

# **Integrated Maintenance and Service Logistics Concepts for Maritime Assets (MaSeLMa)**

## **Summary**

In the maritime sector, service logistics support and maintenance of systems constitute a significant fraction of the exploitation costs. This is on the one hand due to the complexity and high capital value of the assets used in this sector and on the other hand due to the highly variable and mostly severe operating conditions encountered by ships and their subsystems. Moreover, since these assets are often operated at remote locations around the world, unplanned maintenance requires significant logistic effort and hence is very costly. This reveals that an important reason for the high costs for service logistics in the maritime sector is the uncertainty in demand.

The present proposal focuses on developing innovative concepts to improve the predictability of maintenance and service logistics demand on the one hand, and developing smart concepts of service logistics optimization, supply chain coordination and cooperation on the other hand. In that way, the project aims at increasing the service logistics efficiency for these maritime assets. Research is organized in three work packages. The first WP aims to increase the predictability of maintenance (i.e. prevent failures / reduce unnecessary maintenance). WP 2 focuses on the design of service logistics plans that generate optimal maintenance actions, with a specification of resources and materials requirements. And finally WP 3 aims to improve and extend cooperation for service logistics and supply chain management within and across different companies.

It is expected that the project results enable a significant reduction of the total cost of ownership for asset owners and provide the OEMs / system integrators and service providers with opportunities for new business. At the same time, from a scientific perspective, the innovative approach to integrate the fields of maintenance, service logistics and supply chain cooperation is expected to have a large impact.

Finally, by applying an extensive valorization program, it is expected that the scientific results of this project can be applied and implemented on short term within the participating companies. For that purpose base lines studies, experimental pilot projects and case studies will be executed within the companies and a lot of effort will be put in disseminating the results.

## A. Orientation and Project Goals

### A.1 Motivation

In the maritime sector, service logistics support and maintenance of platforms and systems constitute a significant fraction of the exploitation costs. This is on the one hand due to the complexity and high capital value of the assets used in this sector and on the other hand due to the highly variable and mostly severe operating conditions encountered by ships and their subsystems. Moreover, since these assets are often operated at remote locations around the world, unplanned maintenance requires significant logistic effort and hence is very costly. For example, unscheduled maintenance on naval vessels requires visiting a foreign harbour and flying in a service team and its complete logistic support.

This problem description reveals that an important reason for the high costs for service logistics in the maritime sector is the uncertainty in demand. A second major cause is the fact that we discuss moving targets; ships sail all over the world and hence logistics organisation and costs depend on their actual position as well. Safety and security aspects in addition play a major role; as the operational conditions vary considerably in time, demand forecasting is hard and always associated with a high uncertainty. To cover this uncertainty and to guarantee the required availability level, large stocks of spare parts are currently often held (on-board stocks however are limited by space), conservative maintenance intervals are applied and additional capacity (labour) must be available. At the same time, unexpected failures that still occur, lead to down-time of systems and the associated loss of revenues, but also may endanger safety (Navy) or cause environmental risks (vessels).

The present proposal focuses on developing innovative concepts to improve the predictability of maintenance and service logistics demand. The project also includes a supply chain focus geared towards the maritime sector (navy, offshore) that complements and integrates with service logistics (e.g. bundling deliveries to ships or offshore equipment crews). In that way, the project aims at increasing the service logistics efficiency for these maritime assets, following three approaches:

1. Increase the predictability of maintenance (i.e. prevent failures / reduce unnecessary maintenance).
2. Design service logistics plans that generate optimal maintenance actions, with a specification of resources and materials requirements.
3. Improve and extend cooperation for service logistics and supply chain management

These three approaches are depicted in Figure 1 and will be described in more detail below.

In the proposed project, industrial partners will participate in three different roles. For each of these categories, improved predictability of maintenance and logistics demand yields considerable benefits:

- **Asset owners:** to reduce the operational costs and optimize the availability of assets, the asset owners may benefit directly from improved predictability of maintenance needs (Royal Netherlands Navy, Boskalis, Fugro)
- **Service providers:** logistic service providers traditionally take care of the logistic support as demanded by the asset owner / operator, while maintenance service providers act similarly in executing maintenance tasks. However, nowadays these companies can increase their added

value if they can take responsibility for larger parts of the maintenance or logistic process, e.g. based on service level agreements. Improved insight in the maintenance needs of systems in specific conditions enables them to reduce risks and increase revenues (Seacon, Seamar, Novek, Imtech, Alewijnse)

- **Original equipment manufacturers/system integrators:** many OEMs nowadays not only deliver systems, but are also involved in the service logistics during the exploitation phase (Van Laarhoven [2008]). To be able to create profitable contracts, they require insight in the maintenance needs of their systems at the specific operating conditions of their customers. Moreover, getting insight in the usage profiles and operating conditions and the resulting performance of their systems provides valuable feedback for the design process (Damen Shipyards, Thales, Imtech, Novek, Pon Cat).

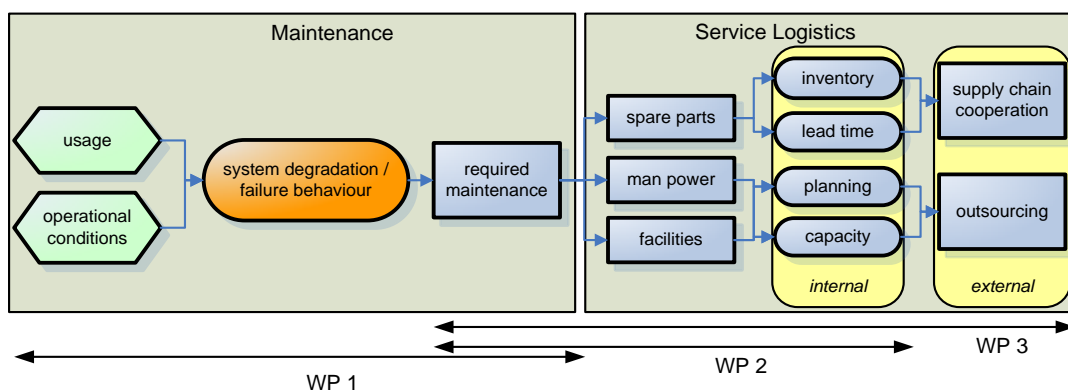


Figure 1: Relation between asset usage, required maintenance and service logistics.

The scientific research in the proposed project is organised in three work packages. Below, we briefly introduce the contents of the three work packages. The detailed description of all activities will be provided in section B. The companies involved will probably have their prime interest in one (or two) of the work packages. However, to maximize the cooperation across the WPs, they are not assigned strictly to the work packages at this stage. Only during the course of the project, and after execution of the baseline studies, the final allocation of the companies to certain WPs will be effectuated, where they attain either an active or passive / following role.

WP 1: Improve the predictability of maintenance (WP leader: Tinga)

The maintenance concepts applied in the maritime sector are generally still rather traditional, meaning that maintenance intervals are often constant in time, independent of the specific usage of the systems and the operating conditions. As a result, many systems and components are repaired or replaced before actually needed, while other components unexpectedly fail before the end of the interval. The early replacements are inefficient in terms of spare part and labour costs, hence lead to ineffective supply chains, while the unexpected failures affect the availability of the systems and may cause significant additional damage. While condition monitoring systems are in use to some extent in this sector, these systems mainly have a *diagnostic* function and still lack a *prognostic* capability. Also, the small amount of failure data (due to the relatively small numbers of similar systems in this sector and their criticality) and the large variation in operational conditions seriously limit the possibilities to predict future failure behaviour based solely on statistical data or stochastic models. This is quite different from sectors such as the chemical and high tech systems industry (the objects

of study of the ProSeLo and CAMPI projects respectively). Therefore, in this WP we aim to improve the predictability of failures (and thus maintenance) by developing models based on the (physical) failure behaviour of the systems and components. Then, by (remotely) monitoring the actual usage and operational conditions, system degradation can be predicted accurately and maintenance can be performed just-in-time. This concept is called dynamic maintenance (Tinga [2010]), referring to the dynamic assessment of the maintenance requirements. At the same time, this work will demonstrate the importance of taking innovative approaches to enable the implementation of successful CBM from an early design stage. It will be identified which data are most important to collect and based on these, which sensors and new sensing technologies need to be used or developed. We thus aim to reduce the number of unnecessary replacements and prevent unexpected failures, which improves availability and reduces both operational and supply chain costs (recall that uncertainty is one of the biggest factors boosting the costs of service supply chains).

#### WP 2: Service Logistics Planning (WP leaders: Tan, van der Heijden)

Based on a better understanding of underlying physical system degradation and wear-out, as well as on more data and information through advanced condition monitoring techniques (WP 1), the next step is to design sound service logistics plans based on improved system knowledge. A complicating key characteristic is that the Maritime sector has a strongly dispersed installed base that also may be moving in time (consider for instance frigates on missions, meaning that corrective maintenance may have to be executed at other locations than the home base in Den Helder). In this work package, we focus on the *tactical* planning level with relations to the strategic choices in the supply chain configuration. The operational scheduling of tasks as derived from these tactical choices will not be the primary focus of this work package. Furthermore, we consider a *multi-actor supply chain* perspective.

The service logistics planning consists of two main components. In the *first component*, an efficient and effective dynamic plan of maintenance actions for the next period (months, up to one year) has to be developed, proceeding from the information supplied by WP-1, such as limits on preventive maintenance actions based on condition monitoring information. The resulting plan includes a specification of required resources (such as service engineers, tools, and spare parts) for a given system. The maintenance plan covers primarily the logistics aspects, rather than the technical specifications, of decisions regarding (i) on-site or off-site repair, (ii) corrective versus preventive maintenance (time based, use based, or condition based), (iii) planning maintenance tasks in time taking into account scale effects in maintenance set-up (clustering of maintenance activities). Rules for taking advantage of opportunity-based maintenance will be included. This means that once a system is subject to maintenance, a number of maintenance actions for parts or subsystems which would have not been initiated otherwise, can also be executed. Furthermore, we will consider the impact of standby redundancy, leading to a trade-off between additional initial system costs and reduced maintenance cost during the life cycle (less urgent maintenance). Also, the replacement and repair levels of modules and components in the system's Bill-of-Material structure are relevant: if we repair a system by replacement of a module (Line Replaceable Unit), what should the appropriate LRU level be from a maintenance logistics perspective? This will also be part of the basis of the maintenance plan. The supply chain perspective will play an important role, as we will also consider the *allocation of maintenance tasks* to multiple actors in the supply chain, in coordination with WP3. We will investigate the impact of task allocation schemes on the overall supply chain performance in

order to find the best allocation. For example, which repairs should be done by the asset owner, which ones by a third party (service provider), and which ones by the OEM.

The *second component* is the effective and efficient deployment of resources to support the dynamic maintenance plan. The maintenance plan constitutes the base to be able to specify the need for spare parts, service engineers, tools, and diagnostic equipment. The question remains about the exact quantities needed as well as their locations. For example, a number of options exist for the positioning of service engineers (permanent availability on site, standby at a service provider's location, etc). Since in general distinct service providers may be needed, coordination problems are bound to occur, both with respect to capacity planning, transport of men and materials, inventory levels and pooling of spare parts. Such coordination issues are particularly hard in a multi-actor supply chain setting as considered in this project. For an excellent supply chain performance, it is of utmost importance that the various organizational units know and understand which performance they may expect from their counterparts. This will typically boil down to performance-based service contracts between collaborating parties in the supply chain. A major question is which *type* of logistic key performance indicators (KPIs) should be used in such contracts, and how optimal KPI *levels* should be set to ensure excellent supply chain performance.

In both components of this work package, the role of information exchange will play a key role. For coordination across multiple organizational units, service level agreements can only be met in an efficient way if the responsible party has access to information from other parties that is critical for its own operations. For example, field data on failure behaviour of components should be utilized to improve spare parts inventory management in the service supply chain. Nevertheless, transfer of such information is not current practice, although it would lead to significant added value. A precise definition of the information needed and its timing is important, since confidentiality issues play a role in the defence industry (e.g., it is not necessarily allowed to communicate which systems are used for which missions during which period). WP2 will develop improved service logistics methodologies that make optimal use of information generated from data, while WP3 will address the organizational and confidentiality issues to enable information sharing to the possible extent.

Furthermore, the service logistics planning has to deal with a considerable level of uncertainty due to corrective maintenance and supply chain uncertainties (e.g. resupply and repair lead times). This means that we should account for sufficient flexibility to deal with these intrinsic supply chain uncertainties. But clearly, the more we are able to reduce uncertainty (WP1), the lower the supply chain costs will be. At the tactical level, we have to specify buffers and to specify flexibility options (e.g. alternative sourcing of parts, options for rescheduling maintenance tasks) that can be used at the operational planning level. For some of these options (e.g. emergency shipments or priority repair), logistics service providers may play a key role.

The maintenance planning and resource planning as described above are not two stages in the planning process that can be considered independently of each other. For example, the consequences of a maintenance plan for the resource planning may require a modification in the maintenance plan to resolve major bottlenecks. Consequently, a joint or iterative approach will be needed instead of a sequential approach, and hence a close collaboration between all researchers and industrial partners in this work package is very important. Therefore, we combine these activities in a single work package.

WP 3: Improve and extend cooperation for service logistics and supply chain management (WP leader: Van Fenema)

Stakeholders in the maritime sector concentrated in North North-Holland have developed a vision for reorganizing and extending their value networks. Key stakeholders include:

- Asset owners with possibly an internal maintenance organization seeking to improve productivity, asset deployability, leverage their capacities, and innovation
- Service logistics facilities (e.g. harbour, airport) interested in expanding their business
- Local and regional government interested in socio-economic development of an industrial cluster
- Service providers (maintenance, logistics) looking for expanding their service offering and business, and finally
- Original equipment manufacturers/system integrators focusing on new service offerings, new/expanded markets, and downstream activities

Reorganizing the way these stakeholders create value and interrelate may seem a daunting task (Anderson et al., 2009; Lilien and Grewal, 2012). The products and services at stake are complex with high demands for quality, safety, and availability (e.g. Caldwell & Howard, 2010; Randall et al., 2010). Under the umbrella of work package 3, participating organizations will work with universities to improve and extend their cooperation in the area of service logistics and supply chain management. The package is oriented towards a number of key themes around new forms of public-private and business to business cooperation. These represent a value creation cycle:

- Interorganizational cooperation, capabilities to match interests
- Value exploration, rethinking business models and value networks
- Sourcing, reverse/inverse sourcing
- Work allocation
- Contracts, incentives
- Pricing, costing aspects of interorganizational cooperation
- Governance, monitoring
- Relationship maintenance, interorganizational innovation management

These themes concern both organizational and interorganizational level topics, and both current value creation and opportunities for value exploration. Work package 3 recognizes and elaborates on relationships between these levels. It takes on the challenge of combining organizations' primary interests (market positioning, unique knowledge, independence etc.) with opportunities for interorganizational value creation. While such interorganizational cooperation and innovation often seem a daunting task, researchers in this project will work with organizations to reframe their perspectives on intra- and interorganizational value creation. This methodological approach offers a change to materialize new forms of cooperation that have been developed in for e.g. the UK<sup>1</sup>. For instance, how can supply chain KPIs be related to organizational control, capabilities, flexibility and redesign? In this WP, we will focus, with participating organizations, on methods, drivers<sup>2</sup>, and key success/fail factors to develop and materialize new forms of cooperation.

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<sup>1</sup> For instance, Cambridge Service Alliance.

<sup>2</sup> For instance scale, risk, technical know-how, flexibility, quality requirements.

## A.2 Relation to Dinalog's innovation themes

This project is directly linked to the main theme "Service Logistics". Moreover, it fits perfectly in the specific focal area "*Developments of new service logistics concepts for different types of companies, ... in sectors such as ..., Maritime and Aviation. Relation between Service Logistics and upkeep systems (repair and maintenance, overhaul up to major modifications) including reverse logistics / reuse.*"<sup>3</sup>

## A.3 Objectives and goals

The main objective of the proposed project is to enhance benefits for both public (Navy) and private organizations by reducing the Total Cost of Ownership (TCO), improving the uptime of assets in the maritime sector, and improving sourcing of services.

To achieve this main objective, the following detail objectives have been set:

- Reduce the amount of maintenance activities on maritime assets by improving the predictability of failures, and utilizing this information to obtain more efficient maintenance plans (WP1)
- Improve the overall service supply chain performance by (WP2):
  - using the information obtained from the maintenance process (Figure 1)
  - adopting intelligent strategies for maintenance optimization, resource pooling and sharing as well as coordination across multiple actors in the service supply chain
- Create, reorganize and extend value creating networks, both within and across different companies, while simultaneously addressing public interests and policy objectives (WP3).

As the maintenance and service logistic costs constitute a major fraction of the TCO for assets in this sector, the goal of the project is to reduce the TCO for the asset owners by 5% through optimizing the maintenance and supply chain processes. At the same time, the knowledge generated within the project enables the participating OEMs, system integrators and service providers to extend existing business and create new business, both in the Netherlands and abroad. The project thus contributes to the Dinalog innovation program goal of increasing the Dutch added value (GDP) in supply chain control and logistics from € 3 billion in 2007 to over € 10 billion in 2020.

Finally, from a scientific point of view, the main objective is to make a significant step forward in integrating the fields of maintenance, supply chain coordination and interorganizational cooperation, as well as quantifying the benefits of this integration. An approach that integrates the three detail objectives mentioned above is without doubt highly innovative with long term impact.

## A.4 Expected results

### Business results

The top management of the Navy and key industry partners envision an innovative maritime cluster to which this project is inherently connected. This cluster should synergize the interests of end-users, defence, industry partners and the Northern North Holland Region.

Especially in the maritime sector, failures frequently lead to safety (failing naval systems) or environmental issues (off-shore incidents), which means that there is a strong drive to prevent

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<sup>3</sup> We refer to the call text of the 4<sup>th</sup> Dinalog R&D call. The resulting pre-proposal was admitted by Dinalog in the course of that call, but its conversion to a full proposal was delayed. Dinalog therefore decided to allow submission of the full proposal during the present 5<sup>th</sup> call.

failures. However, at the same time both shrinking government budgets (Defence) and competitive business environments call for reducing sustainment costs. Therefore, increasing the predictability of failures and thereby reducing the associated maintenance needs and logistics costs can deliver great benefits for the sector, with the ultimate goal to enhance the attractiveness of the combined facilities and companies for further maritime and off shore businesses.

Due to current budget cuts of the Ministry of Defence, the Naval Maintenance Establishment is actively seeking opportunities to turn a threat into an opportunity by striving towards a more intense cooperation with the civilian industry. On the one hand, the industry identifies business opportunities by leveraging on the existing infrastructure and positioning their (service) activities in a unique maritime geographical hotspot. While this process has started about one year ago, the Naval sector has initiated a series of events to further explore the mutual benefits of such a cooperation. At the same time, all parties realize that a high level of innovation is a must-have to differentiate from other areas. Hence, a boost is needed in

- exploiting advanced methods in the underlying maintenance, overhaul, upkeep and logistic processes.
- developing and applying methods for reorganizing and extending value networks.

The research in this project supports that need and can lead to significant economic benefits for both the Navy and the industries. To be more concrete we see the following impact:

Reduction of cost of ownership:	20%
Reduction of spare parts related costs:	30%
Increase of the service business:	80 million BNP (based on 1000 extra FTE)
Number of spin-off companies:	10 *

*\* a number of companies have already shown their explicit interest to launch service operations in the “Kop van Noord-Holland”, pending the success of this project.*

### **Project results**

The project is expected to generate the following concrete results:

- At least 3 proofs of concept, demonstrating the effectiveness of the integral approach
- At least 2 prototypes
- 2 PhD projects
- At least 15 MSc projects
- A website demonstrating results

### **A.5 Relation to government policy**

The project is linked to government policy in several ways. Firstly, the project fits very well to the innovation agenda of the top sector Logistiek, as expressed in the roadmap Service Logistics (Van Laarhoven [2008] and the Uitvoeringsagenda Topsector Logistiek [2011]). Secondly, both the aimed improvement of the service logistics sector competitiveness and the ambition to make the Netherlands leading (World Class) in maintenance are supported. This indirectly also stimulates the aimed development of the knowledge economy. Thirdly, through the participation of the Koninklijke Marine and NLDA, the project contributes to the goals of the Department of Defense to reduce the



Life Cycle Costs of Defense materiel and to increase the cooperation between the Department of Defense and the civilian industry (Hillen [2011]). Fourth, a concentrated effort on advanced methods and procedures in maintenance and service logistics may strengthen the already existing attractiveness of the region North-Holland North on foreign off-shore businesses, corresponding to one of the action lines of the Logistics Top team (attracting foreign businesses). It is noted that the local government (Board of Mayor and Aldermen of Den Helder) as well as the regional government will be closely connected to this R&D project, in particular for WP3.

## **A.6 Orientation**

The scientific impact of this project is unprecedented. Until now, the domains of reliability engineering, maintenance and service logistics have developed quite separately, leading to suboptimal maintenance and logistic support concepts. As will be discussed below for the individual work packages, a lot of research has been done in each of these fields, but the number of papers on integration of maintenance and logistics is negligible. For example, many publications on spare parts forecasting methods are available, but none of them incorporates information on the (predicted) failure times of parts under certain operational conditions.

This project is a serious and highly needed attempt to integrate the different fields. Clearly, failure modelling and reliability engineering should constitute the foundation for a sound maintenance and logistics plan, in combination with elements such as prices and technical capabilities. Based upon that, sound maintenance plans have to be developed, focusing on optimal system performance at minimal life cycle costs. The execution of these maintenance plans requires the availability of spare parts and tools needed, as well as the coordination of manpower and additional resources often belonging to different service providers in an overall logistic frame. The combination and integration of these fields presents a formidable scientific challenge. In order to overcome this challenge, we purposely create an overlap between the research questions and plan for a very intensive collaboration between the researchers as well as the industries involved in the fields mentioned above. For this purpose, while one researcher will primarily focus on the first component of WP-2 (constructing a dynamic maintenance plan with resource requirements), and another researcher will primarily focus on the second component (deployment of resources in the supply chain using service level agreements), both researchers will be working jointly on various aspects of the problem, also being jointly supervised by staff members at different institutes, aligning progress and continuously working with the rest of the involved parties by means of discussing working procedures and data, and through workshops.

The approach followed in this project will lead to the development of original, innovative and promising Life Cycle Management concepts. Apart from the scientific impact, this will also yield innovative and promising practical methods that support the continuous strive in industry to reduce the Total Costs of Ownership (TCO) of capital assets. As explained before, the maritime sector is especially suitable for this approach, but currently still applies rather traditional maintenance and service logistics concepts. The benefits of the developed methods will therefore be considerable.

At the moment, several other projects related to this project are executed. Condition-based maintenance and overall maintenance planning is also part of the Dinalog projects 'Coordinated Advanced Maintenance and Logistics Planning for the Process Industries (CAMPI)' and 'Pro-active

Service Logistics (ProSeLo)'. Further, sharing spare parts in service logistics supply chains is also one of the topics within work package 1 of the ProSeLo project, in close collaboration with a.o. Fokker Services. In contrast and addition to these projects, we note the following fundamental differences:

1. The small amount of failure data (due to the relatively small numbers of similar systems in this sector and their criticality) and the large variation in operational conditions seriously limits the possibilities to predict future failure behaviour based solely on statistical data. This is quite different from sectors such as the process industry and the high tech systems industry (as covered by the currently running projects). We aim to improve the predictability of failures (and thus maintenance) by developing models based on the (physical) failure behaviour of the systems and components, to reduce uncertainty in the service supply chain.
2. Resources other than spare parts are not included in ProSeLo; also, we consider the relation to all preventive maintenance activities, whereas ProSeLo focuses on Condition Based Maintenance using condition monitoring.
3. The setting in the current project proposal is entirely different from the process industry, with as key characteristic that we have a strongly dispersed installed base that also may be moving in time (e.g. due to missions of frigates, meaning that corrective maintenance may have to be executed at other locations than the home base in Den Helder). This aspect, together with the multi-actor setting, makes overall service logistics support a challenging task.
4. We take a *multi-actor supply chain perspective* for planning maintenance activities. Consequently, we will consider the *allocation of maintenance tasks* to multiple actors in the supply chain. We will investigate the impact of task allocation schemes on the overall supply chain performance in order to find the best allocation. For example, which repairs should be done by the asset owner, which ones by a third party (service provider), and which ones by the OEM.
5. We will explicitly address collaboration issues within the service supply chain, such as contract design, organizational issues, confidentiality, and trust between the supply chain actors.

In the following, the work planned in each of the work packages is related to the present state-of-the-art in the scientific world. It should be stressed again that the integration of the fields of maintenance, reliability engineering and logistic support is unique from a scientific point of view.

#### WP1: improved predictability of maintenance

The research in this WP focuses on improving the predictability of required maintenance for assets operated in a largely variable environment. The maintenance concepts applied in the maritime sector are generally still rather traditional, meaning that maintenance intervals are often constant in time, independent of the specific usage and the operating conditions. As a result, many systems and components are maintained too early (costly) or too late (reduced availability due to failures).

To reduce the Total Cost of Ownership (TCO) for the assets, the predictability of incipient failures must be improved to enable just-in-time maintenance. This challenge has already been recognized some decades ago and since then many researchers have been working on this topic to find solutions. However, reliability engineering and maintenance modelling, the fields where maintenance optimization traditionally is based on, mainly rely on a suitable description of the

system degradation or failure behaviour. A wide range of methods have been developed, while the majority of these methods describe the degradation mechanism by a stochastic process (Singpurwalla, 1995, van Noortwijk, 2009, Fouladirad et al., 2008, and Nicolai et al. 2009). But since these methods lack a physical basis for the numerical relation describing the degradation, they still rely on a sufficient amount of (representative) service degradation or failure data to determine the parameters in the applied mathematical relations. A limitation of the data set or a change in usage profiles thus immediately increases the uncertainty in the simulations.

Also in the field of mechanics and materials science a lot of models have been developed on the failure behaviour of materials (see e.g. Pecht & Ko, 1990, Engel, 1993 and Tinga et al., 2009). However, these models are mainly applied to design new systems or to develop better performing materials, while their application in predictive maintenance is very limited. Only quite recently a number of papers appeared on this topic (Orsagh et al., 2005, Watson et al., 2004, Tinga, 2010). The approach followed in this work package is to combine appropriate physical failure models and monitoring data of in-service assets. Together these enable the prediction of individual (sub)system residual life times and the associated optimal maintenance intervals.

While condition monitoring systems are in use to some extent in this sector, systems are mainly *diagnostic* rather than *prognostic*. This means that the P-F interval, the time interval between the detection of an imminent failure (P) and the actual failure (F) is quite limited, and planning the maintenance activities in an efficient way is difficult. By adding physical models to these condition monitoring systems, the prognostic capabilities are improved, and the P-F interval can be increased. Also, the small amount of failure data (small numbers of similar systems (*one-offs*), criticality of assets and systems) in this sector and the large variation in operational conditions seriously limit the statistical data-based prediction of failures. This is quite different from sectors such as the chemical and high tech systems industry. This is another motivation to apply physical failure models to enable predictive maintenance strategies for these assets.

## WP 2: Service Logistics Planning

Key aspects of this work package cover principles of maintenance optimization, resource pooling and sharing as well as coordination across multiple actors in the service supply chain. Since 2005, ideas of pooling and service levels, including differentiation aspects are also addressed in the research programme SLF-R by the Eindhoven University of Technology, the University of Twente, and the Erasmus University Rotterdam, in close cooperation with industry (participation of 14 Dutch companies). Also, this work package relates to the recent IOP-IPCR project "Life cycle oriented design of capital goods", a collaboration between the University of Twente, the Eindhoven University of Technology and industry (2005-2009), see below for details.

We observe that there is abundant scientific literature on subdomains related to this work package, but integration of these subdomains is only addressed in a limited subset of papers which usually combine two subdomains only. Relevant subdomains are particularly:

1. Maintenance planning for capital goods, see Jambulingam and Jardine [1986] for an application to maritime equipment.
2. Allocation of repair activities and the resources required in the service supply chains, so-called Level of Repair Analysis (LORA), see e.g. Basten et al. [2011]

3. Spare part inventory optimization in service supply chains at a tactical level, see e.g. Sherbrooke [2004] and Muckstadt [2005]
4. Resource optimization in service supply chains, such as tools for diagnosis and repair of equipment, see e.g. Vliegen [2009]
5. Dynamic priority setting for spare parts repair and supply in service supply chains, see e.g. Caggiano et al. [2006]
6. Scheduling of resources (people, tools, equipment, space) for planned maintenance at a single site, see e.g. De Boer [1998], Hurink et al. [2011]

In the scientific literature, an integrative approach has been described under the name “Integrated Logistics Support” (ILS), see Jones [2006]. Still, ILS covers a lot of topics without really integrating them. In addition, its model basis is rather limited. Other literature exists in which some integrative models have been developed. Below, we address some key areas that have been studied.

#### *Integration of maintenance planning and spare part supply*

Typically, maintenance actions (e.g. replacement and repair) and the necessary service logistics for maintenance (e.g. spare parts provisioning) have been studied in isolation in the related literature, as stated in Armstrong and Atkins, 1996, and Elwany and Gebraeel, 2008. In particular, there are numerous works in the literature that focus on developing models for optimal equipment replacement (e.g. Pascual and Ortega, 2006, Liu and Huang 2010, and Elwany et al., 2011) and optimal spare parts provisioning policies (e.g. Kranenburg and Van Houtum, 2009, Reijnen et al., 2009, Van Kooten and Tan, 2009, Topan et al., 2010, Huiskonen, 2001, Aronis et al., 2005, and Sahba and Balcioglu, 2011). However, very few consider the impact of each decision on the other, and only for specific systems (e.g. De Smidt-Destombes et al., 2009, and Wang, 2010). We plan to study the joint optimization, which will result in direct improvement on maintenance costs, system availability, energy consumption, environmental impact, and operators’ safety.

#### *Integration of Level of Repair Analysis and spare parts inventory optimization at a tactical level*

This topic has been first addressed by Alfredsson (1997) for single indenture, two-echelon models. In more detail this research has been part of the recent IOP-IPCR project “Life cycle oriented design of capital goods”. Several models have been developed and applied in a case study at Thales Netherlands, a manufacturer of naval sensors and naval command and control systems, see Basten et al. [2012]. This research addresses multi-echelon, multi-indenture models, but considers a central planning perspective, not taking into account the multi-actor characteristic of many service supply chains.

#### *Integration of service tools and spare parts planning*

Multiple resources are needed to perform maintenance, but most literature deals with single resource planning. Vliegen (2009) considers the integral planning of spare parts and service tools needed for corrective maintenance in single location and multi-location models. The availability of service engineers is left out of the research scope. The models are applied in a case study at ASML.

#### *Integration of capacity and materials planning*

A framework for integrative planning in a manufacturing environment has been proposed by Zijm (2000), based on extensive industrial experience. Within the framework, a number of integrative models are proposed. However, the inherent uncertainty associated with corrective maintenance is

not dealt with, while also opportunity based maintenance and coordination across multiple suppliers is not captured.

In general, we observe that integration efforts over resources and parts coupled to demand arising from maintenance plans is still very limited. Many models focus on service supply chains for corrective maintenance, which is an important issue since unexpected downtime costs may be huge. Still, much coordination is possible under preventive and opportunistic maintenance, which is ignored in most models.

Furthermore, most literature contributions ignore the *multi-actor perspective* of service supply chains, and limit a planning approach to the part of a supply chain managed by a single actor, where the processes of other actors are typically modeled as black boxes. For example, the repair, transportation, and resupply processes in spare part inventory systems are modeled by means of planned lead times within which the processes should be completed. Optimal setting of service levels between actors is seldom discussed. Van der Heijden et al. [2012] analyze a model for spare part inventory allocation in multi-indenture, multi-echelon spare part networks, taking into account several options for service levels, specified as guaranteed repair and transport throughput times with costs related to the service levels. In fact, the authors still have a single actor perspective, but choose optimal service levels for activities that may be outsourced. For example, they use standard repair throughput times, but may choose for fast repair at additional costs. The model is applied to a case at Thales Netherlands. Obviously, much more can be done on setting service levels in multi-actor supply chains.

**WP 3: Improve and extend cooperation for service logistics and supply chain management**

WP3 builds on organizational and interorganizational level challenges and opportunities. Organizations are challenged to reframe their business-to-business relationships in pursuit of win-win configurations (Anderson et al., 2009; Lilien and Grewal, 2012). Complex services are conceptualized separately from their value creating processes and the way these are organized (e.g. Caldwell & Howard, 2010; Randall et al., 2010). Interorganizational cooperation is dynamically approached. A Finnish value management method is used based on business-to-business relationships, see Figure 2.

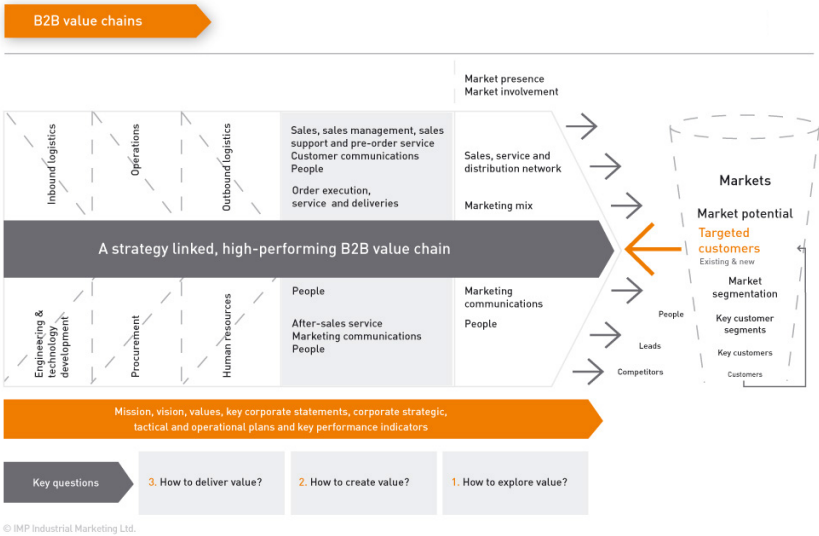


Figure 2: Business-to-business value chains (<http://www.teollinenmarkkinointi.fi/en/imp-services/value-chains>).

This model can be applied to the stakeholders mentioned and their relationships. WP3 encourages them to rethink their (brokering) roles in value chains. For instance:

- Asset owners may become to some extent suppliers of services
- Service logistics facilities may rethink their role in regional, national and international infrastructures and value chains
- Local and regional government may take on new brokering roles to enhance value creation
- Maintenance and logistics service providers may offer new services, responding to sourcing decisions from for instance asset owners
- Original equipment manufacturers/system integrators may supply new services, responding to sourcing decisions from for instance asset owners

Three key questions drive the reorganization and extension of interorganizational cooperation; they concern both organizational and interorganizational level value creation<sup>4</sup>:

Key question <b>1 exploration</b>	<p><b>(Inter) organizational value exploration:</b> How to identify new value opportunities?</p> <ul style="list-style-type: none"> <li>▪ Market segmentation of industrial products, target customer selection and sourcing, understanding and using market information, industry foresight</li> <li>▪ Industrial businesses as customers, market research/market studies, competitor analysis, customer satisfaction, strategic marketing planning</li> </ul>
Key question <b>2 creation</b>	<p><b>(Inter) organizational value creation:</b> How to create value in an efficient way?</p> <ul style="list-style-type: none"> <li>▪ Product management, new product and services development and launch, flexible market offering, value based pricing, service bundling</li> <li>▪ Translate products and capacities into services</li> <li>▪ Managing market offering, distribution, sales channel support and management</li> </ul>
Key question <b>3 delivery</b>	<p><b>(Inter) organizational value delivery:</b> How to gain and deliver value through effective management of company infrastructure?</p> <ul style="list-style-type: none"> <li>▪ Customer relationship management, key account management</li> <li>▪ Marketing and sales channel development and management, distribution channel cooperation</li> <li>▪ Interorganizational cooperation, communication, ICT</li> </ul>

While this approach fits business-to-business markets, an extended model is required to cater for:

- the mix of public and private stakeholders participating in this project, and
- the complexity of products and services at stake (Caldwell et al 2010).

Including research on public-private research and interorganizational services, two perspectives are added to the Finnish model:

- Focus 1 Bridging the Public and Private Divide
  - o Bridging differences
  - o Identifying constraints, boundary conditions, legal frameworks
  - o Fostering mutual understanding
  - o Exploring overlapping interests and opportunities
  - o Identify pilot projects
  - o Governance for public-private cooperation (Klijn and Koppenjan, 2012)
  - o Criteria for choosing governance forms
- Focus 2 (based on the Finnish model) Win-Win: Value Networks

<sup>4</sup> Source: <http://www.teollinenmarkkinointi.fi/en/imp-services/value-chains>

- Translate organizational units and processes into capabilities
  - Translate capabilities into services
  - Market services
  - Deliver on service promises
- Focus 3 Relationships and Performance: Public-Private and Business-to-Business
- Benchmarking similar cooperation forms
  - Interorganizational governance in action, orchestration (Busquets, 2010; Constantine and Lockwood, 1993; Dhanaraj and Parkhe 2006)
  - Capabilities and skills to cooperate across organizational boundaries
  - Monitoring, tension management, adapting relationships
  - Phase-based management
  - Managing workflow dependencies
  - Involving multiple organization levels
  - Sharing knowledge and information within bounds
  - Interorganizational asset management, capacities, responsibilities
  - Manage results, performance indicators, service levels

In short, research for work package 3 will be structured according to these 3 focal perspectives and it will stress a dynamic perspective on reorganizing and expanding interorganizational value creation.

## **B. Activities and Work Packages**

### **WP1: Improved predictability of maintenance**

- WP-leader: prof. dr. ir. Tiedo Tinga, Netherlands Defence Academy
- Leading companies: Navy, Thales Customer Services and support
- Other strongly involved partners: Damen Shipyards, Imtech Marine, Boskalis, Fugro, Pon Power, University of Twente
- Involved full-time researchers: 1 PhD student for 3 years and 1 PhD student for 1 year (to be appointed at Netherlands Defence Academy)
- Number of master thesis projects: 4

### **Approach**

In this WP we aim to improve the predictability of required maintenance by developing a framework based on the (physical) failure behaviour of the systems. By (remotely) monitoring the actual usage and operational conditions, system degradation can be predicted accurately for a specific asset or for a fleet of similar assets and the optimal (just-in-time) maintenance intervals can be determined. The development of such a framework will face several challenges.

Firstly, the complex assets in the maritime sector are built from a large variety of individual (sub)systems that each contain significant numbers of parts or components. The physical failures will occur in a specific part, but modelling all parts of an asset is infeasible. Therefore, a suitable method is required to decide which (critical) parts and (sub)systems must be modelled to obtain the failure behaviour that is representative for the complete asset. Also the interaction and dependabilities of individual systems that together govern the asset reliability must be determined.

Secondly, although selection of only the critical systems reduces the effort, still an infinite number of possible failure modes exist across all maritime assets, since nearly all individual assets are different.

On the other hand, the set of possible failure mechanisms on the material level (e.g. fatigue, wear, corrosion) is quite limited and quantitative life assessment models are generally available in the literature. The challenge is therefore to apply these models to specific (sub)systems or components and to calculate the loads that are generated by the specific usage and operational conditions of the system. Several physics-based failure models for specific systems have been developed (Pecht & Ko, 1990, Engel, 1993 and Tinga et al., 2009), but their applicability is limited to the system considered and the development of the models generally requires a considerable effort. Therefore, in this WP a library of generic failure models will be developed for a range of widely applied subsystems or components, like bearings, gear sets, pumps, rotating machinery (e.g. gas turbines, generators) and corroding structural elements. By only specifying a limited number of parameters, the failure behaviour can then be predicted relatively accurately without the need to develop a sophisticated physical model.

Thirdly, prediction of future failures requires an accurate assessment of the present condition and a prognosis for the degradation of the system in the (near) future. This means that, in addition to the development of physical models, the usage of the system as well as the operational conditions must be monitored. Data on usage (operating hours, start/stops, rotational speeds) or loads (stress, strain, temperature, salinity of environment) will be used as input for the failure models and thus yield the failure prognosis. At the same time, condition monitoring data can be utilized to validate the calculated degradation and improve both the failure models and the accuracy of the predictions. A decision methodology will be developed to determine which quantities must be monitored, at which location and at which frequency.

Fourthly, once the degradation and failure due to various mechanisms can be predicted for a given usage profile, the maintenance policy for the systems or components must be determined. Criteria like maintenance costs, failure costs (both repair and production loss) and criticality in terms of availability, safety and environment must be considered integrally. A first approach to cope with this challenge is already available (Tinga & Janssen, 2013). In this project a simulation based optimization methodology will be developed that can be integrated in the framework. Using these results, in WP2 the maintenance and service logistics on the level of the complete asset will be optimized. to determine the optimal maintenance intervals.

Finally the developed framework will be applied to a number of case studies. Typical assets from the maritime sector will be selected to demonstrate the applicability of the general framework developed.

In summary, a framework for physical model-based dynamic maintenance will be developed, extending a previously proposed concept (Tinga, 2010). The complete framework will consist of the following constituents:

- a decision method to determine which (sub)systems or components are critical to the asset performance and maintenance costs
- a library of generic failure models for a range of widely applied subsystems and components
- a decision method to determine which quantities must be monitored
- a methodology to determine the best maintenance policy (e.g. corrective, time-based, etc.) and to determine the optimal maintenance interval on the component level



The developed methodology will provide the input for the maintenance and service logistics optimization on the asset level performed in WP 2. The complete framework (WP 1 + WP2) will enable both asset owners and service providers to optimize the maintenance process on the (fleet of) assets.

At the same time, this WP will demonstrate the relevance of knowledge on the relation between usage and asset degradation for the design phase, which is a very relevant benefit for the Original Equipment Manufacturers (OEMs). On the one hand the need of implementing CBM from an early design stage, by identifying which data must be collected and which sensors/sensing technologies need to be used/developed, will be demonstrated. On the other hand the insight in the relation between usage and degradation / failures will be shown to contribute to the improvement of the design process. The feedback from the exploitation phase provides useful input for a redesign of the asset.

**Tasks:**

- T1.1 Perform baseline studies at participating companies (M6)
- T1.2 Perform a literature study and write a PhD research proposal (M12)
- T1.3 Write three academic research papers (M24, M30, M36)
- T1.4 Several MSc thesis projects (MSc ME) in close cooperation with the consortium partners
- T1.5 Decision methods to identify critical components and loads / usage / condition parameters (M12)
- T1.6 Development of a library of predictive models for a range of standard components (M18)
- T1.7 Development of a model / method to optimize maintenance intervals on the component level, based on specified usage profiles (M24)
- T1.8 Integration of all developed building blocks into a framework for service logistics optimization of maritime assets (M36)

**Deliverables:**

- D1.1 Reports on the baseline and system requirements
- D1.2 Three research papers
- D1.3 Several MSc theses
- D1.4 Decision methods to identify critical components and loads / usage / condition parameters
- D1.5 Library of physical models
- D1.6 Model / method to optimize maintenance intervals on the asset level
- D1.7 Framework for service logistics optimization of maritime assets, validated on case studies

**WP 2: Service Logistics Planning**

- WP-leaders: dr. Tarkan Tan, Eindhoven University of Technology / dr. Matthieu van der Heijden, University of Twente
- Leading companies: Navy, Thales Customer Services and Support
- Other strongly involved partners: Imtech Marine, Damen Shipyards, Novek,
- Involved full-time researchers: 2 PostDocs for 3 years (one at Eindhoven University of Technology, one at University of Twente)
- Number of master thesis projects: 8

## Approach

The output of WP1 is an essential input to WP2. But since those work packages will be executed in parallel, we will consider a modular approach and start building our methodology by assuming that the criticalities, physical failure models, and data and information that reflect the condition of relevant (sub)systems are readily available through advanced condition monitoring techniques. Since the analysis will be parametric, the results of WP1 will be integrated to WP2 as they become available, without hindering the progress of WP2. The same applies for the two components of WP2 that will be considered in parallel and in close cooperation between the researchers involved. Similarly, WP3 findings will be actively incorporated in WP2, as the collaboration possibilities between the supply chain actors have direct impact on service logistics planning through data availability, task allocation options, etc.

Proceeding from a better understanding of system degradation and wear-out (WP 1), the service logistics plans that we will develop will translate into the planning and scheduling of dynamic maintenance actions, and the specification of the resources (such as service engineers, tools, and spare parts) required for that. Obviously, a clear system configuration database is a prerequisite here. The design phase includes first of all the choice of maintenance procedures where we clearly distinguish between corrective and preventive maintenance. In case of the former, the decision as to repair on site or replace must be made, based on physical system properties and available information. In case of the latter, choices exist regarding time-based or use-based maintenance scheduling, or maintenance schedules based on advanced condition assessment. Considering the characteristics of the maritime sector, i.e. high costs of corrective maintenance and high costs as well as high impact of stand-stills (including safety issues), it is evident that the maintenance activities need to be coordinated. Once a system is subject to maintenance, a number of preventive maintenance actions for other parts or subsystems can also be executed, which would have not been initiated otherwise. This will decrease the likelihood of failure and hence another unplanned visit, saving from all costs and risks associated with it. Similarly, in a period where an (often, large) number of inspection and maintenance tasks have to be planned, also corrective maintenance or repair activities which did not necessarily have to be performed when the failure occurred may be scheduled. Such opportunity-based maintenance based on system configuration will play an important role in efficient service logistics planning.

In case of repair by replacement, the decision is often dependent on the indenture level (i.e. the level in the product configuration), which is determined by defining line replaceable units (LRUs). The service logistics plan should specify the need for spare parts, but also at a system level one may reduce the risk of a stand-still by investing in redundant subsystems (cold and warm stand-by subsystems). More generally, the criticality of each subsystem or part should be assessed as an input of some of the decisions specified above. Finally, the price, the technical capabilities, and the supply characteristics of a subsystem or part may be input to the decision whether to treat it as a consumable or repairable, again having a clear impact on the need for inventories of these subsystems or parts.

In parallel, we examine in the second component of this work package the supply of spare parts and resources (service engineers, tools and diagnostic equipment) in the service supply chain. Hereby, we initially take a maintenance plan for a complete installation as given to develop first decision support methods. In a later stage of the project, we integrate maintenance planning and supply of parts and

resources. A complexity arises from the fact that the demand for these parts and resources is uncertain. The very nature of the project (condition monitoring, followed by maintenance planning) induces that the majority of tasks during a planned maintenance period are preventive maintenance tasks, together with planned modifications or even a complete overhaul. Corrective maintenance, on the other hand, is by definition not planned in advance, although it may lead to the execution of additional inspection or maintenance tasks which are combined once a system has to be recovered anyhow. Another characteristic of corrective maintenance or repair tasks is that both their duration and resource needs are generally unpredictable, in particular when the cause of the failure is still unknown. Regarding materials requirements, preventive and corrective maintenance show different characteristics. Preventive maintenance is scheduled in advance, and generally the timely availability of parts needed to replace degraded parts can be scheduled as well. Unexpected failures leading to parts needs are a different matter. The availability of spare parts to replace failed parts has been studied extensively, see e.g. Sherbrooke (2004) or Muckstadt (2005). There may be choices on the location and number of spare parts available, leading to the study of multi-echelon spare parts systems. Depending on whether several service providers hold similar parts, pooling of parts may be an option. The same pooling option obviously is attractive in case of different installations requiring the same parts. In short, there exist many opportunities to reduce the capital invested in spare parts considerably by sharing inventories for distinct customers, as well as by pooling across different logistics service providers. In general, the challenge is to include sufficient flexibility options in the supply chain planning in order to facilitate SLA fulfilment at an operational level under significant levels of uncertainty due to corrective maintenance as well as uncertain (repair and resupply) throughput times. Such flexibility options may include alternative sourcing (lateral transshipments, emergency shipments, emergency repair), buffers (spare part safety stocks and/or capacity buffers) and priority setting in resource allocation. A logistic service provider may play an important role in the implementation of these flexibility options.

When it comes to actual maintenance planning, coordination of various service providers is even more important. Typically, installation shutdowns should be limited in time hence a careful preparation of all inspection, maintenance and possibly upgrading tasks is important. This holds even more when a number of independent technical and logistic companies are involved. Hence, a sound project plan has to be designed in case of planned maintenance, taking into account both capacity and spatial limitations. An example is the availability of a ship's dock that has to be ensured, hence careful planning across various service companies is of key importance. Typically, each service company will be involved in several projects at distinct sites, hence a new project should also fit the resource availability (service engineers, tools, etc.), given the interaction with other projects.

As mentioned before, we primarily focus on the tactical planning level in this project. Consequently, important issues are dimensioning and allocation of spare parts inventories and resources over the supply chain, based on (non-stationary) demand arising from the maintenance plans. A key factor to make this work in a multi-actor supply chain is the specification and setting of mutual Service Level Agreements (SLAs). At the same time pooling of parts and resources is a relevant issue to enhance efficiency under demand uncertainty. There is no doubt that the pooling of both spare parts and subsystems as well as tools and equipment may significantly reduce the costs involved for all players. That is the ultimate goal of the *maritime campus* for which plans have been drawn in the Den Helder region.

In the table below, we give a preliminary schedule of activities per year. The schedule is more precise for the first year than for the next years, since the precise activities in the years 2-4 will depend upon the research findings in the preceding years.

<p><b>Tasks:</b></p> <p>T2.1 Perform baseline studies at participating companies (M6)</p> <p>T2.2 Perform a literature study (M12)</p> <p>T2.3 Write six academic research papers on identified research questions (M12, M18, M24, M30, M36, M36)</p> <p>T2.4 Conduct eight MSc thesis projects (MSc in Industrial Engineering and Management) in close cooperation with the consortium partners</p> <p>T2.5 Develop decision support models, methods, and prototype tools to construct a dynamic maintenance plan for a subsystem (based on the input from WP1) (M18)</p> <p>T2.6 Develop a method to specify spare parts (LRU definition; repairable vs consumable classification) and their (stochastic) demand patterns, and the resource requirements proceeding from the dynamic maintenance plan (M18)</p> <p>T2.7 Develop models, methods, and prototype tools for deployment of spare parts and resources as specified in the dynamic maintenance plan (T2.4) given the capacities as specified in the resource and spare part plan (T2.6) (M30)</p> <p>T2.8 Develop models, methods, and prototype tools to analyze the impact of service level agreements between actors in the supply chain on the overall service supply efficiency and effectiveness.</p> <p>T2.9 Integrate building blocks into a framework for service logistics optimization of maritime assets (M36)</p>
<p><b>Deliverables:</b></p> <p>D2.1 Reports on the baseline and system requirements</p> <p>D2.2 Six research papers</p> <p>D2.3 Eight MSc theses</p> <p>D2.4 Methods and tools for constructing dynamic maintenance plans and specifying the related spare parts and resource requirements</p> <p>D2.5 Methods and tools for constructing a dynamic plan for deployment of spare part quantities, resources and the impact of service level agreements between actors on the overall service supply chain performance</p> <p>D2.6 Framework for service logistics optimization of maritime assets, validated on case studies</p>

**WP 3: Improve and extend cooperation for service logistics and supply chain management**

- WP-leader: Prof. dr. Paul C. van Fenema, Netherlands Defence Academy
- Leading companies: Navy, Thales Customer Services and Support, Damen Shipyards, Imtech
- Other strongly involved partners: Boskalis, Fugro, Seacon, Seamar
- Involved full-time PhD researcher: 1 Navy officer
- Number of master thesis projects: 4

## Approach

The objective of WP3 is to reorganize and extend value creating networks (including organizational level innovations) in the maritime sector involving public and private stakeholders. These action-oriented objectives translate into the need for a method. WP3's approach consists of developing (designing), testing, and evaluating a method for reorganizing and extending value creating networks, including participating organizations. Method development draws on design theory (Figure 3). The design process shown in the middle of Figure 3 draws on inputs from:

- the environment, i.e. participants, infrastructure earlier mentioned
- knowledge bases, i.e. the 3 focus perspectives
  - o Focus 1 Bridging the Public and Private Divide
  - o Focus 2 (based on the Finnish model) Win-Win: Value Networks
  - o Focus 3 Relationships and Performance: Public-Private and Business-to-Business

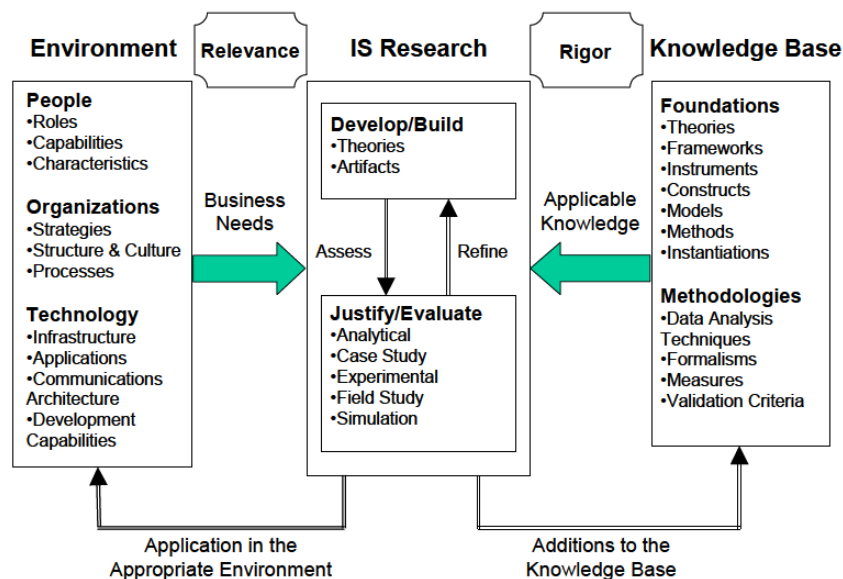


Figure 3 Design Science Research (Hevner et al., 2004).

The method will be designed, implemented and evaluated, allowing participating organizations to make progress in the sense of:

- Understanding the current situation of value networks and interorganizational relationships
- Envisioning opportunities for future value creation, while acknowledging boundary conditions (such as public-private topics)
- Developing feasible new cooperation models, contracts and organizational capabilities for materializing value creation opportunities.

A co-development, iterative approach is adopted, meaning that the method is interactively developed in cooperation with project participants. In terms of evaluation, requirements for the method include: understandable, relevant, and implementable. In short, does the method enable achievement of the WP research objectives?

**Tasks:**

- T3.1 Perform baseline studies at participating companies (M6)
- T3.2 Perform a literature study and write a PhD research proposal (M12)
- T3.3 Prepare and conduct empirical research at WP3 consortium organizations
- T3.4 Write three academic research papers, participate in academic conferences (M24, M32, M40)
- T3.5 Coaching 4 MSc thesis projects (MSc) in close cooperation with PhD candidate and WP3 consortium partners
- T3.6 Develop, implement ('proeftuin'), and evaluate a method for interorganizational value creation (M36)
- T3.7 Analyze empirical results for PhD thesis and academic papers
- T3.8 Contribute to valorization

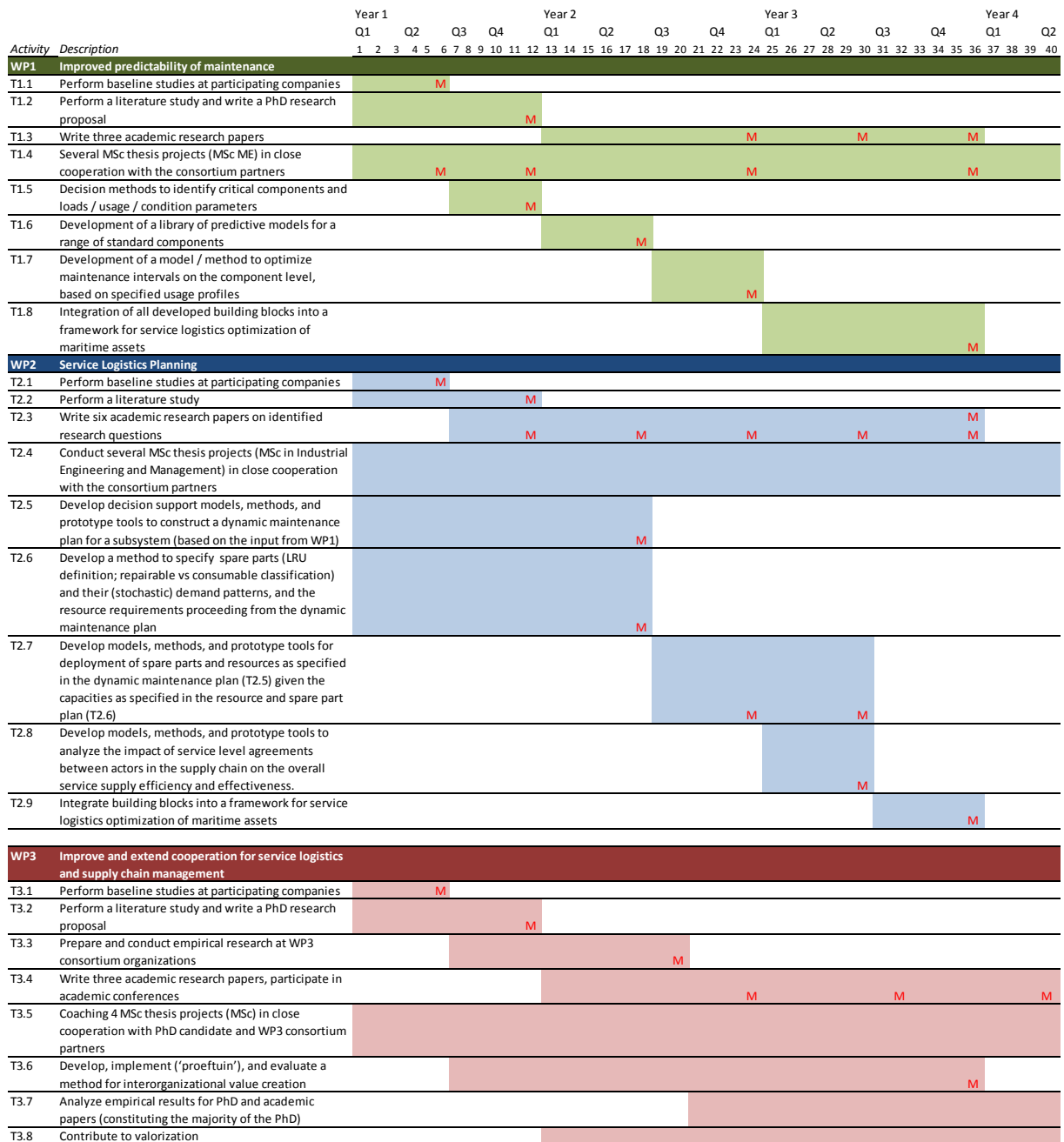
**Deliverables:**

- D3.1 Reports of the baseline studies
- D3.2 Three research papers
- D3.3 Four MSc theses
- D3.4 Method for interorganizational value creation
- D3.5 Inputs for valorization

## Planning

The planning of the project is visualized in the figure below. For each WP the individual tasks are displayed. The M symbols represent the milestones / deliverables, which have also been indicated in the lists of tasks in the previous section (M12 indicates a milestone in month 12).

Note that most of the activities in the planning have ended in month 36, while the end of the project is foreseen in month 40. This time buffer is included to cope with any delays, e.g. due to late hiring of the researchers.



## C. Consortium and Project Organization

### C1. Research Team

Partner's name	Role and input	Specific competence
Eindhoven University of Technology	Steering Group, supervisor of PhD student, WP2 co-leader	Expertise on quantitative modeling and analysis of service logistics and maintenance planning, in particular for capital goods (WP2)
University of Twente	Steering Group, supervisor of PhD student, WP2 co-leader	Expertise in quantitative modeling and analysis of service supply chains and maintenance planning, based on (stochastic) operational research approaches and simulation
Netherlands Defence Academy	Steering Group, WP1 leader, WP3 leader, supervisor of PhD student, Navy officer / researcher	Research expertise on condition based maintenance, physics of failure, monitoring (WP1), and logistics management, interorganizational value creation, cooperation, pricing, costing (WP3)
Gordian Logistic Experts	Steering Group, project leader, leader valorization activities	Matchmaker between practice and science in the field of maintenance and service logistics

CVs of all researchers, including key publications and project experience, are available in Appendix A

### Experience and role of other consortium partners

Partner's name	Role	Specific competence
Royal Netherlands Navy	Asset owner	Maritime military operations all over the world and the maintenance of their assets
Damen	OEM, service integrator	Broad range of ships, certainly including those of all participating asset owners
Thales	OEM, service integrator	All systems making a ship a battle ship (radars, sensors, etc.)

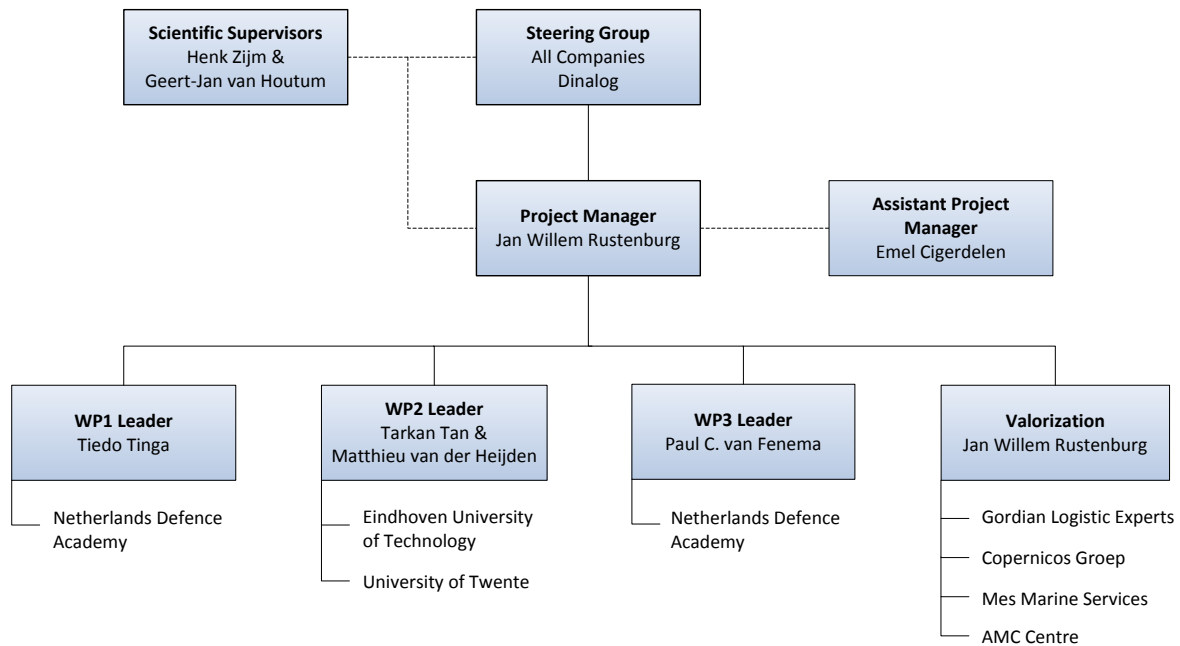


Imtech	System integrator	Tailor-made, innovative solutions in the field of energy & drive systems, platform automation, integrated bridge systems, electrical installation and Heating, Ventilation and Air Conditioning (HVAC).
Novek	System integrator, service provider	Technical services provider in the field of engines, transmissions, cooling systems and special structures
Boskalis	Asset owner	Leading global maritime services company operating in the dredging, offshore energy and inland infra
Fugro	Asset owner	collecting, processing and interpreting data related to the earth's surface and the soils and rocks beneath and providing advice based on the results to clients in many sectors
Alewijnse	OEM, serviceprovider	Total solutions in electrotechnics
Pon Power	OEM, serviceprovider	Design, maintenance of caterpillar diesel engines
Seacon logistics	Logistic service provider	Logistics control tower technology
Seamar	Logistic service provider	Very strong in “Kop van Noord-Holland”
Mes Marine Services	Valorization partner	Smart maintenance and maritime entrepreneurship
Copernicos Groep	Valorization partner	Innovations in co-operations
Asset Management Control Centre	Dissemination partner	Spreading out to large community, including tool development
Maritime Campus Netherlands	Valorization partner	Connection to entrepreneurs & education
Dutch Institute World Class Maintenance	Dissemination partner	Large network of maintenance representatives in many sectors

A short description of the participating companies is provided in Appendix B.

## **C2. Project organization**

The project is organized in three scientific work packages, one project management and one valorization WP, which are all managed by WP-leaders. This is illustrated in the organization chart shown below. Rustenbrug is the project leader responsible for the overall project management, supported by the WP-leaders (Tinga, Tan, v/d Heijden and Van Fenema). Finally, a steering committee consisting of representatives from all participating organizations and Dinalog advises the project leader. Regular meetings (every three months) with all parties involved are foreseen. A clear and approved budget plan governs the project.



## D. Evaluation and Monitoring

### D1. Evaluation

The project will be evaluated and monitored by the workgroup and the steering committee. The evaluation approach used in the ProSeLo project is also applied here, since it has proven to work properly.

#### Scorecard

For the projects as defined, the evaluation and monitoring process will concentrate on the following three main factors of innovation deliverables, all in terms of actual result versus planned result:

1. Innovation content: Per WP and WP phase, three main innovation aspects will be closely evaluated and monitored:
  - a. Conditions for effective innovation: How to enable an effective innovation process; Innovation conditions are defined and will be evaluated.
  - b. The innovation deliverable: What are the new deliverables in terms of approach, procedures, processes, IT systems etc.; Innovation deliverables are defined and will be evaluated.
  - c. Effects of the innovation: The realization of the business case elements for the companies directly involved in the innovation project; Innovation effects are defined and will be evaluated.
2. Innovation schedule: Per WP and WP phase, milestones are defined and progress will be monitored accordingly.
3. Innovation budget: Per WP and WP phase the financial and/or resource budget has been established and monitoring will be performed accordingly.

Per WP, a scorecard will be established containing all above elements with qualitative and quantitative assessments with green/amber/red indicators.

## **Management System**

In order to achieve world-class service logistic innovations, the following management system will be applied:

- WP meetings:
  - Monthly the WP-leaders will meet with their key project members to review progress according to plan and to address (potential) issues for resolution.
  - Once a quarter the full project scorecard will be assessed for input to the overall WP meeting, including the three “innovation content” scorecard elements. This assessment/meeting will include the companies participating in the specific WP.
- Project meetings:
  - Quarterly the project leader will meet with the rest of the workgroup to review the WP scorecards and to address (potential) issues for resolution.
  - Special focus is required by the workgroup to assess the quality of the innovation content elements throughout the total project cycle. Cross WP reviews will be performed in order to assure the highest standards.
  - Every second quarter, the project leader consolidates the scorecard for input to the steering group. This assessment/meeting will include the Dinalog (service logistics) program manager.
- Steering Group meetings:
  - Every 6 months the steering group, consisting of the WP leaders, a Dinalog representative and representatives of all participating companies, meets to review with the project leader the project scorecard and to address (potential) issues for resolution.
  - Special focus is required by the full steering group team to assess the quality of the innovation content elements throughout the project cycle. As required the steering group can address external (national or international) project reviews in order to assure the highest standards.
- Progress reports:
  - The scorecards and minutes of meetings per WP and of the whole project will be published for all involved partners after validation in the appropriate meetings.
  - Publication will be included in the project website with access restricted to the involved partners.

## **E. Valorization and Implementation Strategy**

### **Organization**

The valorisation will be led by Rustenburg (CEO Gordian), who has ample experience in valorisation activities, amongst others in the R&D project Pro-active Service Logistics. Gordian will be assisted by two other (SME) companies: Copernicus Group and Mes Marine Services. The Asset Management Control Centre and World Class Maintenance will be the most direct channels for dissemination. The Maritime Campus Netherlands (MCN) will be a key gateway to local entrepreneurs and Institutes of Higher Education.

Evidently, we will continue the existing effective relation with Dinalog on valorisation. Moreover we will use the valorisation instruments already developed (website, fact sheets, “Kenniscafé”, outlet via social media, master classes, etc.).

## **Vision on valorisation**

A key factor is to *create small prototype environments* in which we explore the combined input of all work packages. An example is to create an intelligent supply chain for the water chillers manufactured by Novek. Participants could be the Defence organisation, Novek and a Logistic Service Provider. Such a prototype requires a *strong interface between the work packages*. Research output must be combined in a logical and practical package that can be tested in the prototype environment. We will apply *concurrent engineering*. The prototype environment will be “fed” with research packages, in a frequent but controlled way of course.

We believe that such an approach will *materialize the innovations* in the quickest way. That is very important to keep the total consortium on board. Moreover, innovation products that have successfully been tested are easily disseminated. This approach requires the *commitment and support of the executive management* of all participating companies. Asset owners must allow some technical systems to be included in the prototype environments including a part of the maintenance & logistics business. All consortium partners have to co-operate in order to make the smartest collective solution as possible. Such an approach is not easy but pre-conditional to success. Therefore not only the commitment but also the continuous support of the executive management is a prerequisite.

## **Activities**

Our valorisation strategy consists of the following activities:

### Creating an interface between research and prototyping

Based on their key competences, the valorisation partners have a supporting role in the work packages.

- WP1: Mes Marine Services
- WP2: Gordian Logistic Experts
- WP3: Copernicos Groep

In addition the valorisation partners have a stimulating role in the prototype environments. So in these environments they have a “total” view.

### Extensive use of Msc students

This appears to be a success factor in earlier service logistics projects. Msc or even Bsc students can be used for exploratory studies, problem definition studies, pilot studies, solving specific problems, creating specific tools, and so on. By doing so the companies have direct profit from collaboration with universities, but the students also bridge the gap between complex practical issues and high-end science.

The students will also perform a base line study at each company at the very beginning of the project. Such a study provides an in-depth and systematic description of the maintenance and logistic processes, including the major challenges. These studies will make the companies’ needs more explicit, and by doing so the content of each work package will be refined.

### Dissemination by various channels

There will be an active dissemination program, in which several organizations will play a role, including national and regional network organizations (DI-WCM, MCN, AMC, SLF), and local and regional government.

The developed knowledge will be disseminated through scientific reports and papers, popular articles in e.g. Supply Chain Management or World Class Maintenance Magazine, presentations at conferences and WCM meetings. Finally we will use an on-line library to store all reports and possibly also other output like prototype tools.

### Direct link to educational programs

This is done in various ways. A key role is for the MCN. They will be able to link innovation products to Maritime Institutes of Higher Educations. Further we intend to conceive teaching cases out of the various studies. These cases are directly used in educational programs in universities, e.g. in the new Maintenance Engineering and Operations MSc specialization at the University of Twente, but also at programs of TiasNimbas.

### Effective operation for valorisation

Gordian has set up an effective operation for valorisation. Elements include:

- Producing popular stories and putting them not only on the internet, bringing them in the social media (specifically LinkedIn and Twitter, including discussions), sending them to specific websites such as Logistiek.nl and sending them to media such as Supply Chain Management, Maintenance in processing.
- Producing and distributing fact sheets of the (intermediate) project results
- Maintaining the website

### Business development

Finally we will stimulate entrepreneurs to create value propositions using innovation results. We will co-operate with the MCN on this matter since they have access to a lot of maritime entrepreneurs.

### **Case studies**

To translate the scientific work in this project into practical solutions for the companies, a number of case studies will be executed in cooperation with the participating industries. In these case studies practical problems will be solved using the knowledge and tools developed in the present project. The case studies will be executed by MSc students and the valorisation partners. Two examples of such case studies are:

- **Problem:** OEM's and system integrators are looking for opportunities to take more responsibility in the downstream maintenance actions. It can be calculated that there is a clear win-win for both the OEM and the customer to work more closely together. For some reasons there is also a lot of hesitation to do this. Because it is all about performance and costs, OEM's could use a good cost-model to make clear business cases.  
**Solution:** How can the business case be constructed in such a way that it is clear where the cost savings and performance improvements will be realised and how large they are ?  
**Involved companies:** Thales, Imtech, IHC, Damen Shipyards, Pon Power. **Involved WPs:** 2 and 3.

- **Problem:** a original equipment manufacturer (OEM) is unaware of the exact usage and operational conditions of the assets that are produced. This means that this information cannot be used to close the feedback loop in the design process. The asset owner quite often (partly) monitors the usage and conditions, but does not share this information with the OEM.

**Solution:** for a number of specific assets or systems (e.g. radar, structure of ship, engine) data will be collected during operation and the benefits of the data for the OEM will be identified / quantified.

**Involved companies:** Thales, Imtech, Damen Shipyards, Pon Power, IHC (OEMs). **Involved WPs:** 1.

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## Appendix A CVs of the researchers

In this appendix the CVs of the researchers involved in the project are listed:

- P.C. van Fenema (Netherlands Defence Academy)
- M.C. v/d Heijden (University of Twente)
- G.J. van Houtum (Eindhoven University of Technology)
- T. Tan (Eindhoven University of Technology)
- T. Tinga (Netherlands Defence Academy)
- H. Zijm (University of Twente)

### Paul C. van Fenema

Paul C. van Fenema is currently a professor of military logistics (50%) and an associate professor in organization science (50%) at the Faculty of Military Sciences, Netherlands Defence Academy. He holds a PhD (cum laude) from Rotterdam School of Management, Erasmus University, and a MSc degree (cum laude) in Law and Economics from Utrecht University. He has been working as a visiting researcher at Florida International University, as an assistant professor at Rotterdam School of Management, Erasmus University, and as a part-time assistant and associate professor Tilburg University.

Combining organization science, logistics management and information management, his research interests include interorganizational value creation, service management and multilevel coordination. He conducted research on globally distributed projects. Paul participated in the KLICT project, co-wrote an article on a humanitarian logistics organization, and co-wrote a book chapter on redeployment of Dutch forces from Afghanistan.

He has published numerous 45 papers in internationally refereed scientific journals as well as book chapters and books. He teaches in courses in organization science, information management, and supply chain management. He co-supervised PhD projects on information sharing, the NH90 project and ERP implementation, participated in the KLICT logistics project, and conducted recent research on Business Process Outsourcing in China.

### Five key publications

- Soeters, J.M.M.L., van Fenema, P.C., & Beeres, R. (2010). *Managing Military Organizations: Theory and Practice*. London: Routledge.
- Uiterwijk, D.J.W.B., Soeters, J.M.M.L., & van Fenema, P.C. (2013). Aligning National 'Logics' in a European Military Helicopter Program. *Defense & Security Analysis*, 29(1), 54-67.
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### Matthieu van der Heijden

Matthieu van der Heijden is currently associate professor in Supply Chain Management and Service Logistics at the University of Twente. He holds a Masters degree in econometrics (1986) and a PhD in Economics (1993) from the Free University in Amsterdam. Before, he has been working as consultant

in operations research and statistics at Philips Electronics / CQM from 1986 to 1994, as an assistant professor at the University of Twente from 1994 to 1999 and as consultant in logistics at TNO in from 1999 to 2000.

His research interests include spare part inventory management, maintenance optimization, inventory management in supply chains and transportation management. He has published about 45 papers in internationally refereed scientific journals in these areas (ISI journals). He has taught many different courses in the area of logistics and operations research, and has supervised dozens of graduation projects. He has supervised 7 PhD students and participated in several research projects in close cooperation with industry, such as simulation, dimensioning and logistics control of an (underground) logistic system around Amsterdam Airport Schiphol (1997-2001), several projects within the TRANSUMO program on sustainable mobility (2005-2009), Service Logistics Forum Research (2005-2013), the IOP-IPCR project "Life cycle oriented design of capital goods" (2005-2010), and the Dinalog project "Proactive Service Logistics for Advanced Capital Goods" (2011-...).

### **Five key publications**

- Van der Heijden, M.C., Van Harten, A., Ebben, M.J.R., Saanen, Y.S., Valentin, E., and Verbraeck, A., "Using simulation to design an automated underground system for transporting freight around Schiphol Airport", *Interfaces* 32, 1-19, 2002.
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### **Geert-Jan van Houtum**

Geert-Jan van Houtum is Professor of Maintenance, Reliability, and Quality at Eindhoven University of Technology since 2008. Prior to that he filled positions as assistant/associate professor at the University of Twente (1994-1998) and Eindhoven University of Technology (1999-2007) and as visiting professor at Carnegie Mellon University (2001). He obtained his M.Sc. and Ph.D. degree in Applied Mathematics from Eindhoven University of Technology in 1990 and 1995, respectively. He does research on the maintenance and reliability of capital goods, and in particular on: (i) Design and control of service supply chains; (ii) Maintenance concepts; (iii) Design for availability. He publishes in journals such as *Operations Research*, *Manufacturing and Service Operations Management*, *IIE Transactions*, *European Journal of Operational Research*, *OR Spectrum*, and *International Journal of Production Economics*. He is associate editor of *OR Spectrum*, the *Flexible Services and Manufacturing Journal*, and *Mathematical Methods of Operational Research*. Much of Prof. Van Houtum's research is in cooperation with industry. He works with companies such as ASML, DAF, Gordian, IBM, Nedtrain, Océ, Philips Healthcare, Stork, and Vanderlande Industries. He is scientific director of the Beta Research School for Operations Management and Logistics, and he is a board member of the Service Logistics Forum and the European Supply Chain Forum. He is project leader of the IOP-IPCR project on "Life cycle oriented design of capital goods", a consortium project with the University of Twente and 15 companies; this project started in 2005 and will be completed in September 2010.

### Five Key Publications

- Rustenburg, W. D., Van Houtum, G. J., and Zijm, W. H. M., "Spare parts management for technical systems: Resupply of spare parts under limited budgets", *IIE Transactions* 32, 1013-1026, 2000.
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### Tarkan Tan

Tarkan Tan is an Assistant Professor in the School of Industrial Engineering at Eindhoven University of Technology. Dr. Tan received his Ph.D in Industrial Engineering from the Middle East Technical University, Ankara, Turkey, in 2002. He pursued one year of his studies towards his Ph.D. degree at Columbia University, Graduate School of Business, Management Science / Operations Research division, New York, as a Fulbright scholar. He joined Eindhoven University of Technology as a post-doc researcher in 2003 and started working as an assistant professor the same year in the Operations, Planning, Accounting, and Control group, where he currently serves at the board as the education officer. He has recently spent an academic term at the University of California, Los Angeles, as a visiting scholar. Dr. Tan has been involved in the supervision of six Ph.D. students and numerous M.Sc. students. He also serves on the executive board of the European Supply Chain Forum. Dr. Tan has been elected twice as the best lecturer in Operations Management and Logistics MSc program, by "Industria", the organization of the Industrial Engineering students of Eindhoven University of Technology. His current research is focused on service logistics, inventory systems with advance demand information, and green supply chains. Within service logistics, he concentrates on spare parts management of capital goods in multi-echelon networks.

### Five Key Publications

- Caro, F., Corbett, C., Tan, T., and Zuidwijk, R., "Double-Counting in Supply Chain Carbon Footprinting", *Manufacturing & Service Operations Management*, 2013 (to appear).
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### **Tiedo Tinga**

Tiedo Tinga (1973) is currently a Professor in Dynamics based Maintenance at the University of Twente and an Associate Professor in Maintenance Technology at the Netherlands Defence Academy. He holds a Masters degree in Applied Physics (1995) and a PhD in Mechanical Engineering (2009) from Eindhoven University of Technology. Before his academic career, he has been working as a research scientist at the National Aerospace Laboratory NLR from 1998 to 2007.

His research interests are in the field of predictive maintenance, where models of the failure mechanisms of (sub)systems can be applied to predict remaining life times and the most appropriate maintenance intervals. Other associated topics are structural health and condition monitoring, reliability engineering, (failure) data analysis and maintenance optimization.

He has published about 35 papers in these areas in scientific journals and international conferences, as well as several books and book chapters. He has supervised quite a number of graduation projects and five PhD students in the area of maintenance. He has participated in several research projects in close cooperation with industry, many of them associated to the Dutch Institute World Class Maintenance, but also leads the Tools for Life Cycle Management project for the Ministry of Defence (2013-2014). He also participated in a number of European projects, e.g. COST538 on Nickel base superalloys. Finally, he initiated the Knowledge Network on Life Cycle Management within the Ministry of Defence, which is used to disseminate the research results of the Defence Academy into the Defence organization.

### **Five Key Publications**

- Tinga, T., "Principles of loads and failure mechanisms; Applications in maintenance, reliability and design". Springer Series in Reliability Engineering, ed. H. Pham. 2013, London: Springer Verlag.
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### **Henk Zijm**

Henk Zijm is currently full professor in Production and Operations Management and head of the Dept. of Operational Methods for Production and Logistics in the Faculty of Management and Governance of the University of Twente. He worked for 8 years with Philips Electronics in various positions in manufacturing and supply chain management and in addition became full professor at Eindhoven University of Technology in 1987. In 1990 he joined the University of Twente as a full professor in Production Engineering and Management. His research interests include production and supply chain management, warehousing, maintenance planning and control, service logistics and process planning. He has been a consultant to a large number of companies both in the Netherlands and abroad. He has published more than 100 articles in international refereed scientific journals and is the (co-)author of two books. He supervised more than 150 master and more than 20 PhD students and serves as associate editor of two journals in his field. In addition, he held several administrative positions, including positions as Scientific Director of the Center for Telematics and Information Technology, and Dean of the Faculty of Electrical Engineering, Mathematics and Computer Science. In

2004, he was selected to become the Rector Magnificus of the University of Twente, a position he fulfilled until January 2009. Besides holding the chair in Production and Operations Management, he also serves as Director of Science of the Dutch Institute for Advanced Logistics (DINALOGO and holds some ancillary positions, including Vice Chairman of the Council of Commissioners of the Development Agency East Netherlands (OOST NV) and member of the Supervisory Board of Roessingh BV, a rehabilitation institute in Enschede, the Netherlands. He is also a past President of the International Society for Inventory Research (ISIR), Budapest.

#### **Five key publications**

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