of the preventive and corrective maintenance is analysed and the amount of preventive maintenance adjusted. Such reliability oriented maintenance practises are commonly referred as Reliability Centred Maintenance (RCM) as they have an emphasis on continuous improvement of the reliability of the system.

Attempts of directing the maintenance towards predictive maintenance so that the preventive maintenance actions are conducted according to the need rather than based on calendar is a significant source of effectiveness. The increased emphasis on preventive maintenance requires adaptation according to the equipment in question and depending on supplier and even on individual product, not relying on one-size-fits-all thinking, which tries to apply a unified generic approach on every similar object to be maintained regardless of their differences in construction. The predictive maintenance has as preconditions that the maintenance requirements are flexible enough to allow the adjustments of preventive maintenance schedules and that mutually acceptable criteria for adjustments can be reached.

Systematic collection and analyzing of the failures and calculations of the MTBF values for each individual location could bring the drivers of the maintenance costs into the spotlight. By opening the detailed statistics of the maintenance under the inspection the maintenance contractor would also have feedback on quality of the maintenance. This may also be counterproductive and be a motivation for maintenance contractor for guarding against revealing such detailed information depending on the current level of maintenance practised.

Frictionless flow of information between the operators, maintenance contractors and the suppliers is a key for continuous improvements within the organizations. By sheltering the information the partners are also preventing the pressure for developing the capabilities of their organizations and thus not developing their long term competitive advantages. As the maintenance of the signalling systems is related to the safety, the openness in dealing with the possible shortages in maintenance management issues should be sufficient so that the corrective measures can be arranged in due course. The safety related assessments of the situation i.e. the various checking actions if a condition found in one location exists elsewhere can be time consuming and causing extra efforts, but resources for such actions are needed to avoid diminishing of the safety.

Ideology of the operator driven maintenance is under the existing circumstances and organizational boundaries rare. The roles of the operators i.e. the train dispatchers or rail traffic controllers of the CTC are restricted to the management of the traffic whereas the maintenance is seen purely as a domain of the maintenance contractor. By directing the rail traffic controllers towards the maintenance supervising and giving them a more central role in it might involve the rail traffic controllers in the maintenance issues and be a rich source of information and mental resources. Organizational boundaries between the operating company and the maintenance contractors are currently high and somewhat limiting such straightforward handling of issues.

Identifying of the weak spots and the listed objects of inspections, which must be periodically inspected needs continuous attention and updating so that a negative phenomenon is caught in time without excessive failures. When such a list of weak spots is created and the prevented measures scheduled, can the yearly surveys with the OEM supplier help to guarantee the quality of the maintenance and reveal if the objects are not inspected or preventive actions conducted in due course.

Maintenance controlling is feasible only when the information required for the checkups are in electronic format in which various queries on the completeness of the planning against the requirements and the executed maintenance against the plans can be performed. The ratio between the workload of the preventive and the corrective maintenance should also be open to the mutual evaluation of the partners. Unless such openness in sharing information exists, the maintenance controlling is in practice limited to the outcomes of the maintenance. The efficient and effective maintenance management requires controlling capabilities, which in practice can be achieved only by a CMMS, which is administrated by the purchaser and which systematically collects the maintenance requirement, plans and records the actions by the maintenance contractors. Such a system would require significant administrative overheads to operate, but without such ICT tool the controlling capabilities may be insufficient.

A performance indicator for maintenance management is: *the degree of effortlessness for performing the two checkups, the consistency of the maintenance requirements and the plans and the completeness of the executed maintenance according to the plans.*

4.1.10 Knowledge and Competence Management

This finding has been highlighted by the suppliers, which have experiences in helping the transferring of the maintenance responsibilities from one contractor to another. Also the experienced maintenance contractors tend to emphasize the importance of the knowledge.

Knowledge and competence management is a crucial factor in maintenance of the systems during their lifecycle. The maintenance of the computerized interlocking systems requires quite a lot knowledge and competence and those must be managed in order to optimize the capabilities and ensure the sufficient levels of them for the maintenance.

There are critical questions, which require answers. Where the knowledge is kept up-to-date even regarding the legacy systems and in what kind of organization? How the knowledge is geographically dispersed within the global multinational supplier organizations? How is that knowledge available locally for maintenance contractors? How is the deep product knowledge built and maintained within the maintenance contractor? Unless such questions have a clear answer and the practises are strategically ensured in the contracts, the knowledge and competence management may become a risk factor in lifecycle management of the systems.

The collaboration in accumulation of the knowledge and in the models ensuring the availability of the knowledgeable people requires agreements and facing the facts. The maintenance is knowledge intensive today and even more so in the future as the computerized systems replace the relay interlockings, so the continuous improvements in the capabilities of the maintenance contractor are unavoidable. The dialogue between the supplier and maintenance contractor needs to focus on issues, where the maintenance contractor needs improvements in product knowledge.

Maintenance training sessions are typically arranged in connection to the commissioning of the new systems and to some extent during the yearly maintenance surveys as a part of the MSA activities, but those trainings are directed to the workforce already having a solid background in the industry. The training of the newcomers in the field is a more challenging task.

Finnish National Board of Education (FNBE) has a program for vocational qualification in maintenance of rail signalling, but that program is lacking a focus on PKM and it is thus not suitable for delivering the product oriented training for specific products. The vocational qualification programs of FNBE are time consuming and lengthy in duration and they can be utilized only in the companies already in the business and are thus not well suited for fast trainings that are needed for NPI or when a new maintenance contractor with new personnel is initiated to the local systems to be maintained.

A set of product specific training should be defined between the partners, so that the requirements for product training are mutually accepted so that no major disagreement exists whether the product training is sufficient or excessive. Such product specific training would provide an initial minimum level of knowledge sufficient for conducting preventive and corrective maintenance with the help of maintenance manuals and possibly with the available support of the MSA. Having a defined set of product specific training allows all partners to acknowledge, when the maintenance contractor and its staff has sufficient qualifications for the maintenance of the systems. By having such mutual agreement on minimum qualifications, the disputes and differing views on that issue can be avoided.

Maintenance contractors should nevertheless not assume that formal trainings can solve the need of building the critical mass of the product knowledge. On the contrary the formal trainings must be seen as the sources of minimal level of knowledge and the emphasis of training must be in the process of learning by doing and continuous efforts supporting the learning. The continuous learning is a cultural matter, which can be promoted by the management systems of the maintenance contractor.

A performance indicator for the PKM is: *the degree of details for the minimal product knowledge requirements for the maintenance of the interlocking in question and the quality of evidence provided by the maintenance contractor in demonstrating the capabilities of its staff.*

4.1.11 Infrastructure Supporting the Product Specific Learning and Diagnostics

This finding is based on the critical comments by the maintenance contractors. The systems in use are not well suited for practicing and if no systems exist for learning purposes, the hands-on learning is difficult to arrange without formal class room trainings.

In addition to the trainings and to the culture promoting the continuous learning, the physical infrastructure can support the product specific learning efforts. The purchaser can build an infrastructure, which promotes the product specific learning efforts of the maintenance contractor by investing in the extra equipment, which is dedicated to the learning purposes only. Learning systems can be tested and manipulated without interfering in the systems in production and without disturbing the train traffic, so they enable various tests and practising with the real product. The learning systems can cater for the teaching purposes of the traffic controllers and maintenance contractors alike, but their location should not be in a special location dedicated to teaching only, but rather in the premises, which are near the systems in production. In that way the systems are easily accessible to learning during the normal daily business without a special course or other arrangements, which merit the usage but simultaneously form a threshold for frequent and casual use. The premises for learning systems should be controlled by RHK so that the teaching aimed for third party maintenance staff is possible as well.

Currently the learning systems are not always purchased for initial investment cost reasons, but their more systematic utilization ought to be evaluated anew. The systems may serve also as a spare part buffer, because if needed they can be cannibalized for emergency spare parts.

Another way of promoting the knowledge of the maintenance contractor with the structures and characteristics of the systems in use is the focused investments in diagnostics capabilities of the systems. If the systems provide rich sources of diagnostics for its own states the systems can be teachers of maintenance by giving hints of symptoms and revealing root causes of the problems. As the signalling systems are depending on transmission systems the diagnostics characteristics are growing in importance. Often practical corrective maintenance faces a problem, whether the root cause of the failure at hand lies within the maintained system itself or within the commercial transmission systems it utilizes. In order to be promptly able to distinguish between those two basic types of failure, the diagnostics of the transmission systems ought to be at such quality that an answer is possible without excessive delays. Increased investments in diagnostics characteristics have as a precondition the detailed requirements specifications, which leave room for variation depending on product.

Increased capabilities of monitoring and diagnosing of the states of the systems and the remote execution of the maintenance actions through data communication systems are other areas, which require continuous attention. The maintenance contractor should also be capable in monitoring both the system and the transmission connections to the system in order to be able to get information from the failures of the transmission system. Technological solutions, which empower the maintenance contractor in those aspects are beneficial and should be increasingly invested in.

A performance indicator for the infrastructure supporting learning is: *the frequency in utilizing a system for learning purposes by the staff of the maintenance contractor, without interfering with the train traffic.*

4.1.12 Coping with the Increasing Costs towards the End of the Lifecycle

The finding on the difficulties in determining the length of the lifecycle and the increasing costs towards the end of the lifecycle has been emphasized based on researcher's experiences and on the ideas of the representatives of the maintenance contractors.

Increasing wear out of the systems is an inevitable phenomenon which must be coped with as the age of the installation is approaching the end of the lifecycle. Components of semiconductor-based electronics have a limited lifecycle, which is temperature dependent so that a system in the well ventilated and air-conditioned room can have a significantly longer useful life in comparison to the similar system, which is operated in a room with constantly high temperatures. Temperature affects the semiconducting silicon structures of the electronics and the functioning of the components. Rotating hard drive disks have limited life but may run lengthy periods in continuous usage without stoppages. Wear and tear of the systems is as such natural and cannot be prevented, but favourable conditions can slow down its progress. Tidiness and cleanliness of the premises and proper air-conditioning may add many productive years to the systems.

Computerized interlocking systems utilize in their hardware and software versions, which were commercially available during the developing and delivery periods of the systems. Both hardware and software parts of the computers have notoriously short lifecycle and their availability on the marketplace is limited to a relatively short period. After the cessation of the production of a part the availability of it soon expires and the only way to get the parts are the unreliable aftermarket sources. When some of the components have reached such a stage in their lifecycle or even single component has, a whole part of the system becomes difficult to reproduce. Even if the components are available, their utilization may be limited if the old production lines capable of soldering such components have already been scrapped.

A directive of the European Union, the "directive on restrictions for the use of certain hazardous substances in electronic and electrical equipment" (2002/95/EC) limits the use of lead, cadmium and other substances in soldering. Although the stationary fix installations are not directly affected by the directive, it has lead to the changes in soldering methods and speeded up the cessation of some production lines. The directive may in the long run adversely affect to the efforts of prolonging the lifecycle of the systems by causing untimely problems for availability of spare parts.

Maintainability of the system becomes more challenging as the availability of the spare parts becomes limited and extra efforts are needed for finding spare parts out of secondary sources. Maintainability of the system is depending on a number of factors, which must be in place in order that the maintenance can be properly executed. Even a minor factor can become a limiting factor and its absence can prevent the maintenance actions. It can be for example the availability of the old computers capable of running certain maintenance software or even outdated connectors to the computers, which are no longer supported by the modern computers. As the maintainability becomes more difficult, the costs of the up-keep of the full maintainability grows as more and more efforts are needed even to maintain the capabilities. Also the failures due to the wear and tear become commonplace and the spare parts get more expensive, both adding to the costs. The illustration below describes the tandem development of the maintainability and the maintenance costs during the lifecycle.

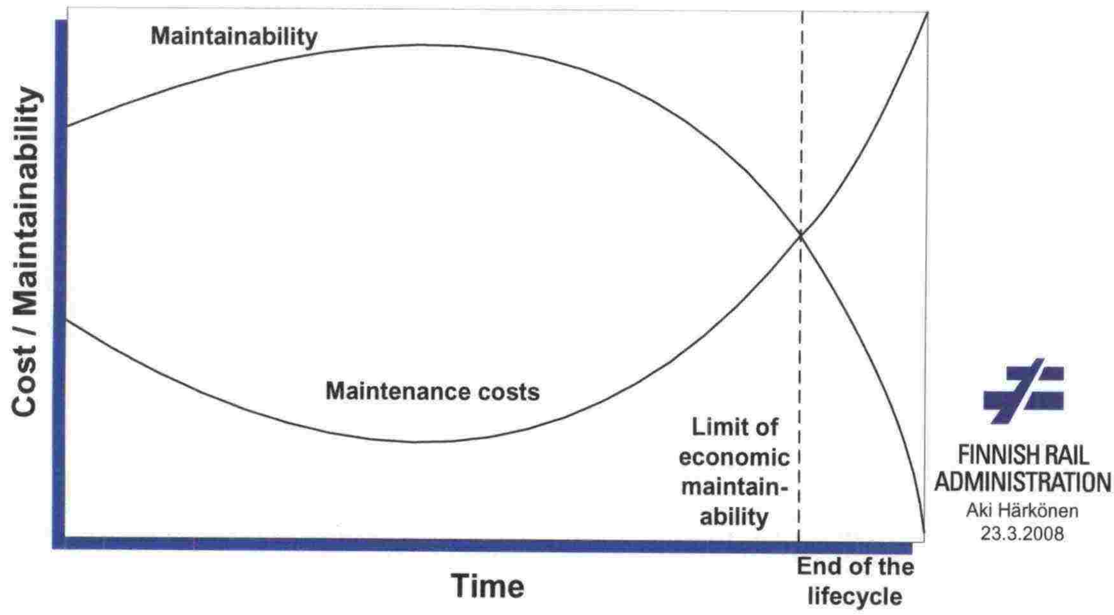

Figure 20. Cost and maintainability as functions of time

In Figure 20 the costs of the maintenance rise as the time passes by and the wear and tear takes its toll and simultaneously the maintainability sinks due to several reasons. As the maintenance costs have risen to a high level and can be anticipated to grow further and the maintainability has sunken to a low level, the end of the lifecycle has been reached and the situation is only getting worse. The limit of economic maintainability is not a sharp line but rather a gray area with gradually growing maintenance costs and lowering maintainability. The nearness of the limit of economic maintainability ought to be forecasted in due time in order to prepare for the needed measures.

As the limit of the economic maintainability is being approached, a strategic decision must be reached. Whether the product in question will be replaced by a totally new installation or the current installation is renewed by targeted reinvestments, is the strategic question. It might be possible to utilize targeted reinvestments thus restoring the maintainability to an acceptably high level and simultaneously lower the running maintenance costs. The illustration below highlights the effects of reinvestments.

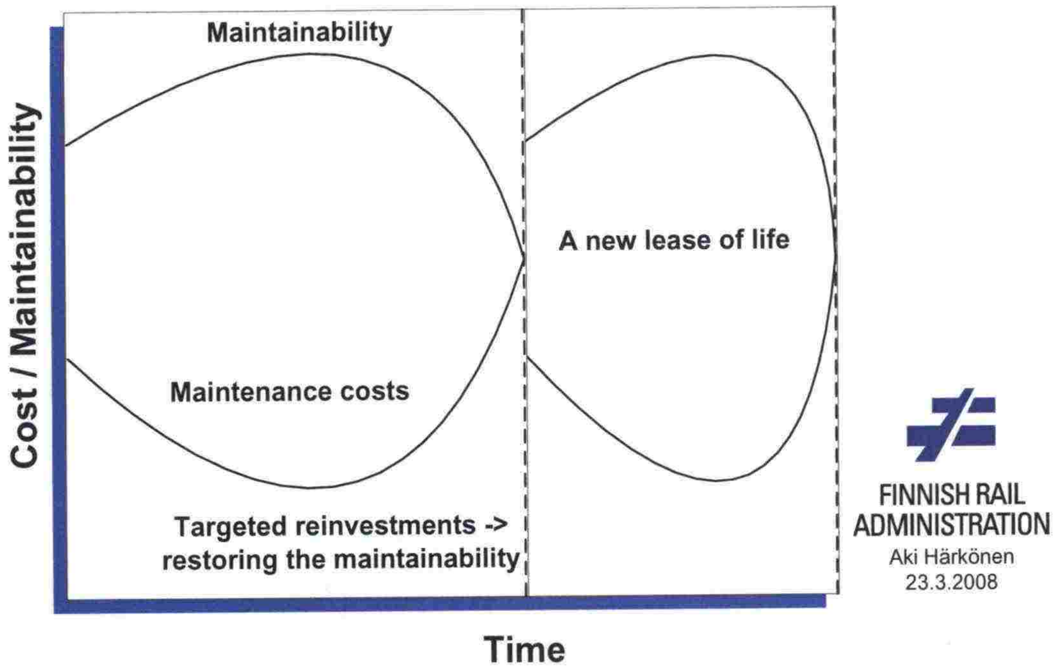

Figure 21. Targeted reinvestments and a new lease of life

Figure 21 describes the effects of targeted reinvestments aimed at restoring the maintainability. As the nearness of the limit of the economic maintainability is recognized and the targeted reinvestments executed, the product gets a new lease of life. Maintainability is again brought at a high level and it is even rising as the system stabilizes after the reinvestments and the maintenance costs are lowered. Depending on the extent of the reinvestment, the new lease of life is shorter than the original useful life and as the time passes by, the lifecycle nears to its end again as the maintenance costs rise and maintainability deteriorates.

Coping with the increased costs towards the end of the lifecycle requires conscious attention to methods and criteria, which enables the partners to identify the nearness of the end of the lifecycle. If the end of the lifecycle is reached by surprise, the time required for preparing the necessary investments for replacements or renewals is limited and the substandard level of maintainability must be endured longer with the high maintenance costs. Costs of losses in production and other subsequent costs may also simultaneously reach unbearably high levels.

A performance indicator for the coping with the increased costs towards the end of the lifecycle is: *how well defined and communicated between the partners are the indicators of maintenance costs and the factors of maintainability capable of forecasting the nearness of the limit of the economic maintainability and reaching the end of the lifecycle.*

4.1.13 Summarizing the Insights of the Study

The insights of the study can be summarized in the performance indicators for the issues deemed relevant for the further developing and for continuous improvement. They are success factors for PLM approach and can be advanced in collaboration with RHK, the signalling infrastructure suppliers and the maintenance contractors.

The dozen (12) performance indicators for measuring the state of PLM capabilities are:

1) A performance indicator for the quality of the MSA is: how many well-analyzed and closely-argued proposals and measures with a price tag for improving the quality of service of the system are there.
2) A performance indicator for the PDM of the equipment is: how fast can the product data of any given object in the equipment room or on trackside be identified and preparations for reloading the data for corrective maintenance purposes finished.
3) A performance indicator for CM is: how fast can the configuration of any given object in the equipment room or on trackside be identified and the tools and the instructions prepared for the execution of the reconfiguration.
4) A performance indicator for the document management of the equipment is: how complete the set of documentation available on site is in comparison to the installed equipment on site and in comparison to the available documentation in electronic format.
5) A performance indicator for the management of spare parts is: how fast can the number of network wide availability of any given spare part item be figured out with the information of the current locations of those spare parts.
6) A performance indicator for product feedback is: how many well prepared product feedback items are both sent to the supplier by the maintenance contractor or the operator and after being analyzed replied to the sender by the supplier.
7) A performance indicator for international knowledge base is: does the supplier provide an internet service dedicated to gathering the maintenance incidents and information from its customers to form an international knowledge base aimed at improving maintenance knowledge.
8) A performance indicator for engineering changes is: how detailed is the description of the specifications and requirements to be used for the engineering change in the tendering documentation and how detailed is the supplier information of the specification status of the planned outcomes of the change.
9) A performance indicator for maintenance management is: how easily the two checkups, the consistency of the maintenance requirements and the plans and the completeness of the executed maintenance according to the plans, can be performed.
10) A performance indicator for the PKM is: how well defined the minimal product knowledge requirements for the maintenance of the interlocking in question are and how the maintenance contractor can demonstrate that its staff possesses such product knowledge.
11) A performance indicator for the infrastructure supporting learning is: how frequently the staff of the maintenance contractor can utilize a system for learning purposes, without interfering with the train traffic.
12) A performance indicator for the coping with the increased costs towards the end of the lifecycle is: how well defined and communicated between the partners are the indicators of maintenance costs and the factors of maintainability capable of forecasting the nearness of the limit of the economic maintainability and reaching the end of the lifecycle.

Those dozen performance indicators are aimed at critically evaluating the current state of the areas, which can be further developed as the key areas for improving PLM of the rail signalling infrastructure. Other performance indicators could be identified for the subjects, but the dozen performance indicators are not meant to be tools for passive observation, but rather wake-up calls for focusing attention to the areas described. The areas, which need that continuous attention and improvements, are pictorially illustrated below.

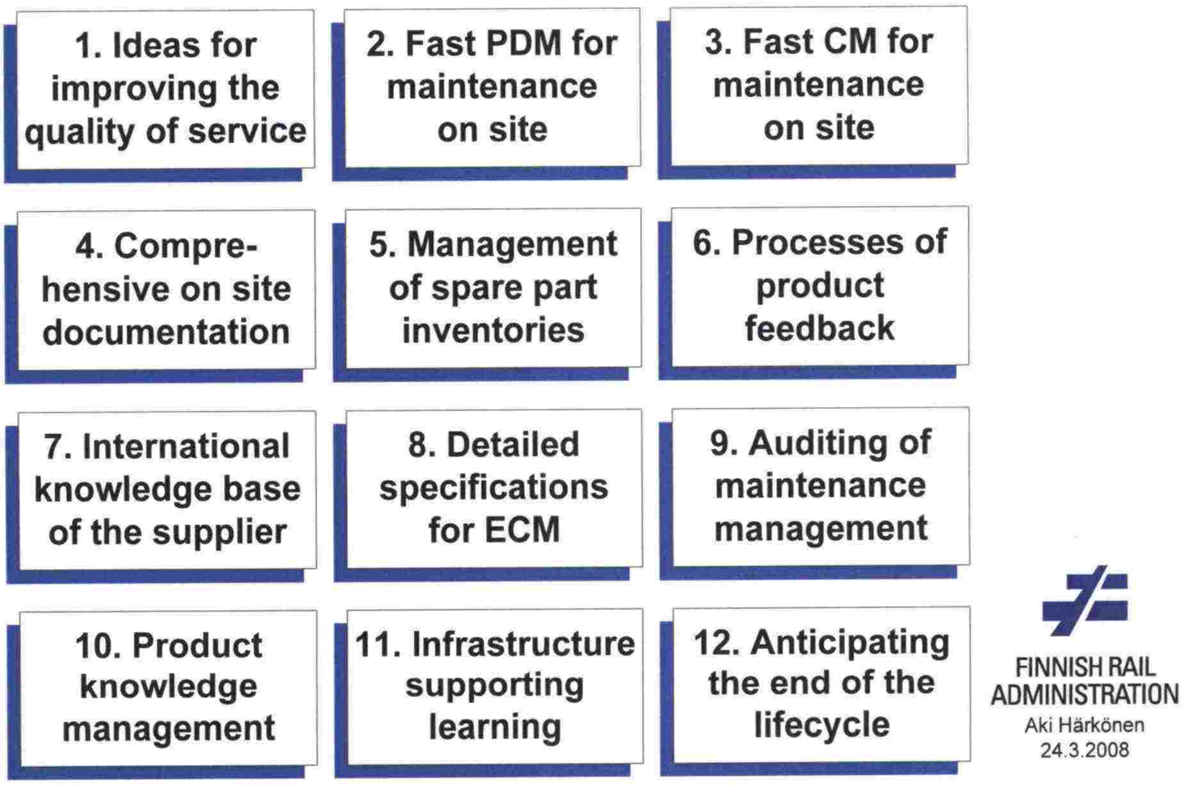

Figure 22. Dozen performance indicators for measuring the state of PLM

The dozen areas highlighted in Figure 22 have each influence on the effectiveness and efficiency of the daily maintenance business, but they also define the long term success of PLM efforts. Ideas for improving quality of service should be constantly evaluated and if cost-benefit-ratio is favourable, executed. Fast PDM and CM and comprehensive documentation on site can help reducing the mean time to repair (MTTR), the central maintenance performance indicator. Efficient management of spare part inventories can reduce the capital tied into the stockpiles and ensure the sufficient local inventories for corrective maintenance. Processes of product feedback and international knowledge base can facilitate the interactions between the maintenance contractor and the supplier. Detailed specifications for ECM can alleviate the preparation and commissioning of the necessary changes. Auditing of maintenance management can reveal problem areas in the chain of the requirements, the planning and the executing of maintenance. PKM needs constant attention as the complexity of the systems requires more knowledgeable maintenance staff. The infrastructure can support the learning efforts by providing opportunities for exercises. The methods, which enable partners to evaluate the current lifecycle stage of the systems and to anticipate the approaching end of the lifecycle, are invaluable in securing time for necessary reinvestments or other actions so that maintainability of the systems is constantly kept on an adequately high level.

The performance indicators can be utilized in the maintenance audits, where the purchaser, the maintenance contractor and the supplier can together measure the need for continuous improvements. The recurrent surveys on the premises can be utilized as a forum for checking the situation according to the performance indicators. The performance indicators can be used in internal audits of the maintenance contractor or in inspections realized by the regional maintenance manager or in other ways, which help to evaluate the local situation in the premises to be audited. Some of the performance indicators are such that they can be included in the maintenance contracts as well.

As experiences out of various audits have been collected and the levels achieved by the performance indicators are evaluated, the target levels and measures for improvements can be agreed. Also the methods of continuous utilization of the performance indicators can be agreed by the partners.

When more attention is directed to the current state of PLM and measures improving the situation are planned and executed, the overall capabilities of the maintenance can be developed and the benefits can be reaped in terms of fast and reliable corrective maintenance with lower MTTR. Also the MTBF of the systems can be increased as well-targeted measures improve the quality of service of the systems and failure sources are eliminated and prevented. Subsequently, with lower MTTR and higher MTBF the quality of service of the rail signalling infrastructure can reach higher levels and the punctuality of the rail traffic can be improved.

The performance indicators helping to focus on continuous improvements are as such not enough, but a more systematic effort for managing the collaboration during the lifecycle of the product is also needed. In the following the collaborative process of PLM for the signalling infrastructure is described to cover this need.

4.2 Collaborative Process of PLM for Railway Signalling Infrastructure

Another set of results developed in this Master's thesis is collected into a collaborative process of PLM for railway signalling infrastructure, which is derived from the inputs by the interviewees and from the previous experiences of the researcher. The collaborative process of PLM has as the background philosophy, that the partners, as described with intersecting circles in Figure 1, the purchaser, the supplier and the maintenance contractor, should in unity manage the lifecycle of the system. Unless each partner is sharing in the responsibilities and risks pertaining to producing accurate information on the RAMS of the systems, proposing measures for upkeep of maintainability of the system and initiating actions needed for improving the RAMS, the overall effort of the partners is not on a desirably high level. If the partners are neglecting their share of the effort and minimizing their PLM related costs by not actively bearing the costs necessary for analysing, planning and executing improvements, PLM has not great chances for sustained success.

Purchaser influences especially with its purchasing policy the long term PLM of the system. Fundamentally, the decision on the supplier defines and solidifies the subsequent PLM circumstances. If the decision on the supplier is solely based on short term benefits related to the initial investment costs, PLM aspects are neglected. A balanced view on the TCO requires that PLM issues are weighted alongside the evaluation of the initial investment costs. The purchaser has also the main role in actively ensuring that the maintenance contracts contain responsibilities for various PLM tasks alongside the daily maintenance routines for preventive and corrective maintenance. Unless clearly specified, required, controlled and paid by the purchaser, such task are not automatically performed, but probably due to the cost reasons or otherwise neglected. The purchaser has divided interest to protect; it must minimize the costs, optimize PLM efforts and maximize the RAMS according to the traffic needs. In such divided mode of attention to the interests, the ones which are most clearly defined and the easiest to measure – in this case the interest of minimizing costs – take precedence. The minimizing of costs can also be mandated by the lack of available funds or caused by the inefficiency in directing the available funds according to the greatest benefit.

Supplier as the holder of the product knowledge has a key position in openly providing the necessary information and the ideas, which can be utilized in PLM of the infrastructure. The supplier can have a pro-active approach in suggesting and communicating the relevant issues, which must be considered during the useful life of the system and especially when approaching the end of the lifecycle. The supplier has also divided interests as it also wants to sell new systems to the customer. The prolonged upkeep of the maintainability of the existing installations and subsequent lengthening of the lifecycle of them is counterproductive to the selling of the new systems.

Maintenance contractor has also opportunities to actively participate in collecting and analyzing valuable information, which can be used as a basis for continuous upkeep of the high maintainability of the infrastructure. It can utilize the information derived from the maintenance in anticipating trends and forecasting the future developments and thus provide early warning signs and inputs for planning the necessary preventive measures.

It can also actively ensure that the equipment room premises are well organized so that the fast corrective maintenance is structurally supported. The maintenance contractor has also divided interest. In order to make profit it tends to minimize and postpone the extra efforts, unless they are immediately beneficial to its day-to-day efforts. The maintenance contractor may also see various issues related to the maintainability of the systems as way of gaining competitive advantage if the knowledge is not spread to the other partners. By being open and transparent it may lower the barrier of entry to the maintenance market and thus weaken its competitive position.

In order to balance between the contradictory interests of the partners, a method is required so that the partners can be continuously reminded of the necessity of mutual efforts towards improved PLM. The method must extend to the whole lifecycle of the system. In the following, a systematic approach taking into account the different phases of the lifecycle and the conflicting interests of the parties, is introduced.

In managing the lifecycle of the system, the lifecycle can be divided into five phases: 1) the specification and bidding, 2) the project phase, 3) the warranty period, 4) the useful life of the system and 5) the end of the lifecycle. In each phase of the lifecycle there are possibilities for the collaborative process of PLM, which balance the differing interests of the partners and ensure that PLM aspects are taken into consideration. Based on the study, in each phase of the lifecycle, there are issues, which merit collaboration aimed at enhancing PLM aspects of the system and preventing that the interests of a single partner hinder the overall PLM effort. In the process diagram below, the collaborative process of product lifecycle management for railway signalling infrastructure is presented with its 18 process steps.

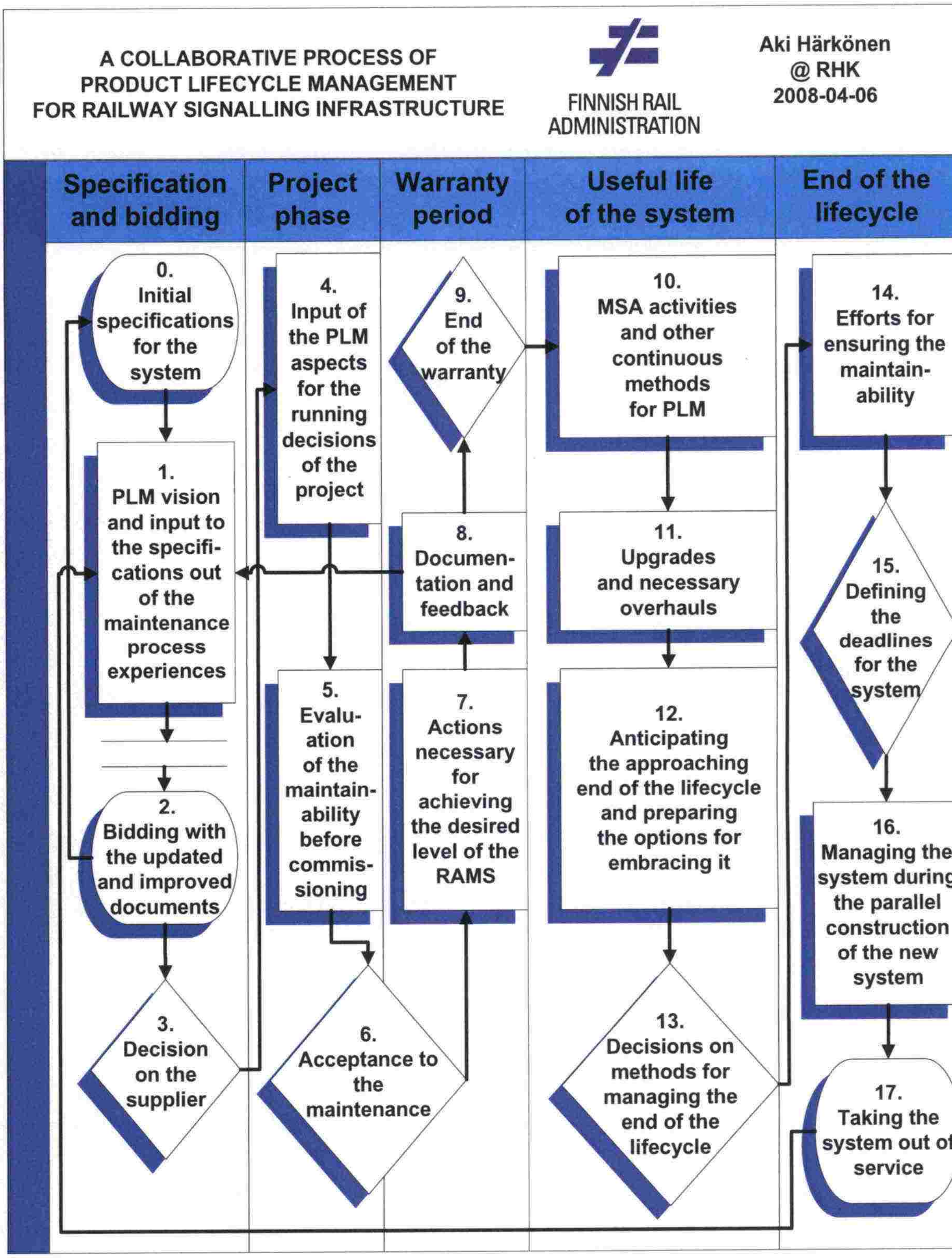

Figure 23. Collaborative process of PLM for railway signalling infrastructure

Figure 23 describes the collaborative process of PLM for railway signalling infrastructure. The lifecycle of the railway signalling infrastructure is divided into five phases. Each phase has process steps or sub-processes depicted with rectangular symbols and points of decision with square symbols. The process starts and terminates with the circular symbol. The individual process steps are described in detail in the following subsections.

4.2.1 Initial Specification of the System

The purchaser RHK has specifications that are used to describe the functionality and technical characteristics of the interlockings. The specifications have been continuously improved and even international efforts have been made in order to make the specifications more unified in terminology and more clearly understandable in defining the requirements for the supplying companies.

Initial specifications are the currently available versions of the specifications. When the collaborative process of PLM produces change proposals, which must be addressed, they are after the evaluation adapted to form the new initial specifications, which are then subject to future changes.

4.2.2 PLM Input to the Specifications

New sections to the existing specification and input describing the ideas for improving PLM aspects of the specification can constantly be made, as long as it happens before the bidding is initiated.

Maintenance contractors and suppliers can propose changes, which could enhance PLM of the systems. Proposals must be analyzed so that their effect on PLM and the costs and for the competitive circumstances can be evaluated. Changes that would made mandatory such functions, which can be delivered by only few suppliers, could prevent the competition and be harmful for the TCO of the system. Overly costly solutions could be difficult to motivate with PLM aspects.

PLM input can be derived on many steps of the collaborative process, but especially the knowledge and feedback collected from the documented results from the warranty period and from the retiring the system can produce valuable hindsight and should be taken into account.

As soon as valuable PLM inputs can in collaboration with the partners be incorporated into existing specifications, the future tendering can take place with the updated specifications.

4.2.3 Bidding with the Updated Specifications

Bidding with the updated specification must take place according to the Finnish laws and regulations for governmental purchasing. The tendering phase in itself does not leave much room for collaboration with the partners, but is managed by the purchaser.

The updated documents should contain all the necessary feedback derived from the previous purchases and when the bidding is done with the updated documents, those updates should form the basis for future bidding as well.

Bidding must take into account PLM aspects of the system, so that the TCO point of view and PLM point of view are sufficiently reflected in the evaluation of the offers in a way, which makes it possible for the purchasing to emphasize those as significant selection criteria.

4.2.4 Decision on the Supplier

The decision on the supplier is the most important decision affecting PLM of the system. If PLM aspects are not sufficiently evaluated in choosing the supplier and the product it proposes as the solution, the TCO can be higher than desirable. The short term benefits in terms of low initial investment costs may be tempting and suppliers, which are desperately seeking sales, may utilize dumping pricing to get projects. Unless such dumping pricings and other aggressive marketing methods are thoroughly weighted against the long term PLM of the systems, the purchasing may end up buying cheaply, but costing dearly in the maintenance of the systems.

In order to prevent such risks in the purchasing, the evaluation of the tenders must take PLM aspects sufficiently into account, so that the quality evaluation contains means of evaluating PLM and the TCO issues in a comprehensive way.

4.2.5 PLM Input for the Running Decisions of the Project

The project has to make running decision on various items and if the representatives of the maintenance contractor are actively involved at the project meetings, PLM aspects may be better taken into account. The mere participation to the meetings is not sufficient, but rather the maintenance contractor should have initiative to analyze and propose improvements to the plans, when the changes are still possible. The project could then adopt well motivated changes, which could improve the RAMS of the system. If the project can not adopt those changes due to cost or schedule reasons, the ideas can be saved and collected to be used in future inputs to the planning.

The project may consider the input of the maintenance contractor for the running decisions of the project as a nuisance and brake in executing the project effectively and efficiently, but if the project clearly sees the target as delivering a well functioning and maintainable system, the professional input by the maintenance contractor is more than welcome. The input of the maintenance contractor should be free of any commercial bias or personal preferences, but as the representatives of the maintenance contractor are human beings, the personal previous experiences and the technical issues cannot be totally separated from each other.

4.2.6 Evaluation of the Maintainability before Commissioning

This is an important process step, which requires close collaboration between the partners at the stage, when the commissioning is approaching and the various issues affecting the maintainability may be open or not yet fully on target. As the time pressure for the project schedule grows, the project has little time for concentrating on maintainability issues and they are easily postponed to the time after commissioning. The maintenance immediately after commissioning may thus start with inadequate means, which affects adversely the effectiveness and efficiency of the maintenance. Unless promptly corrected such a poor maintainability may also lead to the substandard level of RAMS and limit the market potential of product in the future.

The evaluation of the maintainability before commissioning should be taken very seriously and the purchaser should be willing to postpone the commission if the maintainability is not on target. In practice many issues are sometimes solved after the commissioning, but that should not be a standard procedure, but rather an exception.

4.2.7 Acceptance to the Maintenance

Based on the thorough evaluation in the previous process step, the decision on the acceptance to the maintenance can take place. The acceptance should be well motivated and documented and any open issues left to be solved should be listed in detail, so that they can be addressed and corrected during the warranty period.

The documentation for the acceptance to the maintenance forms the basis for following process steps, where the open issues and the unfinished solutions affecting the maintainability are addressed. The collaboration between the partners is crucial in agreeing the responsibilities and costs related to the fulfilment of the necessary measures for achieving the mutually accepted level of maintainability at the start of maintenance and in the end of the warranty period, which follows thereafter.

4.2.8 Actions for Achieving the High Level of RAMS

The warranty period offers opportunities to actions aimed at improving RAMS of the system. When the initial experiences of the RAMS of the systems are being collected, a thorough description of occurrences and failures with root cause analysis is unavoidable; as well targeted and effective modifications and improvements are sought after. The role of the maintenance contractor is significant in analyzing the current state of the system. Unless the situation is well communicated by the maintenance contractor and understood by the purchaser, the supplier may be able to avoid addressing the problems in due time.

The warranty period is challenging for the collaboration of the partners as the commercial pressures for the supplier may hinder the necessary actions. The costs incurred by the actions in warranty period may make or break the financial results of the project and the supplier has strong interest in protecting the profitability of the project by minimizing costs related to improvements.

Nevertheless, the finalization of the project and achieving the high level of RAMS should be a focus of attention for all the partners. In order to utilize the warranty period, various actions may be necessary. Not all the issues are automatically the responsibility of the supplier, but also issues, which are out of scope of the original project, may be considered and executed by the purchaser and the maintenance contractor alike.

4.2.9 Documentation and Feedback

When a system has been commissioned and already some experiences from the maintenance during the warranty period are collected, the circumstances are especially fertile for an effective and efficient collaboration between the partners.

The supplier has motivation to correct the possible problems discovered during the warranty period in order to be able to end the warranty period in due course. Also the future markets for the product are depending on the achieving a sufficient level of RAMS.

Various technical solutions and ways of realizing the product and executing the project should be documented and evaluated and based on those, feedback for the future bidding can be created.

The documentation can contain various managerial findings or discoveries for managing future projects, but especially important are the findings, which have an effect on RAMS of the system. Those should be included in PLM input and used for shaping the specifications for future bidding.

4.2.10 End of the Warranty

The end of the warranty period is commercially an important step, where the purchaser decides, that the supplier has finalized its warranty obligations in a proper manner. From that point on the commercial responsibilities for the upkeep of the maintainability lies on the shoulders of the purchaser.

The decision on the end of the warranty period affects the collaborative atmosphere between the partners and it must be done in a way, which leaves no room for speculation for accepting substandard products. The decision on the end of the maintenance must be solidly based on documentation, which includes the learning and feedback and also the current state of the system. The maintenance contractor has a crucial role in documenting the state of the system in an analytical and clear way and thus creating an input for an informed decision.

4.2.11 Continuous PLM Methods

Continuous PLM methods, which are utilized during the useful life of the system, can be formalized in the MSA agreements between the purchaser and the supplier if the scope of the installation merits an MSA. The dozen performance indicators described above are a palette of methods, from which the most critical ones can be chosen and practiced even without an MSA.

By continuously evaluating PLM aspects of the systems, the partners can in collaboration ensure that the maintainability of the system is not suddenly collapsed, but rather the lowering level of maintainability can be seen in foresight and necessary modifications and measures for sustaining the maintainability can be initiated in due time.

A key to the success of the continuous PLM methods is the sharp picture and the clear understanding of the current state of the system. Only with the well reported state of the system and with the collection of the trends indicating the changes in comparison to the previous years, can the decision on necessary measures be made based on solid technical fundament and economically without unnecessary haste.

The collaboration between partners makes it possible for partners to pay attention to PLM issues at all times, even when seemingly no urgent need of activity is present. By utilizing continuous yearly routines, can the communication channels be kept open and the teams responsible for the maintenance related issues within the organizations of the partners keep in contact with each other. When then urgent need for action arises, the partners' readiness for activity can be quickly mobilized into action.

4.2.12 Upgrades and Overhauls

The useful life of the system typically requires software updates and minor upgrades in configurations, which are performed along the maintenance as new information and discoveries are made in collaboration with the partners. They help in keeping the RAMS on a high level.

However, the more extensive overhauls are avoided during the useful life of the system due to cost reasons. Even if the supplier could be able to provide new hardware and software improving the situation, the cost-benefit-ratio of such an overhaul, when the improved RAMS is compared to the costs incurred, is typically unfavourable and the overhaul is not executed. Sometimes the problems are deep-rooted in the system and its technical solutions and cannot be amended by a targeted overhaul.

In some cases the system contains parts or subsystems, which clearly are substandard in comparison to the over-all quality of the system or the system contains parts, which have a significantly shorter lifecycle than the system in general. In such cases the partial overhauls, which replace the substandard parts, can be deemed cost-efficient and executed.

Upgrades and overhauls can prolong the useful life of the system and maintain its RAMS well towards the end of the planned lifecycle of the system. The collaboration in evaluating, planning and executing necessary upgrades and overhauls is essential and helps the partners to prepare so that the budgeting and scheduling of the future overhauls can be managed effectively and efficiently.

4.2.13 Anticipating the Approaching End of the Lifecycle

As the lifecycle of the system is approaching the end of the lifecycle, various signs of lowering maintainability can be detected. More frequent failures, increased need for preventive maintenance, problems in supplies of spare parts etc. begins to build up.

Those signs need a constant evaluation, so that the trends, which give early warnings and weak signals for the approaching end of the lifecycle, can be detected early enough. The maintenance contractor holds a key position in collecting the information, which builds the basis for trend lines, which can be evaluated by the partners. The purchaser must in its contracts with the maintenance contractor ensure that that kind of information is produced in a form, which is available to all the partners, so that no hiding of important information is hindering the joint efforts of the partners in evaluating the state of the system.

The maintenance contractor can be tempted to hide the information as a trade secret or avoid the collection of the information due to cost reasons. The supplier may be willing to concentrate on the selling of the excessive and expensive overhauls or it may see the prolonging of the lifecycle as a brake for sales of the new systems. The purchaser may be unable to bring the partners together in an effective joint effort. The collaboration efforts of the partners must be motivated with the long term mutual benefits of the partnership in order to circumvent the short-sightedness in seeking one-sided short term benefits.

The purchaser can with its own behaviour either support or punish the short-sightedness in its own way of managing the partnerships. If the MSAs and other practices support the long term view of the partners and the suppliers and the maintenance contractors can benefit for their long term commitments also in short term, the readiness for mutual efforts exists.

When the partners are capable and willing to collaborate in producing data, analysing the trend lines and reaching conclusions, the approaching end of the lifecycle can be met with foresight and the collaborative process of PLM for railway signalling infrastructure can bring tangible value in improved PLM of the systems.

4.2.14 Decisions on Methods for Managing the End of the Lifecycle

As the partners have reached the conclusion that the system has indeed come to the end of the lifecycle, the decision on the way of managing it must be made. The collaborative effort of the partners can produce scenarios and options for managing the end of the lifecycle.

The emphasis can be on the side of the maintenance contractor or on the supplier, depending on the nature of the decided methods. If the chosen method is a gradual cannibalization of the existing systems, so that the system is replaced with totally new systems and the parts derived from the replaced systems are recycled as spare parts to the maintenance of the remaining systems, the maintenance contractor can be the main partner. If the decision is reached to restore the functionality of the system with a major overhaul, the more active partner is the OEM supplier.

The strategic decision whether to restore the functionality with major overhauls executed by the OEM supplier or to gradually replace the systems with a totally new systems, is the critical one, which must be made by the purchaser.

The decision on the methods for managing the end of the lifecycle has as the background many technical, commercial, budgetary and organizational issues, which the purchaser must evaluate balancing the different facets of the issue. The quality of the collaboration with the OEM supplier and the maintenance contractor is also playing a role in evaluating the methods.

4.2.15 Efforts for Ensuring the Maintainability

As the end of the lifecycle has been reached and the decisions on the methods of managing it are made, the partners can effectively and efficiently commit themselves to the tasks at hand.

The efforts for ensuring maintainability emphasize PKM. As the availability of the knowledgeable people capable of maintaining the legacy systems are in short supply, extra efforts are needed to maintain the sufficient level of knowledge as the problems are becoming more frequent i.e. the demand for knowledge increases.

Also the inventories of the spare parts need an extra effort and handicraft methods of repairing electronics and other in normal conditions exceptional methods may have to be adopted. As the scarcity of the spare parts increase, so does the cost of them, therefore the efforts ensuring the maintainability and the sufficient levels of available spare parts bring with them increased costs.

Fertile collaboration between the partners can essentially facilitate the efforts necessary for ensuring the maintainability of the system. The supplier can provide the necessary product knowledge and the supply of spare parts, if the planning of coming need does not come as a surprise, but the readiness is built in advance. The maintenance contractor is able to heighten the readiness for corrective maintenance and it can manage the extra efforts, which require additional attention, if planned in due time. The collaboration between the partners can at this stage at the end of the lifecycle bear the fruit, which has been the sown during the close collaboration during the previous phases.

4.2.16 Defining the Deadlines for the System

Extra costs and attention involved in managing the systems during the end of the lifecycle cannot efficiently be maintained in perpetual. The partners can avoid the uncertainty of the future by giving themselves clear target dates, when the systems are taken out of service.

By committing themselves to a target date, the partners make sure that the budgeting of the reinvestments has the necessary technical and administrative support and a defined deadline, which signals the real future maintainability of the systems. If due to budgetary reasons the defined deadlines of the systems cannot be kept, but the end of the lifecycle must be prolonged to an uncertain future the decision makers have been warned. If then after the passing of the deadlines the production suffers from low RAMS, and the consequences affect the business of the TOCs, the unfortunate circumstances do not come as a surprise, but rather as a realization of the more or less manageable risk taken.

The defined deadlines must be such that the budgeting, planning and executing the reinvestments can be done in due course without unnecessary haste and extra costs attached to them. A deadline is a compromise of the conflicting interests of the partners, but in the end the purchaser bears the responsibility of setting it and of the consequences, if the deadline is misplaced.

4.2.17 Managing the System alongside the Construction of the New System

The system must be still managed during the last leg of lifecycle, when the system is phased out and replaced with a new system. At this stage the system must perform its task during the time it takes to build a new system. The construction of a new system may cause various sources of disturbances to the system in use and the steps in commissioning of the new system may be a challenge as the legacy systems is stopped. The legacy systems may cease to function when once stopped and the execution of the phase out needs rigorous planning to minimize all the imaginable risks attached to it.

Collaboration between the partners requires at this stage also cooperation with the project in charge of the construction of the new system and exchanging necessary information.

Tempting as it is to recycle functional parts like substations or trackside objects of the legacy system into the new system in order to minimize initial investment costs and make commissioning easier, the practice should be done only under the close scrutiny taking into account PLM aspects. If the recycling is done excessively, the new systems may start their lifecycle as already outdated and problems typical to the end of the lifecycle are reached too soon again. A distinction between the restoring and replacing a system must be clear as decided earlier so that if the system is only put through a major overhaul and restored the expected lifecycle and the payment period for the investment is shorter than in replacing the system totally with a new system.

4.2.18 Taking the System out of Service

The last process step in the collaborative process of PLM for the railway signalling infrastructure is achieved when the system is taken out of service.

The parts of the decommissioned system may be recycled as cannibalized parts to the other systems still existing in use or the parts may even be sold to the supplier, which can utilize them in the global sourcing of aftermarket spare parts. Alternatively the recyclable spare parts may be auctioned in the flea market of the infrastructure managers, if such markets have been established.

Unrecyclable parts must be destroyed and managed according to the environmental rules regulating the disposal of the electronics waste and the OEM supplier may be used as the responsible partner in the task.

As the system is decommissioned the various lessons learnt during the process can be collected and utilized as an input in the coming and future projects.

4.2.19 Summarizing the Collaborative Process of PLM

The collaborative process of PLM for railway signalling infrastructure describes the process steps and decisions, which can be used for efficiently and effectively managing the lifecycle of the rail signalling infrastructure in collaboration between the partners. The eighteen steps starting from initial specifications for the system and ending at taking the system out of service each provide opportunities for increased collaboration and more thorough management of PLM aspects.

The process has five distinguishable phases, which are: 1) the specification and bidding, 2) the project phase, 3) the warranty period, 4) the useful life of the system and 5) the end of the lifecycle. During each phase of the process there are process steps and decisions, which can have an impact on PLM aspects of the future steps. The early phases of the process are of utmost importance and decisions made during the specification and bidding and the project phase affect the subsequent phases. By influencing the management during those early phases, the later phases i.e. the warranty period, the useful life of the system and the end of the lifecycle, can be more predictable and controllable in terms of PLM.

The successful influencing for the management of the systems under the collaborative process of PLM for railway signalling infrastructure is founded on the willing cooperation and participation of the partners in collaboration. Unless the collaboration can take place in a way, which enables the effective and efficient planning, analysing and decision making, the process cannot produce remarkable results in terms of increased RAMS.

When the partners utilize the collaborative process and the decisions are based more on PLM and the quality of service point of the view, the process can with small incremental steps improve the overall quality of service of the rail signalling infrastructure. The process can cause tangible improvements in terms of better quality of service and less infrastructure related failures and thus be a significant contributor in decreasing the amount of the signalling infrastructure related delays to the train traffic.

On the other hand, if the process can be utilized under the favourable collaboration between the partners, the attention on PLM and the subsequent improvements in RAMS of the system are possible and highly probable.

The collaborative process of PLM for railway signalling infrastructure incurs extra administrative overhead costs, but as the process takes place along with the normal procedures of management, the costs can be outweighed by the savings possible through better anticipation of the actions needed and by the minimized loss of production i.e. failure times of the systems.

In the following section the conclusions for the management are discussed.

5 CONCLUSIONS AND DISCUSSION

This section discusses the conclusions on utilizing the collaborative process of PLM for railway signalling infrastructure, the current purchasing versus Public Private Partnerships and managerial implications of the study. This section covers also limitations and applicability of the results and the future research directions.

5.1 Utilizing the Results of the Research

The findings of the research presented in the previous section are collected in two separate subsections i.e. the insights from the interactions between RHK and partners and the collaborative process of PLM for railway signalling infrastructure. How the results can be utilized is discussed below.

5.1.1 Utilizing the Insights from the Interactions between RHK and Partners

The insights from the interactions between RHK and the partners produced findings, which are compressed into the dozen performance indicators for measuring the state of PLM.

Those performance indicators can be utilized in measuring the current level of PLM very practically in one location at a time. The maintenance contractors can initiate internal checking of the state in twelve maintenance areas and RHK can launch inspections with the signalling experts of the outsourced regional managers of RHK. Depending on the collaborative relations and MSAs between RHK and the OEM suppliers, the inspections and surveys carried out by the supplier can also produce information based on those performance indicators.

When the dozen performance indicators are used in the field, they might have to be modified into more tangible and practical form in order to focus on particular aspects relevant to each location. In the general form presented in the results, they can be utilized universally at railway signalling infrastructure or even in other industries with similar infrastructure characteristics. The performance indicators are especially aimed at outsourced maintenance, but not limited only to it.

The dozen performance indicators are as such not all-encompassing tools for covering all the facets of PLM. They are rather a basic toolbox containing the most important tools, which are needed to identify the most obvious shortages in PLM, which may occur in practice in field conditions. By using them the partners can discover the accidental mismanagement and malpractice in terms of PLM and take appropriate actions to improve the situation accordingly.

When the dozen performance indicators are used and the results analyzed, the partners can critically observe their current quality of PLM and evaluate whether their current achieved level is sufficient taking into account the increasing computerization of the interlockings and further concentration of traffic control at the CTCs.

When the performance indicators reveal shortages, the partners must evaluate, whether they are tolerable or not and how the shortages are amended. The planning, financing and scheduling must be agreed upon. As any decision making must be based on a solid and thorough understanding of the current situation, the performance indicators can produce information, which enables partners to recognize the reality of the current PLM.

After the dozen performance indicators have revealed shortages and they have ultimately been fixed, they can improve the quality of service of the railway signalling infrastructure and provide tangible improvements in railway signalling maintenance management. The executed improvements can positively affect the quality of service and help the production i.e. the rail traffic to achieve higher performance levels in terms of punctuality.

5.1.2 Utilizing the Collaborative Process of PLM

The collaborative process of PLM for railway signalling infrastructure highlights the process steps, which allow ample opportunities for the mutual collaboration between the partners.

The lifecycle of the product is divided into five phases and the whole lifecycle contains 18 process steps or decisions, for which the purchaser, the maintenance contractor and the supplier can make a contribution based on their collaborative interactions. Each process step or decision includes concrete ideas, which help to concentrate on relevant issues. The issues are described in a general and not technically specific terms, but rather in a way, which concentrates on the collaborative process and the desired outputs, whereas the detailed outputs are collected in each practical application of the collaborative process.

Some of the process steps may prove to be more suitable to the collaboration and they are utilized more frequently and others are deemed secondary or otherwise less productive. The practice will show, how well each process step produces relevant and tangible results and ideas, which can concretely be executed within the projects.

The practical utilization of the process may suffer from the Not Invented Here (NIH) phenomenon, if the maintenance contractors, the suppliers and even the members of RHK purchasing organization, see the process as a threat to the smooth running of the project and something they are not given enough influence or something they are not acquainted with. The NIH phenomenon can be alleviated by communicating the planned process early and by making sure that the process is not adversely affecting to the schedules of the projects. The process requires manpower and other resources, which may become bottlenecks in thorough execution and the real available manpower for the process must be communicated and agreed by the partners.

In order to make the collaborative process of PLM easier to adopt within the projects, the marketing of the process to the partners should concentrate on the great benefits achievable by it and the easiness of executing the process.

The benefits of the collaborative process of PLM are in the process of bringing the partners more closely together in solving mutual problems and in helping the partners realize the issues, which need closer attention. The mere existence of the process signals the importance of PLM to the partners and can help in creating a culture, where PLM issues are seen as equally important as any other project management issue. The process also produces results, when the collaboration highlights problems that are subsequently solved.

RHK as the purchaser must take initiative and leadership in arranging and demanding the items covered by the process to be taken into practical execution by the projects. The utilization of the collaborative process of PLM can be made easy by scheduling and arranging the necessary forums, which are needed to produce the outputs at each process step. The process can be scheduled to the projects as agreed by the purchaser and the supplier. The maintenance contractors can prepare various issues needed in the process steps, in which it has the main responsibility.

The thorough practicing of the process requires managerial support and leadership in committing necessary resources to the execution of the process. Controlling of the process must be formalized in practical handbooks and guidelines directing the utilization of the process and documentation of the outputs. If the process exists only between the covers of this Master's thesis, its practical value remains non-existent. On the other hand, even partial practical adaption of the process can produce more PLM outputs to the projects and thus improve the current situation.

When the collaborative process of PLM for railway signalling infrastructure is utilized at the specification and bidding phase of the lifecycle, the incorporation of PLM vision and input can help the purchasing of the new interlocking to increasingly concentrate on the TCO point of view. The purchases may thus be directed to the higher quality products with more superior RAMS.

When the process is utilized at the project phase of the lifecycle, the running decisions of the project and the preparations for commissioning can better take into account the maintenance point of view.

As the process is followed during the warranty period, the partners can make sure the project is finalized in a way, which makes the useful life of the system more manageable and the experiences gained can be collected, so that the future projects may benefit from them.

The useful life of the system can be prolonged by the outputs of the process steps and the coming end of the lifecycle can be anticipated in due time. The limit of economic maintainability can then be anticipated and the end of the lifecycle can be encountered with ease.

If the process has been coherently followed during the previous phases of the lifecycle, the end of the lifecycle can be handled so that the tasks at hand are met with the foresight and preparedness. Unnecessary surprises and excessive hassles and the losses in the production can be better avoided. Also the financial planning can anticipate the budgetary needs, when the end of the lifecycle is supported by the process.

The utilization of the collaborative process of PLM for railway signalling infrastructure is aimed at facilitating the management of the systems during the whole lifecycle. When properly utilized, the outputs make the target systems better in terms quality of service and in terms of RAMS.

5.1.3 Summarizing the Utilization of the Results

The two main results of the study i.e. the insights from the interactions between RHK and partners and the collaborative process of PLM for railway signalling infrastructure are practical in nature and can be adopted to the daily business of the partners.

The results of the study can be implemented within the current organizations and without remarkable extra efforts or resources. The available manpower may restrict the thoroughness of the execution and be a bottleneck, but the process can be followed at least to some extent without any extra manpower.

The maintenance contractors, the suppliers and the regional managers of RHK can all benefit from the dozen performance indicators for measuring the state of PLM and the collaborative process of PLM in their efforts in developing the current practices.

The utilization of the results can bring with it many improvements in collaboration between the purchaser, the maintenance contractors and the suppliers and tangibly improve the maintenance management of the parties.

The utilization of the results can increase the reliability, availability, maintainability and safety (RAMS) of the systems, when corrective and predictive measures are executed after the partners – based on the tools suggested in the results – have realized the need for improvements. As the utilization of the results can increase the achieved level of RAMS, it can also be a contributor in improved quality of service of the railway signalling and the better punctuality of the train traffic for the TOCs.

5.2 Current Purchasing vs. Public Private Partnerships and PLM

As the results of the study emphasize a closer collaboration of the partners and mutual efforts bringing partners together to solve problems, the question arises, whether the Public Private Partnership (PPP) model incorporating the supply and the maintenance of the system into a single service, would be more feasible to the purpose.

The current purchasing of the signalling infrastructure is based on the organizational division of the tasks, where the infrastructure manager RHK is in charge of the purchasing of the infrastructure and maintenance for it. The signalling suppliers deliver the infrastructure and provide lifecycle services for the infrastructure, for example services under the framework of the MSA. The maintenance contractor is in charge of the first line maintenance during the lifecycle. How the current purchasing and the PPP models in vogue differ from each other in terms of PLM is briefly discussed below.

5.2.1 State of the Current Purchasing in Terms of PLM

Currently the signalling infrastructure investments are mainly conducted in parallel with the investment projects targeting the permanent way. The signalling infrastructure is renewed along with the renewal of the rails, the sleepers and the superstructure. This has been so far possible as the length of lifecycle of the relay interlockings somewhat exceeds that of the permanent way and the renewal of the permanent way must take place, when the interlockings have still plenty of useful years left.

Modern computerized electronic interlockings have significantly shorter lifecycles in comparison to relay interlockings and their renewal must take place before the permanent way is in the condition, which requires renewal. In the future the current purchasing practices must increasingly conduct investments projects affecting the signalling infrastructure only. This is a challenge for PLM and affects the way in which the renewals and replacements of the signalling infrastructure is scheduled and budgeted. The sufficient funding of the signalling infrastructure investments regardless of whether they are tied to a permanent way project or not, must be ensured.

Effective and efficient PLM of the computerized rail signalling infrastructure requires increasingly targeted renewals restoring the maintainability. Such targeted renewals are perhaps not sufficiently taken into account due to current organizational and budgetary reasons. The targeted renewals fall between two categories of major replacement investments and minor maintenance projects. They can be too small in terms of cost and scope to be managed by the investment projects, but too big to be taken care by the maintenance projects.

Planning and executing of the targeted renewals restoring the maintainability must be increasingly focused on despite the fact that the organizational and budgetary constraints may somewhat hinder their realization.

Current purchasing can emphasize TCO approach, if PLM aspects presented in the results of the study are adopted. The collaborative process of PLM for railway signalling infrastructure does not contain unfathomable objects or overly revolutionary changes in current practices, but are rather an evolution of the current practices with an increased emphasis on PLM. The organizational and budgetary practices may need some fine-tuning to cope with PLM challenges presented.

5.2.2 Societal Trend towards the Public Private Partnerships and PLM

Infrastructure investments consume remarkable amounts of societal capital. The yearly fluctuations of the funding needs and the budgetary constrains affect the possibilities of simultaneous execution of the projects even if PLM of the rail signalling infrastructure would require targeted renewals or replacements of the systems.

The societal trend in managing the infrastructure investments increasingly emphasizes PPP models, where the contract between the customer and the service provider contain tasks, which are in traditional models separated between the supplier and the maintenance contractor. In terms of PLM this means a totally new environment, where the service provider adopts total responsibility according to the contract. The illustration below describes the relations between the customer and the service provider.

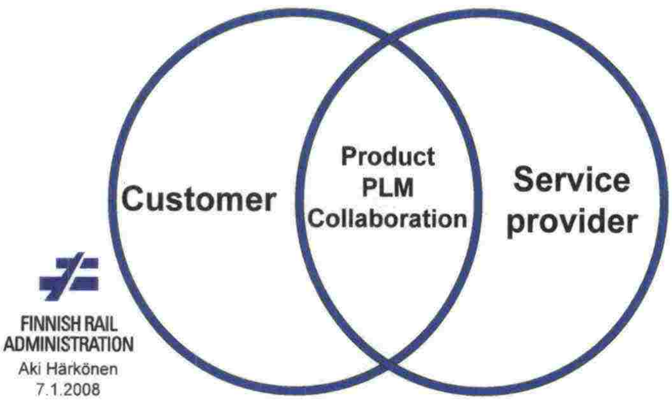

Figure 24. Collaboration for PLM between the customer and the service provider

The Figure 24 describes the PPP partners, the customer and the service provider. The responsibilities of the service provider vary according to the PPP agreement, which regulates the risk and income sharing between the partners. PPP agreements are typically much longer in duration in comparison to the traditional investment projects or maintenance agreements. They are also in Finnish referred as so called "lifecycle models". The Finnish euphemism is somewhat misleading, because PPP models are not necessary or intrinsically very PLM oriented.

Two basic variations of PPP models are the Build-Operate-Transfer (BOT) and the Build-Operate-Own (BOO), where the agreement covers a lengthy period of time, after which the infrastructure assets are either transferred to the customer or owned by the service provider. Other possible parameters defining the true nature of each PPP agreement are indefinite and the must be evaluated in detail in terms of PLM.

When used for railway signalling infrastructure BOT and BOO models can both be adjusted as feasible, but a thorough consideration must be made before the length of the service period is agreed upon. If the length of the service period is determined solely based on the main PPP project i.e. the permanent way infrastructure project, the risk sharing of the signalling infrastructure may be seriously imbalanced and results in problems at the end of PPP service period. If a BOT model is used, PPP service period should preferably continue to the very end of the lifecycle of the system. If the service period terminates when the end of the lifecycle has been reached, the service provider, i.e. the sole supplier and the holder of the intellectual property essential for PLM, can heavily cash in on the customer at the end of the lifecycle. A BOO model can be timed somewhat freer, but require detailed descriptions of the responsibilities of the partners, when the system is decommissioned and replaced.

PPP models can be a blessing or a curse in terms of PLM, but if they are thoroughly planned taking into account the ideas proposed by the collaborative process of PLM for railway signalling infrastructure among other things, they can be made feasible.

PPP models are in vogue and a societal trend. A recently published political paper i.e. the guidelines of the traffic politics and the developing and financing plan of the traffic network until the year 2020, promotes the use of PPP in the larger infrastructure projects in the range between 100 M€ and 150 M€. The double track project between

Kokkola and Yli-vieska stations in West Finland has been named as a PPP project. (MINTC 2008: 44, 52)

5.3 Managerial Implications

Practical implementation of the results requires that the dozen performance indicators for measuring the state of PLM and the collaborative process of PLM are both sufficiently and repeatedly communicated to the partners, so that they can be adopted in various organizations in Finland and abroad. Materials in Finnish language are inevitable in order to communicate the main findings of the study to the domestic partners on the field.

When accepted to the everyday business, the collaborative process of PLM for railway signalling infrastructure affects the way the signalling infrastructure projects and signalling maintenance process is managed under the current management at RHK. The process emphasizes the long term view and PLM aspects thus enabling the partners to collaborate more efficiently and effectively during the whole lifecycle of the system. The closer co-operation brings tangible benefits for maintenance management and improves quality of service of the rail signalling infrastructure, thus helping the partners to perform their tasks better and helping the customers, the TOCs and their end-customers i.e. the freight carries and train passengers to have a more punctual service.

Existing organizational structures support the use of the collaborative process of PLM for railway signalling infrastructure as such and no adjustments of the organizations are mandated by the mere utilization of the process. All organizational units within RHK having a role in the signalling infrastructure management can utilize the ideas and create opportunities so that the process can achieve its full potential.

Manpower required by the collaborative process of PLM for railway signalling infrastructure can to a significant part be attached to the current outsourced services provided by the project management and the regional management consultants. The instructions and the guidelines to be utilized in managing and controlling the process can be produced by the existing civil servants of RHK. The internal co-operation group for signalling infrastructure management at RHK should take a lead in promoting the process in future projects. With sufficient managerial support the process can be adopted to the practise.

5.4 Limitations and Applicability of the Results

The study is emic in nature i.e. it has an insider point of view to the current Finnish environment of the rail signalling infrastructure management. The study may also contain some bias and myopia regarding the role of the purchaser RHK.

Many discoveries of the research can be utilized in other organizations, where the similar industry characteristics exist; the separation of infrastructure manager and the user of the infrastructure (in this case the TOCs), 100 % outsourced third party maintenance, and the technically sophisticated oligopoly suppliers of the infrastructure.

Many individual items of the collaborative process of PLM for railway signalling infrastructure can be utilized regardless of the organizational structures and industry characteristics. The findings are not narrowly limited to the rail signalling infrastructure, but can be used in various types of industrial infrastructure equipment and in several managerial settings.

5.5 Future Research Directions

Collaboration management and PLM are crucially important themes in managing rail signalling infrastructure. Contractual relationships, which govern the collaborative relationships between the partners, would deserve further attention. PLM and the railway signalling infrastructure management provide a fertile ground for many further studies. The utilization of the PPP model for the rail signalling infrastructure, the benchmarking of PLM practices at various rail signalling infrastructure managers and the contractual models suitable for PLM for rail signalling infrastructure with or without PPP, could be further studied. Within the partners, the maintenance contractors and the signalling suppliers could further study the practicable execution of various PLM aspects in their internal processes and in their relationships with their customers. Especially varied service models for product support, which may better take into account the whole lifecycle of the systems and PLM aspects could be further researched.

6 SUMMARY

This research has studied the methods of PLM and collaboration management applicable in the relationships between the purchaser RHK and its signalling infrastructure suppliers and its signalling maintenance contractors.

As the result of the study, the insights from the interactions between RHK and the partners and the collaborative process of PLM for railway signalling infrastructure have been composed in a way, which makes their application in practical projects quite straight forward.

The dozen performance indicators for measuring the state of PLM are down to earth tools, which can be utilized in field conditions in evaluating the local level of PLM. They can be utilized in internal audits of the maintenance contractor and in inspections performed by the regional management consultants. The analysis based on the findings produced by the usage of the performance indicators, can help the partners to improve the local PLM conditions and thus contribute to the better maintenance management of the systems.

The main result of the study, the collaborative process of PLM for railway signalling infrastructure describes process steps and decisions, which are significant in contributing to PLM of the systems. The process steps highlight the collaboration required in acquiring outputs necessary for the relevant phase of the lifecycle of the system.

In order to take advantage of the results of the study, the ideas proposed must be adopted to the daily business of signalling infrastructure management within the organizations of the partners. The adaptation can take place gradually in pilot projects and when signalling maintenance and purchasing specifications are updated to be used in subsequent competitive biddings. RHK must as the purchaser take the lead in utilizing the results and it must act as the convener inviting the partners in collaborative interactions necessary for the outputs.

The results of the study are feasible in improving the level of PLM and as such can contribute to the improved quality of service of the rail signalling infrastructure. By thorough application of results to the daily business of rail signalling infrastructure management, the partners can achieve a higher standard of operations and their customers i.e. the TOCs and their end-customers can enjoy more punctual rail traffic.

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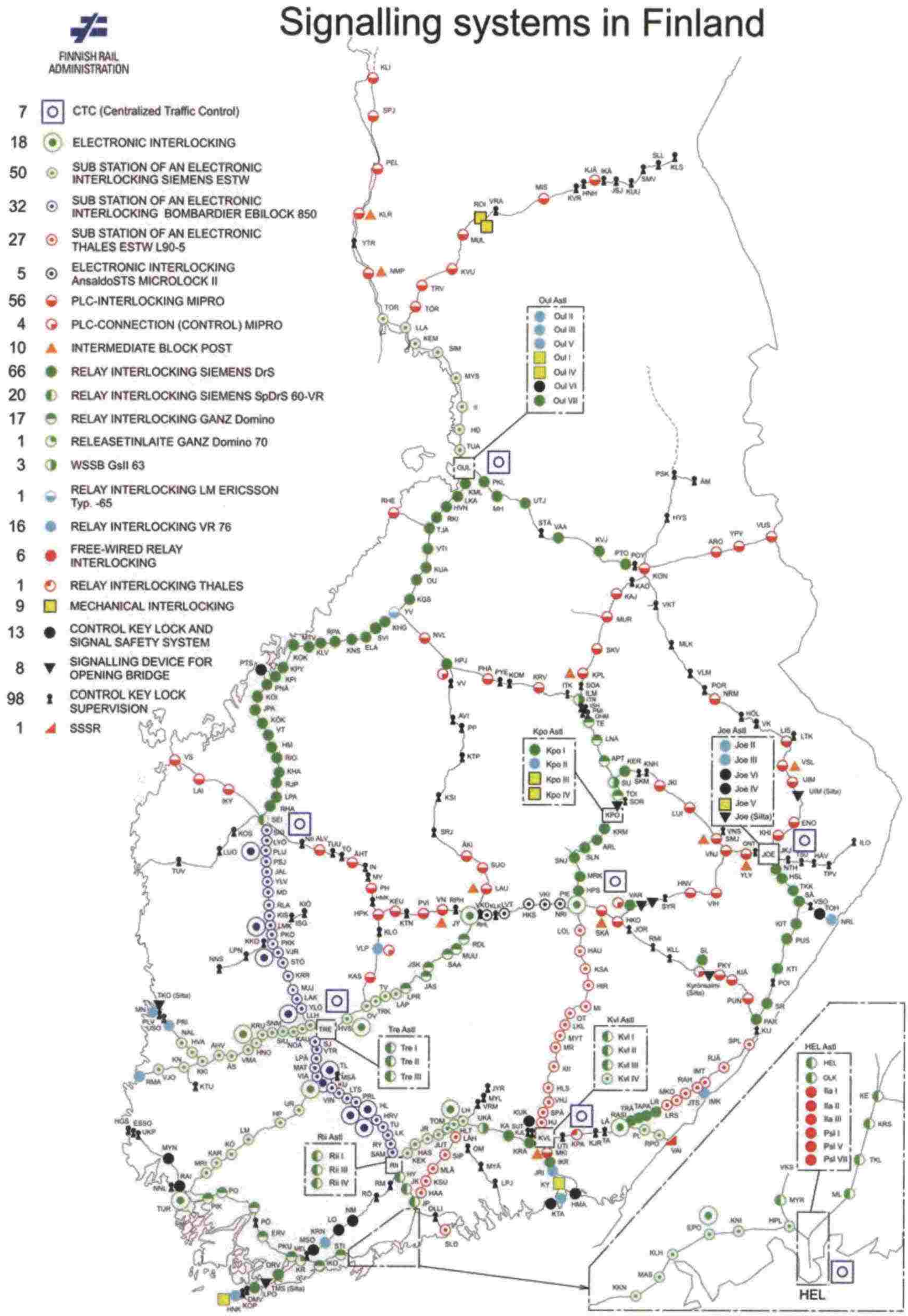
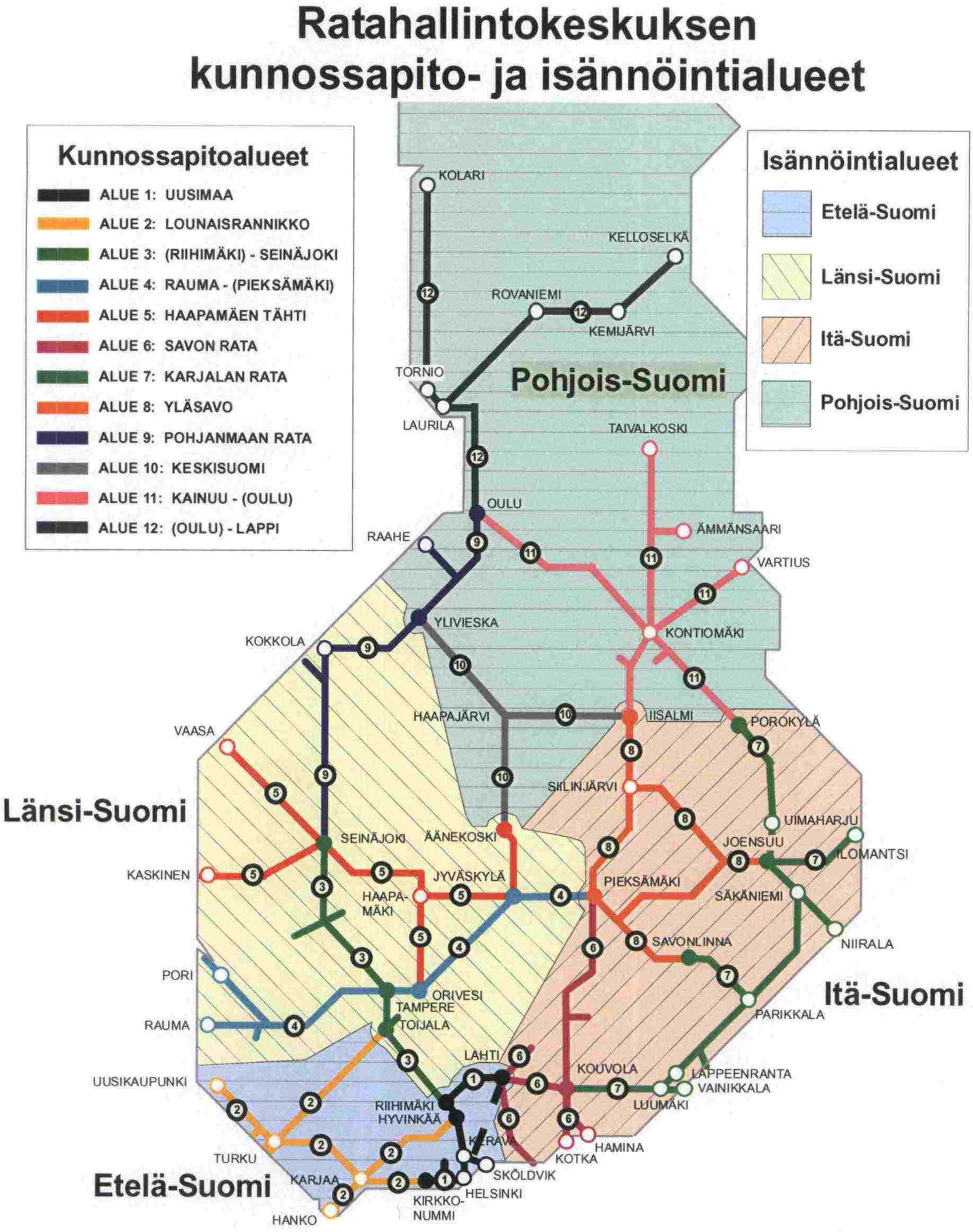
Signalling Systems in Finland

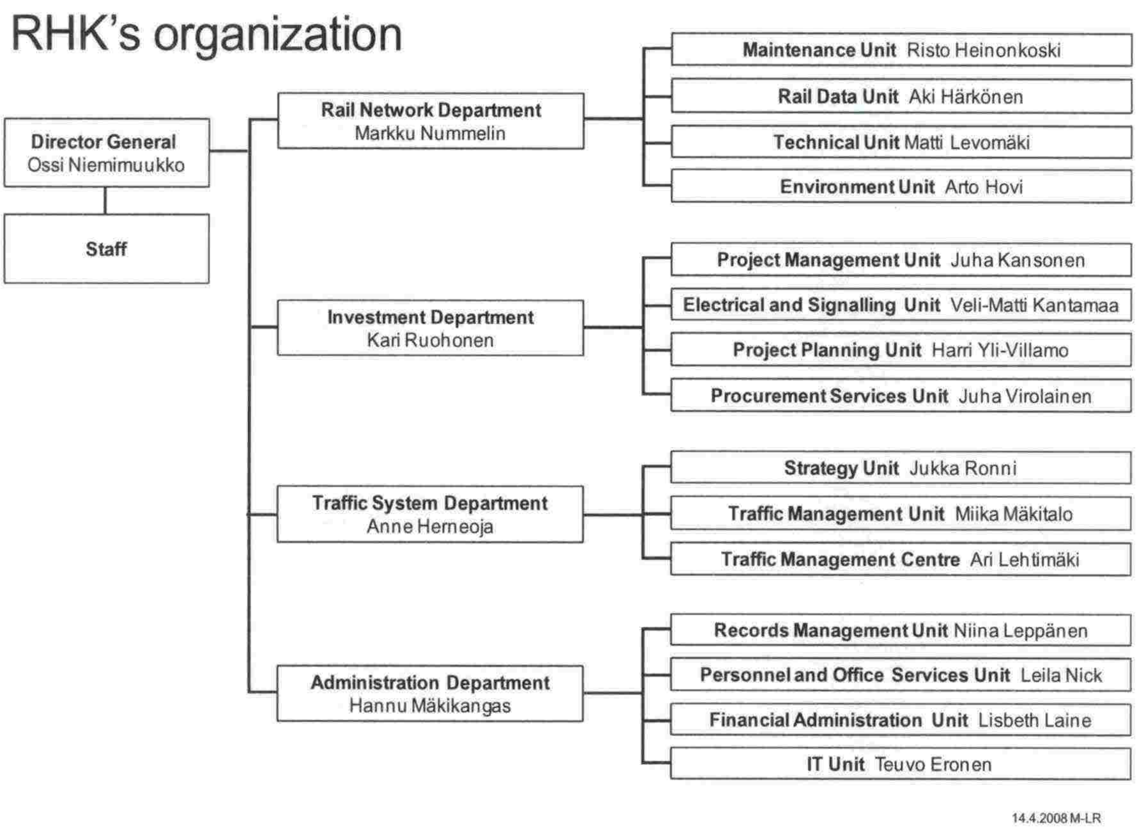


Maintenance Areas (12) and Regional Management Areas (4)



Organization of the Finnish Rail Administration (RHK)

The organization chart of RHK (dated on 14th Apr. 2008). The researcher, Mr. Aki Härkönen is the head of the Rail Data Unit and the signalling maintenance process under the Rail Network Department belongs to his responsibilities.



Material for the Semi-Structured Interviews

Form

MDPIM, MASTER'S THESIS ON PRODUCT LIFECYCLE MANAGEMENT

Time:

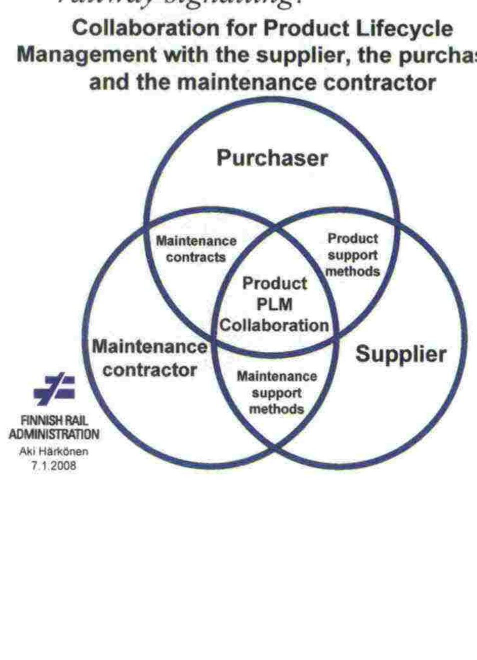
Place:

Participants:	*Aki Härkönen*	*RHK*
	NN	

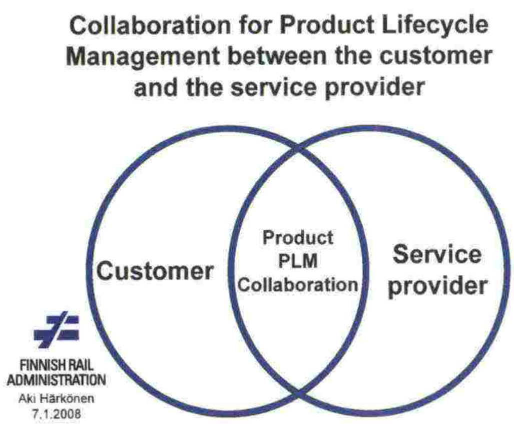
How the methods of Product Lifecycle Management (PLM) and can be applied in the collaborative relationship between the purchaser RHK and its signalling equipment suppliers and its signalling maintenance contractors?

To answer to this research problem, the following questions must be raised:

1) *What would be the practical application of collaborative process of Product Lifecycle Management (PLM), which could be utilized between RHK, its signalling suppliers and its maintenance contractors?*
2) *What methods of PLM the partners would utilize in order to achieve an optimal and continuously improvable railway signalling maintenance?*
3) *How the collaborative process of PLM could facilitate signalling maintenance management at RHK and improve the collaboration with the signalling suppliers, rail infrastructure managers and maintenance contractors and ultimately improve the quality of the service of the railway signalling?*



The focus there is existing circumstances with three main players. In the centre there are the ***products****, Product Lifecycle Management ideology practised, but not the ITC solution, but rather the* ***collaboration****, which could and should be practiced in the future.*



The future may bring new models with increasingly service based approaches. This should be discussed as well, but not as the main subject.

Below are many items, which we may choose from and concentrate to those, which have greatest potential for improvements and changes.

Current situation
Diagnostics
Product Data Management (PDM)
Document Management
Part management, installed base and spare parts
Configuration management (CM)
Product feedback management
Workflow management
Requirements and specifications management
Maintenance Management
Safety Management
Intellectual property management
Quality Management
Product Knowledge Management (PKM) and competence management
Transmission line management
Other ideas

List of Interviewees

The researcher, Mr. Aki Härkönen has between January and April 2008 conducted interview sessions with seven (7) signalling infrastructure suppliers and (2) maintenance contractors, representing the most important partners of RHK within the signalling infrastructure management. Some organizations were involved in multiple sessions.

The persons, who have contributed to the study with their input to the semi-structured interviews and other PLM related discussions during the research, are listed in alphabetical order below with some organizational information:

Albert, Roland	Funkwerk Information Technologies Malmö AB, Malmö
Arnold, Stefan	Thales Rail Signalling Solutions GmbH, Maintenance, Stuttgart
Bimer, Thomas	Bombardier Transportation Sweden AB, Stockholm
Enckell, Christoffer	Bombardier Transportation Finland Oy, Helsinki
Excell, Harry	Siemens Ltd., Espoo
Galló, János	GTKB, Baja
Graser, Klaus	Thales Rail Signalling Solutions GmbH, Maintenance, Stuttgart
Heller, Paul	Thales Rail Signalling Solutions GmbH, Maintenance, Stuttgart
Holmström, Anders	Bombardier Transportation Sweden AB, Stockholm
Ipp, Oliver	Thales Rail Signalling Solutions GmbH, Sales, Stuttgart
Jussila, Jari	Siemens Ltd., Mobility, Director of Projects, Espoo
Kadar, Zoltan	Funkwerk Information Technologies Malmö AB, Malmö
Kantamaa, Veli-Matti	RHK, Electrical and Signalling Unit, (MIRSE), Helsinki
Katajala, Matti	Mipro Ltd., Chief Software Architect, Mikkeli
Kis, Dora	Funkwerk Information Technologies Malmö AB, Malmö
Lahti, Jukka	Eltel Networks Oy, Oulu
Laine, Ari	VR-Track Ltd., Signalling Maintenance Manager, Helsinki
Lindblom, Hans	Bombardier Transportation Sweden AB, Stockholm
Luostarinen, Aki	Mipro Ltd., Maintenance, Mikkeli
Maksa, Timo	Siemens Ltd., PLM Process Executive, Espoo
Matikainen, Lassi	VR-Track Ltd., Director of Maintenance, Helsinki
Mutonen, Timo	VR-Track Ltd., West Finland, Signalling Maintenance, Helsinki
Nyberg, Rainer	Bombardier Transportation Finland Oy, Helsinki
Pencz, Rudolf	GTKB, Baja
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Roivainen, Janne	Eltel Networks Oy, Oulu
Ruohomäki, Vesa	Mipro Ltd., Maintenance, Mikkeli
Sjöbergh, Bertil	Ansaldo STS Sweden AB, Safety Manager, Stockholm,
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