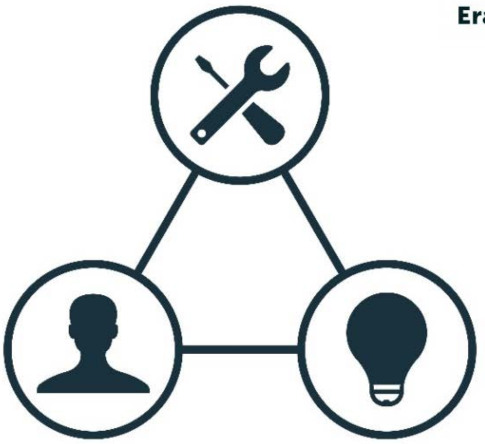
Perspective round 2020/2021
Phase 2: Programme design

OpsCenter

Operations control centers for sustainable after-sales services

P20-56



Content

1. Overview 1

1.1 Title 1

1.2 Applicants and user representative(s) 1

1.3 Summary 1

1.4 Unique selling point(s) 1

1.5 Timing and costs 1

2. Programme description 2

2.1 Problem definition 2

2.2 Vision of success (Impact) 2

2.3 Sense of urgency and uniqueness 2

2.4 Objectives and challenges 3

2.5 Consortium 3

2.6 Outcomes 4

2.7 Output 4

2.8 Overview programme and projects/work packages 4

2.9 Budget 7

2.10 Added programmatic value 7

2.11 Utilisation plan 7

3. Annexes 8

3.1 Selection of research groups' key publications and patents 8

3.2 Abbreviations and acronyms 10

3.3 References 10

3.4 Letters of support 10

1. Overview

1.1 Title

OpsCenter: Operations control centers for sustainable aftersales services

1.2 Applicants and user representative(s)

Programme leader: Dr.ir. Rob Basten (Eindhoven University of Technology)
User representative(s): Dr.ir. Maartje van Reedt-Dortland (Ministry of Defence) & ing. Walter Mesterom (PDM)
Applicants: Prof.dr.ir. Tiedo Tinga (Netherlands Defence Academy & University of Twente), prof.dr. Harold Krikke (Open University), dr. Philippe van de Calseyde, prof.dr. Evangelia Demerouti, prof.dr.ir. Geert-Jan van Houtum & dr. Yingqian Zhang (Eindhoven University of Technology), prof.dr. Henk Akkermans (Tilburg University), dr. Matthieu van der Heijden & dr. Engin Topan (University of Twente), prof.dr. Rommert Dekker (Erasmus University Rotterdam) & dr. Sena Eruguz (Free University Amsterdam).

1.3 Summary

By 2030, carbon emissions cost hundreds of euros per ton, raw materials have limited availability, and qualified people are scarce. At the same time, high-tech equipment is increasingly complex, and users have *lights-out operations* (i.e., automated factories without human presence on-site). This requires companies in the high-tech industry to *act more sustainably* and *minimize resource consumption*. For this, smart maintenance and other after-sales services are necessary, with a flexible and resource efficient supply chain managing all required resources, e.g., engineers and parts. All equipment needs to be connected to operations control centers (OpsCenters), enabling continuous monitoring and pro-active decision making using shared data. With a future-proof supply chain and incorporating the business context and ecological footprint, the positive impact on the environment will be huge, with increased profits in the Dutch high-tech industry of hundreds of millions of euros.

In this project, we develop these OpsCenters. Using *artificial intelligence* (AI), data are transformed into *predictions* and *suggestions* for pro-active interventions that avoid downtime. We require *explainable AI*, as human decision makers typically select the best option, using key relevant information. Supporting supply chains are *pro-active and resilient*, using all supply possibilities, including 3D printing. Large users of equipment may set up OpsCenters themselves, but they are mostly operated by original equipment manufacturers (OEMs), since they have most technological knowledge. This requires quantitative insights in the *ecological footprint* and *servitization* with the right contracts and collaboration modes, enabling maximal exploitation of the useful life of equipment and reuse of scarce materials at the end of the life.

1.4 Unique selling point(s)

The consortium combines OEMs, users of equipment, researchers working on technical aspects of predicting and decision making, and researchers working on business models and quantitative ecological footprinting. These combinations are unique, but required to perform the relevant research and achieve impact: improved sustainability and reduced resource usage of high-tech equipment through implementation of OpsCenters in practice.

1.5 Timing and costs

Requested Budget from NWO: € 2.065.371			**Anticipated cash contribution:** € 280.000			**Anticipated In-kind contribution**: € 560.000	
Programme duration: 5 year				**Total programme costs**: € 2.905.371			
Position	TU/e	UT	TiU	OU	EUR/VU	NLDA/UT	**Total**
PhDs	3	1	1	1		1	**7**
PostDocs		1			1		**2**

2. Programme description

2.1 Problem definition

By 2030, following our vision in Section 1.3, it is key for companies in the high-tech industry to *act more sustainably* and *minimize resource consumption*. However, maintenance, spare parts delivery, and other after-sales services required to keep equipment operational are not ready for this future. This leads to a high footprint and equipment not being used optimally, causing users to not be competitive. For the Ministry of Defence, unavailable equipment may even be dangerous. By 2030, the complexity of the equipment and the delivery of the services, exacerbated by scarcity of required resources, make it extremely difficult to make the right decisions on service delivery. This is even more so due to the many requirements that need to be fulfilled: Equipment and service delivery must be resilient, efficient and sustainable. It is thus extremely difficult to achieve the targets of the KIA Circular Economy: lifetime extension, smart maintenance of equipment (MMIP 1E) and chain logistics (MMIP 1F).

There are various causes for this problem. Useful information to act upon is lacking, e.g., on failure predictions and the impact that decisions have on the use of resources or the ecological footprint in general. Organizations are unwilling to share data and collaborate, due to their business models. The supply chain is not future-proof, and there are too many potential decisions for a human decision maker to handle without adequate support.

We believe that if the after-sales service supply chain is future-proof and the business models are mutually beneficial, it is possible to bring data together and make decisions in an OpsCenter that result in circular companies. Multi-disciplinary research in close collaboration with industry is required to achieve this.

2.2 Vision of success (Impact)

If our project is successful, a step towards the circular economy is realized by a lower footprint of equipment and services. By 2030, equipment users have *lights-out operations* (for the Ministry of Defence this translates into self-supporting teams). *Servitization* is omnipresent, i.e., original equipment manufacturers (OEMs) sell the function and use of equipment instead of equipment itself. Users then need less equipment because improved maintenance leads to higher reliability, less downtime and longer lifetimes. Transportation of spare parts and service engineers has decreased because fewer unplanned service visits are required, OEMs maximize the useful life of equipment, and they reuse scarce materials at the end of the life. This is achieved through transparency on the ecological footprint of equipment and services.

The success will be made possible due to smart maintenance and other after-sales services, and a flexible and sustainable service supply chain managing all resources required to perform these services, e.g., service engineers and spare parts. The maintenance and supply chain activities are controlled by OpsCenters in which data are shared across organizations, activities are continuously monitored, and pro-active interventions are proposed to avoid downtime. Data are transformed into *predictions* on failures and supply, using techniques from (*explainable*) *artificial intelligence* (AI). These are typically used by human decision makers who select the best option supported by key relevant information, including the sustainability footprint. Large users of equipment may set up their own OpsCenters, but typically OEMs operate them, since they have most knowledge on a wide installed base.

Implementing OpsCenters means that both the organizations supplying and using equipment are competitive, resilient, and sustainable, resulting in huge impact on the environment. Since the economic potential of predictive maintenance and other smart services is enormous (McKinsey, 2015; PWC & Mainnovation, 2017), implementing OpsCenters will increase profits of the high-tech industry in the Netherlands by hundreds of millions of euros.

2.3 Sense of urgency and uniqueness

This is the right time to work towards smart after-sales services and lights-out operations. We have an aging work force and increasing global competition and tension. We also see new technologies being developed such as 3D printing, sensor technology and IoT, which makes it technically possible to print spare parts on demand and collect big data on equipment and supply chains. At the same time, we see that organizations don't share IP and data, and that equipment is so reliable that failures don't happen often. Actual implementation of predictive maintenance and other smart services thus remains limited in practice, due to technical challenges, data limitations, and organizational aspects (PWC & Mainnovation, 2017; Akkermans et al., 2020).

We believe that implementation can be achieved only through a consortium such as ours, that combines OEMs, users of equipment, researchers working on technical aspects of predicting and decision making, and those working on business models and sustainability impact. By changing the business models and supply chains, we make it possible to benefit from recent and upcoming progress on AI for predicting and decision making in OpsCenters. Specifically, we investigate predicting based on big data combined with limited failure data and physical failure models, using, e.g., transfer learning and graph neural networks, and operational decision making using (other) techniques from AI, such as random forests. The composition of our consortium allows us to access much relevant research, performed in projects on predictive maintenance (PrimaVera, SUPREME, Real-time Data-Driven Maintenance Logistics), 3D printing of spare parts (SINTAS), control towers (Marconi), and service supply chains and business models (ProSeLoNext). The Marconi project is arguably closest related to ours, but it focuses heavily on the logistics and the challenges that result from the movement of assets, making the type of decision making that is investigated very different. Furthermore, its scope is much narrower than ours. However, we might benefit from their software architecture that technically enables sharing and storing data. This is complementary to our project.

2.4 Objectives and challenges

Our objective is to develop OpsCenters for after-sales services, which is key for smart industry (MJP 34). OpsCenters and the supply chains they control, are examples of cyberphysical systems. Our key technical challenge (linking to MJPs 44, 45 and 48) is to apply and further develop techniques from *artificial intelligence* for predictions and suggestions for interventions. The challenge lies in combining huge amounts of sensor data, possibly from multiple equipment types, very limited failure data, and physical failure models into reliable predictions (using, e.g., transfer learning and graph neural networks). For the suggestions for interventions, the challenge lies in making decisions that simultaneously minimize costs and footprint, while they maximize resilience. Furthermore, the suggestions should be such that a human decision maker may adhere to them, i.e., *explainable AI*.

There are further technical challenges in the design of a supply chain that has the responsiveness and flexibility to allow the operational control that we require, and the design of the collaboration between the human decision maker and the data driven decision support system that is the heart of the OpsCenter. Further scientific challenges are quantifying the impact that decisions have on the footprint, and designing the business models of and collaboration between the organizations to facilitate *servitization*.

2.5 Consortium

Scientific community

Various disciplines, such as maintenance and reliability engineering, AI, operations research (OR) and operations management (OM), work together to develop the new technology, while other disciplines (organizational behaviour and human decision making, sustainability) develop insights into the factors influencing the rate of success.This improves the chances of valorization of the OpsCenter.

The scientific community involved is very experienced. Prof.dr.ir. Geert-Jan van Houtum is a board member of the Service Logistics Forum, while prof.dr. Henk Akkermans is the Director of Stichting World Class Maintenance. Various subsets of both the scientific and user community have long-lasting collaborations in research projects (e.g., ProSeLo, ProSeLoNext, SINTAS, PrimaVera); Rob Basten, OpsCenter' principal investigator, was project leader of ProSeLoNext.

Group: ***researchers***	**Insti-tute**	**Expertise**
Operations, Planning, Accounting & Control: *Basten & Van Houtum*	TU/e	OM & OR: after-sales services using new technologies
Information Systems: *Zhang*	TU/e	AI: machine learning & optimization
Human Performance Management: *Van de Calseyde & Demerouti*	TU/e	Organizational behaviour & human decision making
Industrial Engineering and Business Information Systems: *Topan & Van der Heijden*	UT	OR: maintenance & after-sales service logistics using new technologies
Militaire Wetenschappen / Dynamics Based Maintenance: *Tinga*	NLDA /UT	Maintenance and reliability engineering
Tilburg School of Economics and Management: *Akkermans*	TiU	OM: business models
Marketing and Supply Chain Management: *Krikke*	OU	OM: circular economy & sustainability
Operations Analytics: *Eruguz*	VU	OR: maintenance & after-sales service logistics
Erasmus Research Institute of Management: *Dekker*	EUR	OR: reverse & after-sales service logistics

User community

The stakeholders have been involved in consortium meetings to discuss and refine the research questions and approach. We have discussed the use cases and our joint vision. Furthermore, the user representatives (from the Ministry of Defence and PDM) were involved in a brainstorming session on the Impact Pathway. We thus propose practically relevant research that the stakeholders are eager to apply. The organizations listed below play a key role in the pathway towards the vision of success. For example, the OEMs and user spend a considerable amount of time developing (pilot) OpsCenters within their organizations based on their use cases. This will be done in close collaboration with PDM and the scientific community and ensures a feedback loop, useful for this and future research. The network organizations will contribute to turning outputs into outcome. Together, the user community is covering the entire innovation chain necessary to utilise the results.

Organization	Expertise	In cash	In kind	Current level of commitment
ASML	OEM – Lithography machines	€ 40.000	€ 80.000	☐ I ☐ N ☒ C
Marel Poultry	OEM – Poultry processing systems	€ 40.000	€ 80.000	☐ I ☐ N ☒ C
Ministry of Defence	User – Freedom and security	€ 40.000	€ 80.000	☐ I ☐ N ☒ C
PDM	Service provider – High tech consulting	€ 40.000	€ 80.000	☐ I ☐ N ☒ C
Service Logistics Forum	Network organization – Valorization	-	€ 5.000	☐ I ☐ N ☒ C
Vanderlande	OEM – Logistic process automation	€ 40.000	€ 80.000	☐ I ☐ N ☒ C
World Class Maintenance	Network organization – Valorization	-	€ 5.000	☐ I ☐ N ☒ C
FastMicro	OEM (SME) – Contamination inspection	€ 10.000	€ 40.000	☐ I ☒ N ☐ C
Philips	OEM – Medical equipment	€ 40.000	€ 80.000	☐ I ☒ N ☐ C
Scania	OEM – (Military) vehicles	€ 40.000	€ 80.000	☐ I ☒ N ☐ C

2.6 Outcomes

The outcome that we aim for is the setup of OpsCenters at organizations in and outside of our consortium. Our main assumption is that the knowledge developed in our project will enable organizations to set up these OpsCenters. To achieve that, there are some intermediate outcomes we need to achieve: Of course, adoption of the knowledge generated in the project at organizations. It is further of key importance that new business models have been implemented and that quantified visibility exists at organizations on the impact that decisions have on the footprint. To make the OpsCenters a success, the supply chain also has to be made future-proof.

2.7 Output

We aim for insights into the design of future-proof supply chains, techniques to make demand and supply predictions using huge amounts of sensor data and limited failure data, operational decision making combining operations research and machine learning, the interaction between decision support systems and human decisions makers, collaborative business models, and new methods to measure the impact of decisions on the footprint. These insights need to be adopted throughout the organizations in the user committee so that they can set up pilot OpsCenters.

2.8 Overview programme and projects/work packages

We propose six work packages (WPs), as depicted in Figure 1 and discussed below. WPs 2 and 3 are the core of the OpsCenter: making predictions (WP2) that are used for operational decision making (WP3). The right decisions are possible only if the supply chain is designed right (WP1) and if it is clear how decisions impact the footprint (WP4). Furthermore, to enable data collection and to ensure that all parties involved are better off, the right business models need to be in place (WP4). Finally, we propose a separate WP5 through which the use cases of the user community are organized while governance is organized in WP6.

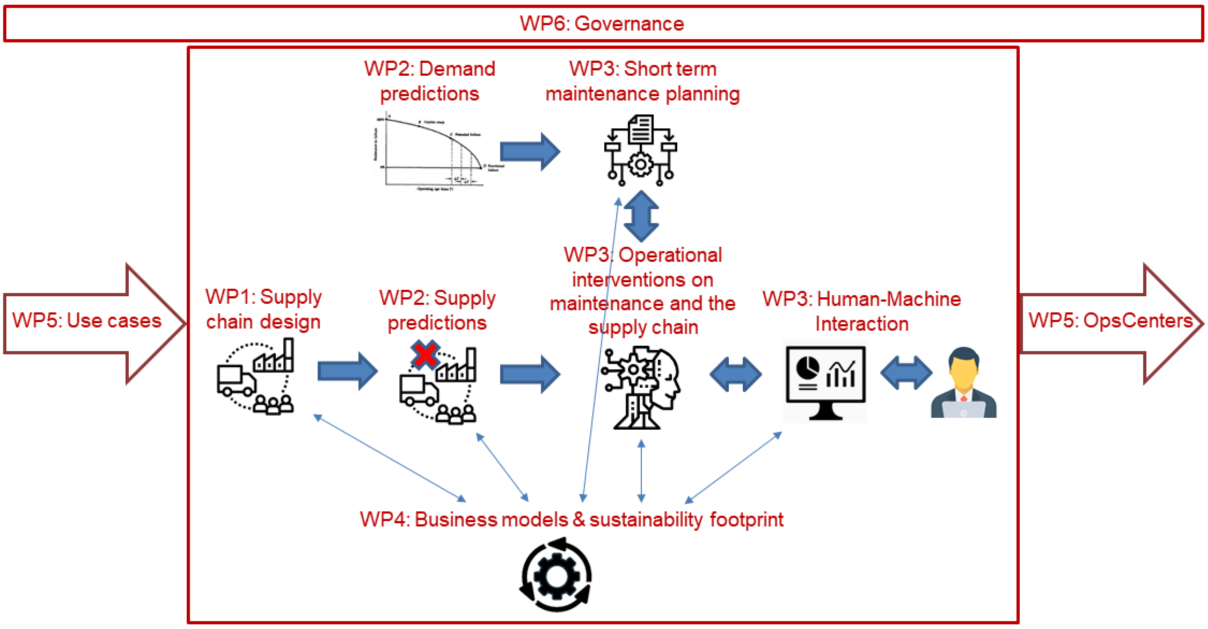


Figure 1: Overview of OpsCenter project

WP1: Future after-sales service supply chains

Research question: *How to design responsive, resilient, and resource efficient service supply chains?*

To operationally control the supply chain such that after-sales services can be performed when needed, with differentiation between customers with different service level agreements, i.e., to enable WP3, the supply chain needs to be designed right. Making the supply chain responsive and resilient may mean that more resources need to be close to the equipment that is to be serviced. Lamghari-Idrissi et al. (2020) find for spare parts that this helps indeed. Stocking more, leads to fewer emergency shipments, but it also leads to higher obsolescence rates and thus higher scrap rates. With input on the footprint (WP4), we aim to design the supply chain such that it is not only resilient and responsive, but also efficient and sustainable. 3D printing of parts may help in this respect, because it can be done close to the location where the part is needed, responding to an accurate demand prediction (WP2), with a short lead time and low inventories. Although there has been some research on this topic (Knofius et al., 2020; Westerweel et al., 2020), it is unclear how to incorporate 3D printing in the supply chain. It is also unclear which organization should be printing the parts. If the user prints, then the OEM needs to license the right to print to that user. That contract needs to be designed such that both parties benefit, requiring a change in business model (WP4).

For service engineers, being responsive while being efficient is also challenging. Having more service engineers close to the equipment would lead to high responsiveness, but it isn't very efficient. Also here, new technology may help. Operators of equipment or first line service engineers may use augmented reality to perform activities that they wouldn't be able to perform without. Second or third line service engineers at a more central location may be able to assist without going to the equipment if they have a direct link to the operator or first line service engineer. The question is then how many service engineers with which skill sets to position at various locations. The skill sets are important inputs for WP3 to decide in which cases to call in the help of the centrally located service engineers.

To design the complex service supply chain that is resilient, responsive, and resource efficient, while it can achieve different service levels for different customers, new models are required. To this end, we use methods from stochastic operations research (SOR), such as Markov Decision Processes (MDPs) and inventory theory.

WP2: Demand and supply prediction using data and physical models

Research question: *How to achieve accurate demand and supply predictions in the face of limited failure data?*

To properly plan and coordinate the after sales services and to avoid wasting components' remaining useful life (RUL), it's crucial to have insight in expected supply lead times and expected demand for after-sales services, i.e., the expected time to failure of (critical) parts. For mature systems with a constant operational profile and sufficient numbers of failures, the expected time to failure can be adequately estimated from historic data gathered using IoT. However, many military and civil systems are used in a variable manner and companies introduce new systems regularly, i.e., they often have the problem of limited relevant data for accurate predictions.

To address this issue, predictive models that are trained with specific failure data have to adapt to different distributions and limited fault information, probably coming from a similar but different system. In machine learning, this situation is referred to as *transfer learning* or domain adaptation. Da Costa et al. (2020) show, using adversarial learning with Long Short-Term Neural Networks, that we can achieve good performance on domain adaptation for RUL predictions under varying operating conditions and fault modes. We will extend the approach of Da Costa et al. and investigate how the algorithms perform under various domain adapting situations provided in the use cases.

In addition, we will develop hybrid failure models that combine basic physical failure models (e.g., wear, fatigue, corrosion; Meghoe et al., 2019) with machine learning models. The use of physical models requires specific system knowledge from experts, but also ensures that the models are not black boxes, can quickly be tuned to a specific application and do not require extensive training data sets. With machine learning, data collected from sensors or condition monitoring systems allow to incorporate the specific operational profile of individual systems in the predictions. Graph Neural Networks (GNNs; Wu et al., 2020) are deep learning based methods that operate on graphs. GNNs have been recently applied to many application domains, including link predictions in social networks. We will investigate how failure data and system knowledge can be effectively and efficiently encoded in GNNs to model the (unknown) relations between failures from different components, to achieve a hybrid failure prediction model. Moreover, the developed GNN model will be coupled with a recurrent neural network, such that the results of Root Cause Analyses (i.e., precisely determining the failure mechanism and circumstances for each observed failure) can be fed back into the predictive model, thus learning from past failures.

The developed methods will be applied to demand and supply prediction problems that have a similar challenge: lack of a relevant type of data, e.g., historical failures. Although the demand itself cannot be described by a physical model, it is directly governed by (the physics of) failing parts and systems. We will therefore use the prediction of moment, type and location of the failure to more accurately predict the demand for after-sales services**.** For supply prediction, we will develop a multi-task learning approach that combines relevant data from multiple actors in the supply chain, such as status information from (external) repair shops, component manufacturers and distributors.

WP3: Operational control of after-sales services and the service supply chain

Research question: *How to make operational level decisions using predictions and new supply options?*

Day-to-day operations have a big impact on the performance and sustainability of after-sales services. We deploy failure predictions (WP2) to optimize asset maintenance towards these criteria. This is then used to predict demand for resources to execute maintenance (e.g., spare parts, service engineers). We match this with supply predictions for these resources (WP2), and we use artificial intelligence (e.g., neural networks or random forests) to classify the supply chain status as being healthy or being at risk for specific types of mismatches. We deploy both deep machine learning and operational research techniques to propose interventions to correct these mismatches; see Topan et al. (2020) for a recent literature review and identification of gaps. We thus include a feedback loop to learn from the actual impact of decisions taken by algorithms and human planners to improve future interventions.

Operational planning aspects covered are, amongst others: scheduling just-in-time maintenance for crucial failure modes to reduce wasted useful life; clustering maintenance jobs to reduce asset downtime and for efficient resource deployment; repositioning resources in the supply chain, anticipating expected need, and preventing emergency supplies; expediting or delaying processes anticipating need for resources (return and repair of failed parts, procurement of new parts, distribution of new and remanufactured parts, relocation of tools and service engineers, etc.); postponing preventive maintenance if required resources are scarce and can better be reserved for potential upcoming failures; and deploying alternative supply sources for parts, such as 3D printing (WP1) and refurbishment (WP4), if predicted demand exceeds predicted supply.

AI based classification methods and other intelligent alert generation mechanisms will be used to separate cases with simple, risk-free interventions that can be implemented automatically, from cases that require human input. We thus reduce the work load for human planners so that they are deployed where they are needed: To decide on complex cases that require their expertise. We ensure effective and efficient decision making, preventing information overload (Ton et al., 2020), by focusing on *explainable AI* and using expertise from human-machine interaction to come to a user-friendly dashboard displaying useful information, including suggestions for interventions and their impact on footprint and costs.

In this way we aim to reduce (human) resource usage, wasted useful life of parts, and asset downtime. We further aim to de-stress the supply chain, thereby improving the quality of human work.

WP4: Business environment

Research question: *How to develop sustainable business models for service partners?*

This research question manifests itself at two levels. At a company level, it is a fundamental problem for the adoption of OpsCenters in service triads that costs and benefits are dislocated in time and place. When services are smart and IoT enabled, following WPs 2 and 3, uptimes and revenues will increase for the asset owner. However, as a result, the revenues for the other stakeholders may decrease: OEMs or service providers may sell fewer spare parts and chargeable maintenance hours. So, what is clearly beneficial for the complete service triad, is not realized due to these misalignments. Contractual arrangements are needed that overcome these misalignments: performance-based contracts. This calls for an integrated perspective on costs and benefits of smart after-sales services over time. *Servitization* will only become a success when all stakeholders in the service triad are aligned as business partners.

Secondly, at a broader society level, there is again dislocation in time and place of costs, now of the societal costs and benefits of ecological footprints. It has long been assumed that servitization will automatically lead to a decrease in the sustainability footprint, in particular if circular concepts are implemented. However, in practice there is no transparency of the ecological footprints of all the combined activities in the organizational ecosystem, of which the service triad is the focal point. Without such transparency, the societal costs of ecological footprints cannot be taken into account and sustainability will not be optimized, e.g., through higher circularity.

To address misalignment issues at the company level, we will construct formal business models of these dynamics with the relevant stakeholders. This is a proven method to develop the integral transparency needed for appropriate performance-based contracts (Akkermans, 2001). However, to do so in an interorganizational setting remains a research frontier. To address sustainability misalignments at the society level, we will develop integral sustainability footprints using streamlined Life Cycle Analysis (LCA) to generate the transparency required to move to more circular and sustainable after-sales arrangements, where resource consumption is minimized. Because it naturally connects to processes that need these resources, footprinting will be based on inputs (water, energy, materials). We may also calculate the carbon footprint (or other outputs). Again, this method is proven in small-scale contexts (Krikke, 2011) but remains a research frontier for entire business ecosystems.

WP5: Utilisation

We describe the use cases that we will work on throughout the project; the further utilisation plan is in Section 2.11.
ASML: ASML has a good view on its forward flow of spare parts. However, it aims to extend that by including service engineers and tools, and by including the reverse and repair flow, thus closing the loop and maximizing reuse of materials. It further aims to predict demand for services and resources, and (partly) automate its fulfillment through

an OpsCenter using, e.g., (deep) reinforcement learning. This should guarantee availability of materials and sustainable operations.
Marel Poultry: Marel first aims to gather and combine process and technical data. Process data enable detection of suboptimal process performance, while technical data can be used to find the root cause(s). This can then be used to advice customers on which parts to check and replace, and which adjustments to do on the equipment. As a second step, the maintenance schedule is taken into account: If preventive maintenance is coming up soon, the customer can wait, while other maintenance may be expedited if the equipment needs to be maintained anyway.
Ministry of Defence: In mission areas in the future, teams of the Royal Netherlands Army need to be mobile, instead of fixed at big bases. Spare part availability can then be guaranteed by predicting which parts are required, complementing limited local spare parts inventories by 3D printing, or using drones to deliver parts and return waste materials, thus closing the loop. Such a supply chain needs to be designed properly and an OpsCenter is required to control this at the operational level. Furthermore, contracts need to be in place to allow 3D printing.
Vanderlande: Vanderlande is investing in the development of predictive services to pro-actively support its customers and continuously improve. This will enable a shift from time and material-based service contracts towards performance-based contracts and intelligent services. Remote monitoring, predictive models and an OpsCenter are key to achieve this. Vanderlande has the ambition to deliver lights-out logistics process automation solutions that require minimum human intervention.

WP6: Governance
Activities within this work package focus on program transcending activities and management to ensure the programmatic added value and goals for the utilisation advance as planned. They include amongst others, the organization of two symposia, development of a website and other communication outings, monitoring and evaluation meetings and the consultation of stakeholders.

2.9 Budget

Work package	Personnel	Material	Investment	Other	In kind contribution	Total costs
WP1	€ 374.342	€ 30.000			€ 20.000	€ 424.342
WP2	€ 459.940	€ 30.000			€ 28.000	€ 517.940
WP3	€ 624.312	€ 40.000			€ 36.000	€ 700.312
WP4	€ 459.940	€ 30.000			€ 28.000	€ 517.940
WP5	€ 160.000	€ 35.000			€ 448.000	€ 643.000
Governance	€ 78.837			€ 23.000		€ 101.837
Total	€ 2.157.371	€ 165.000		€ 23.000	€ 560.000	€ 2.905.371

2.10 Added programmatic value

WPs 2 and 3 belong together, since together they cover the complete decision making in OpsCenters. Furthermore, WPs 1 and 4 are crucial: Implementation in practice is only possible if a future-proof service supply chain and the right business models are in place, while the impact on sustainability is clear throughout so that the OpsCenter will achieve the impact we aim for. We elaborate further in Section 2.3 on sense of urgency and uniqueness.

2.11 Utilisation plan

During the project, pilot versions of OpsCenters are developed at the user and OEMs in our consortium, in close collaboration with PDM and the scientific community (see Section 2.7). The use cases described at Section 2.8 form the basis for this. We thus ensure that our scientifically robust research output is practically relevant.

The next step is to realize advanced OpsCenters, first within the consortium, then outside (see Section 2.6). To achieve this, we need adoption of our findings throughout the user community and their stakeholders. Therefore, we will contact other stakeholders to share knowledge and gather input during the project, for example through stakeholder consultations and symposia, and also through graduation projects of students.

To create impact, other target groups need to be aware of the project results as well. PDM will play an important role using its experience in implementing smart solutions in high-tech industry and its network. The knowledge will further be disseminated through several platforms in the Netherlands, including our partners in the user community, World Class Maintenance and the Service Logistics Forum, and the Platform Service Logistics, the Hogeschool van Rotterdam (minor Service Logistics), and within Europe via the European Factories of the Future Research Association (EFFRA). We will further deliver a booklet with the results in a format that is useful for a wider audience. Ultimately, this project will strengthen the high-tech industry in the Netherlands and create additional industrial activity through ensuring sustainability, both in monetary and ecological terms.

3. Annexes

3.1 Selection of research groups' key publications and patents

TU/e OPAC

- Arts, J.J., Basten, R.J.I., & Van Houtum, G.J. (2016). Repairable stocking and expediting in a fluctuating demand environment: Optimal policy and heuristics. *Operations Research*, 64(6), 1285-1301.
- Arts, J.J., & Basten, R.J.I. (2018). Design of multi-component periodic maintenance programs with single-component models. *IISE Transactions*, 50(7), 606-615.
- Karabağ, O., Eruguz, A.S., & Basten, R.J.I. (2020). Integrated optimization of maintenance interventions and spare part selection for a partially observable multi-component system. *Reliability Engineering & System Safety*, 106955.
- Song, J.S.J., van Houtum, G.J., & Van Mieghem, J.A. (2019). Capacity and inventory management: Review, trends, and projections. *Manufacturing & Service Operations Management*, 22(1), 36-46
- Westerweel, B., Basten, R.J.I., Den Boer, J. & Van Houtum, G.J. (2020). Printing spare parts at remote locations: Fulfilling the promise of additive manufacturing. *Production & Operations Management*. In press.

TU/e IS:

- Da Costa, P.R.D.O., Akçay, A., Zhang, Y., & Kaymak, U. (2020). Remaining useful lifetime prediction via deep domain adaptation. *Reliability Engineering and System Safety*, *195.*
- Da Costa, P.R.D.O., Akçay, A., Zhang, Y., & Kaymak, U. (2019). Attention Long Short-Term Memory Network for Remaining Useful Lifetime Predictions of Turbofan Engine Degradation. I*nternational Journal of Prognostics and Health Management*, 10, 034*.*
- Verwer, S., & Zhang, Y. (2019). Learning optimal classification trees using a binary linear program formulation. In: *Proceedings of the Thirty-Third AAAI Conference on Artificial Intelligence (AAAI-19)*, 1625-1632.
- Firat, M., Crognier, G., Gabor, A.F., Hurkens, C. A., & Zhang, Y. (2020). Column generation based heuristic for learning classification trees. *Computers & Operations Research*, 116, 104866.
- Verwer, S., Zhang, Y., & Ye, Q. C. (2017). Auction optimization using regression trees and linear models as integer programs. *Artificial Intelligence*, 244, 368-395.

TU/e HPM:

- Demerouti, E. (2014). Design your own job through job crafting. *European Psychologist, 19*, 237-247.
- Demerouti, E., Bakker, A.B., & Halbesleben, J.R.B. (2015). Productive and counterproductive job crafting: A daily diary study. *Journal of Occupational Health Psychology, 20*, 457- 469.
- Demerouti, E., Bakker, A.B., Nachreiner, F., & Schaufeli, W.B. (2001). The job demands - resources model of burnout. *Journal of Applied Psychology,* 86, 499-512.
- Efendic, E., Van de Calseyde, P.P.F.M., & Evans, A.M. (2020). Slow response times undermine trust in algorithmic (but not human) predictions. *Organizational Behavior and Human Decision Processes, 157*, 103-114.
- Van de Calseyde, P.P.F.M., Evans, A.M., & Demerouti, E. (2020). Leader decision speed as a signal of honesty. *The Leadership Quarterly.* In Press.

UT IEBIS:

- Knofius, N., Van der Heijden, M.C., & Zijm, W.H.M. (2016). Selecting parts for additive manufacturing in service logistics. *Journal of Manufacturing Technology Management, 27(7)*, 915-931.
- Knofius, N., Van der Heijden, M.C., Sleptchenko, A., & Zijm, W.H.M. (2020). Improving effectiveness of spare parts supply by additive manufacturing as dual sourcing option. *OR-Spectrum*. In press.
- Topan, E, Eruguz, A.S. Ma, W., Van der Heijden, M.C. & Dekker, R. (2020). A Review of Operational Spare Parts Planning for Service Control Towers, *European Journal of Operational Research*, 282(2), 401-414.
- Topan, E., & Van der Heijden, M.C. (2020). Operational level spare parts planning in a multi-item two-echelon spare parts inventory system. *European Journal of Operational Research,* 284(1), 164-175,
- Topan, E., Tan, T., Van Houtum, G.J., & Dekker, R. (2018). Using imperfect advance demand information in lost-sales inventory systems with the option of returning inventory. *IISE Transactions, 50(3)*, 246-264.

NLDA FMW

- Meghoe, A., Loendersloot, R., & Tinga, T. (2019). Rail wear and remaining life prediction using meta-models. *International Journal of Rail Transportation*, 8(1), 1-26.
- Rommel, D.P., Di Maio, D., & Tinga, T. (2020). Calculating wind turbine component loads for improved life prediction. *Renewable energy,* 146, 223-241.
- Peeters, J.F.W., Basten, R.J.I., & Tinga, T. (2018). Improving failure analysis efficiency by combining FTA and FMEA in a recursive manner. *Reliability engineering & system safety,* 172, 36-44.

- De Jonge, B., Teunter, R., & Tinga, T. (2017). The influence of practical factors on the benefits of condition-based maintenance over time-based maintenance. *Reliability engineering & system safety,* 158, 21-30.
- Tinga, T. (2010). Application of physical failure models to enable usage and load based maintenance. *Reliability engineering & system safety,* 95(10), 1061-1075.

TiU TiSEM

- Akkermans, H. A. (2001) Renga: A systems approach to facilitating inter-organizational network development. *System Dynamics Review. 17(3),* 179-193.
- Akkermans, H.A. & L.N. Van Wassenhove (2018). A dynamic model of managerial response to grey swan events in supply networks. *International Journal of Production Research 56(1-2)*, 10-21.
- Van de Kerkhof, R., Akkermans, H., & Noorderhaven, N. (2016). Knowledge lost in data: Organizational impediments to condition-based maintenance in the process industry. In H. Zijm, M. Klumpp, U. Clausen, & M. Ten Hompel (Eds.), *Logistics and Supply Chain Innovation: Bridging the Gap between Theory and Practice (pp. 223-237).* Springer International Publishing. (Lecture Notes in Logistics).
- Akkermans, H.A., van Oppen, W., Wynstra, F., Voss, C., (2019). Contracting Outsourced Services with Collaborative Key Performance Indicators. *Journal of Operations Management 65 (1)*, 22-47.
- Akkermans, H.A., Zhu, Q., Fang, F., Lamper, L. van de Kerkhof, R. (2019). Designing Smart Services: A System Dynamics-Based Business Modeling Method for IoT-Enabled Maintenance Services *Proceedings of the 52nd Hawaii International Conference on System Sciences.*

OU MST:

- Krikke, H.R. (2011). Impact of closed-loop network configurations on carbon footprints: A case study in copiers. *Resources, Conservation and Recycling, 55,* 1196– 1205.
- Krikke, H.R. (2010). Opportunistic versus life cycle oriented decision making in multi-loop recovery: An eco-eco study on disposed vehicles. *The International Journal of Life Cycle Assessment, 15(8)*, 757-768.
- Zoeteman, B.C.J., Krikke, H.R., & Venselaar, J. (2010). Handling WEEE waste flows: On the effectiveness of producer responsibility in a globalizing world. *International Journal of Advanced Manufacturing Technology, 47(5-8),* 415-436.
- Wang, Y., Zhu, Q., Krikke, H.R., & Hazen, B. (2020). How product and process knowledge enable consumer switching to remanufactured laptop computers in circular economy. *Technological Forecasting and Social Change*, 161.
- Den Boer, J., Lambrechts, W., & Krikke, H.R. (2020). Additive manufacturing in military and humanitarian missions: Advantages and challenges in the spare parts supply chain. *Journal of Cleaner Production*, 257, 120301.

EUR ERIM:

- Hekimoğlu, M., Van der Laan, E., & Dekker, R. (2018). Markov-modulated analysis of a spare parts system with random lead times and disruption risks. *European Journal of Operational Research*, 269(3), 909-922.
- Dekker, R., Heij, C., & Hekimoğlu, M. (2016). Assessing End-Of-Supply Risk of Spare Parts Using the Proportional Hazard Model. *Decision Sciences,* 47(2), 373-394.
- Van Jaarsveld, W., Dollevoet, T., & Dekker, R. (2015). Spare parts inventory control for an aircraft component repair shop. *Omega*, 57, 217–229.
- Zhu, S., Dekker, R., Van Jaarsveld, W., Wang, R., & Koning, A.J., (2017). An Improved Method for Forecasting Spare Parts Demand using Extreme Value Theory, *European Journal of Operational Research*. 261(1), 169-181.
- Zhu, S., Van Jaarsveld, W. & Dekker, R. (2020). Spare Parts Inventory Control based on Maintenance Planning. *Reliability Engineering & System Safety*, 193, 106600.

VU

- Eruguz, A.S., Sahin, E., Jemai, Z., & Dallery, Y. (2016). A comprehensive survey of guaranteed-service models for multi-echelon inventory optimization*. International Journal of Production Economics*, 172, 110–125.
- Eruguz, A.S., Tan, T., & Van Houtum, G.J. (2017). A survey of maintenance and service logistics management: Classification and research agenda from a maritime sector perspective. *Computers & Operations Research, 85,* 184-205.
- Eruguz A.S., Tan, T., & Van Houtum G.J. (2017). Optimizing usage and maintenance decisions for k-out-of-n systems of moving assets. *Naval Research Logistics*, 64, 418–434.
- Eruguz, A.S., Tan, T., & Van Houtum, G.J. (2018). Integrated maintenance and spare part optimization for moving assets, *IISE Transactions*, 50(3), 230-245.
- Karabağ, O., Eruguz, A.S., & Basten, R.J.I. (2020). Integrated optimization of maintenance interventions and spare part selection for a partially observable multi-component system. *Reliability Engineering & System Safety*, 200, 106955.

3.2 Abbreviations and acronyms

AI	Artificial Intelligence
IoT	Internet of Things
LCA	Life Cycle Analysis
MARCONI	Maritime Remote Control Tower for Service Logistics Innovation
MDP	Markov Decision Process
OEM	Original Equipment Manufacturer
OpsCenter	Operations Control Center
PrimaVera	Predictive Maintenance for Very Effective Asset Management
ProSeLoNext	Proactive Service Logistics – The Next Steps
RUL	Remaining Useful Life
SINTAS	Sustainability Impact of New Technology on After Sales Service Supply Chains
SLF	Service Logistics Forum
SME	Small and medium-sized Enterprise
SOR	Stochastic Operations Research
SUPREME	Smart Sensoring and Predictive Maintenance in Steel Manufacturing
WCM	World Class Maintenance
WP	Work Package

3.3 References

- Akkermans, H. A. (2001) Renga: A systems approach to facilitating inter-organizational network development. *System Dynamics Review. 17(3),* 179-193.
- Akkermans, H.A., Basten, R.J.I., Zhu, Q. & Van Wassenhove, L., 2020. *Transition paths for condition-based maintenance-driven smart services*. Working paper. Submitted for publication.
- Da Costa, P.R.D.O., Akcay, A., Zhang, Y. and Kaymak, U., 2020. Remaining useful lifetime prediction via deep domain adaptation. *Reliability Engineering & System Safety*, 195.
- Knofius, N., Van der Heijden, M.C., Sleptchenko, A., & Zijm, W.H.M. (2020). Improving effectiveness of spare parts supply by additive manufacturing as dual sourcing option. *OR-Spectrum*. In press.
- Krikke, H.R. (2011). Impact of closed-loop network configurations on carbon footprints: A case study in copiers. *Resources, Conservation and Recycling, 55,* 1196– 1205.
- Lamghari-Idrissi, D., Basten, R.J.I., Dellaert, N. and Van Houtum, G.J., 2020. Which spare parts service measure to choose for a front-end wafer fab? *IEEE Transactions on Semiconductor Manufacturing*, 33(4): 504-510.
- McKinsey (2015). *The internet of things: Mapping the value beyond the hype*. McKinsey Global Institute.
- Meghoe, A., Loendersloot, R., & Tinga, T. (2019). Rail wear and remaining life prediction using meta-models. *International Journal of Rail Transportation*, 8(1), 1-26.
- PWC & Mainnovation (2017). *Predictive maintenance 4.0. Predict the unpredictable*.
- Ton, B., Basten, R.J.I., Bolte, J., Braaksma, J., Di Bucchianico, A., Van de Calseyde, P., Grootman, F., Heskes, T., Jansen, N., Teeuw, W., Tinga, T., & Stoelinga, M. (2020). PrimaVera: Synergising predictive maintenance. *Applied Sciences,* 23 (10), 1-19.
- Topan, E, Eruguz, A.S. Ma, W., Van der Heijden, M.C. & Dekker, R. (2020). A Review of Operational Spare Parts Planning for Service Control Towers, *European Journal of Operational Research*, 282(2), 401-414.
- Ventevogel, P.C. (2020). *Construction of a proactive alert management model by using artificial intelligence*. MSc thesis, University of Twente: Enschede, the Netherlands.
- Westerweel, B., Basten, R.J.I., Den Boer, J. & Van Houtum, G.J. (2020). Printing Spare Parts at Remote Locations: Fulfilling the Promise of Additive Manufacturing. *Production & Operations Management*. In press.
- Wu, Z., Pan, S., Chen, F., Long, G., Zhang, C. & Philip, S.Y., 2020. A comprehensive survey on graph neural networks. *IEEE Transactions on Neural Networks and Learning Systems*.

3.4 Letters of support

ASML Netherlands B.V.
De Run 6501 5504 DR
Veldhoven
The Netherlands

To:
Dr. ir. Rob Basten
Eindhoven University of Technology
PO Box 513
5600 MB Eindhoven
The Netherlands

Date: 30 November 2020

Subject: Letter of Intent OpsCenter Research Proposal at ASML CSCM

Dear Dr. ir. Basten,

ASML is the world's leading provider of lithography systems for the semiconductor industry, manufacturing complex machines that are critical to the production of integrated circuits or chips. ASML employs more than 23,000 people from 123 different nationalities. Headquartered in Europe's top tech hub, the Brainport Eindhoven region in the Netherlands, ASML's operations are spread across Europe, Asia and the US.

For ASML it is beneficial in participating and sharing knowledge with and universities and peer companies on latest developments in service logistics. Developing methodologies and processes to enable a more efficient and flexible service supply chain to reduce costs is one of ASMLs priorities. Creating an end-to-end view on the service supply chain and enabling efficient exception handling through control tower concepts is one of the key elements in this research in which ASML is interested.

As ASML CSCM we are very interested in the research described in the OpsCenter proposal. We have been actively involved in formulating the vision of success and problem statement through discussions during consortium meetings and a smaller break-out-session with the project leader. If the program design is selected to be worked out to full program proposal, we intend to contribute 40,000 Euro in cash and 80,000 Euro in-kind, spanned over 5 years. During these hours we will use the (preliminary) results of the project to build a (prototype) tool within our company based on our use-case. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Yours sincerely,

Herru Perdana
Manager CSCM Service Business Applications

Marel Poultry
Handelstraat 3
5831 AV Boxmeer
P.O. Box 118
5830 AC Boxmeer
The Netherlands

t +31 (0) 485 586 111
e info@marel.com
w marel.com/poultry

Dr. ir. Rob Basten
Eindhoven University of Technology
PO Box 513
5600 MB Eindhoven
The Netherlands

17 November 2020

Dear Professor Rob Basten,

Marel (www.marel.com) is the leading global provider of advanced processing systems and services to the poultry, meat and fish industries. Marel consists of three key industries – Marel Poultry, Marel Meat and Marel Fish – which are among the most respected in the industry. We have over 6,300 employees worldwide, offices and subsidiaries in over 30 countries, and a global network of more than 100 agents and distributors. The strong research and development strategy of Marel is supported by an annual investment of around 6% of revenues in innovation, which is above the average expenditure of competitors in the field. Highly qualified researchers and technicians, a great working relationship with leaders in the food processing industry and a pioneering mind-set contribute to our successful product development that has kept Marel at the forefront of the industry during the last decades. In close cooperation with our customers, Marel Poultry creates innovative solutions for the poultry processing industry, driving excellence in sustainability, food safety, and performance.

With the poultry processing industry becoming more and more advanced in combination with high line speeds, double shifts and production schedules of 6 days a week, our customers increasingly focus on availability, performance and quality of their production equipment and ask us to ensure this. Services such as time-based preventive maintenance are increasingly being offered to customers to minimize reactive maintenance waste. Two bottlenecks in the business model transformation, from paying for the spare parts and field service engineer (FSE) hours to performance based or pay-per-use, are:

1. High risk due to varying process circumstances that might impact the performance of equipment
2. Limited impact by Marel on controlling and monitoring these process circumstances

In order to reduce the impact of the current bottlenecks and limit the risks, condition monitoring on the process might be used to get more insight into the customers' process and increase the efficiency of FSE utilization. Although condition monitoring and condition base maintenance will likely increase the utilization of remaining useful life compared to time based preventive maintenance, the trade-off for opportunistic maintenance (to combine it with preventive maintenance that is due on short notice) needs to be made. Within this trade-off, also the availability/planning of parts and FSE's should be considered. How to setup the service control tower where condition monitoring is integrated with preventive maintenance, spare part availability and FSE planning is an important and relevant topic. Although the basis of an IT infrastructure is setup to collect field data, securing the data and legal issues on the ownership of the data are also relevant topics.

Marel Poultry
Handelstraat 3
5831 AV Boxmeer
P.O. Box 118
5830 AC Boxmeer
The Netherlands

t +31 (0) 485 586 111
e info@marel.com
w marel.com/poultry

Since the cost of most of the service parts is relatively low compared to other high tech industries, it is tempting to be on the safe side when deciding on safety stock levels. However, due to the large amount of service parts this still results in high stock costs both for the customer as for Marel. Currently the safety stock is determined mostly based on historical spare part consumption. Although this is relevant input, stock levels can likely be better tuned on the demand based on information in preventive maintenance schedules and condition monitoring. Also the application of 3D printing for some of our spare parts could be an option to further lower safety stocks without lowering service levels.

As Marel Poultry, we are very interested in the research described in the OpsCenter proposal. We have been actively involved in formulating the vision of success and problem statement through discussions during consortium meetings and a smaller break-out-session with the project leader. If the program design is selected to be worked out to full program proposal, we intend to contribute 40,000 Euro in cash and 80,000 Euro in-kind. This intended contribution will be paid or used in instalments to be defined during the full period of the 5-year project. During these hours we will use the (preliminary) results of the project to build a (prototype) tool within our company based on our use-case. In this way, we strengthen the valorisation of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Yours sincerely,

Signed by: Dirk den Hartog
Function title: Service Director
Company: Marel Poultry B.V.
Date: 17 November 2020

Royal Netherlands Army

Eindhoven University of Technology

P0 Box 513

5600 MB Eindhoven

The Netherlands

Ministry of Defence

LogisticsTraining Centre

Location
Dumoulinbarracks
Het Zeisterspoor 109
Soesterberg

Mailing address
PO box 109
3769 AP Soesterberg
The Netherlands

Contact
Major M.W.J. van Reedt Dortland
researcher

T 033 42 19139
M 06 23087316
MWJ.v.ReedtDortland@mindef.nl

www.landmacht.nl

Our reference
2020014387

Please quote date, our reference and subject when replying.

Date 26 November 2020
Subject Letter of intent OpsCenter research proposal

Dear Dr. ir. Basten,

Dear Rob,

The Ministry of Defence (MoD) adds to peace, security and safety on the ground. It has three tasks defined by law. These are the protection of the Netherlands' territory and that of its allies, support the improvement of the (international) rule of law and stability and provide assistance in case of disasters and crises. The Ministry of Defence has almost 63,000 employees.

In order to support all missions, logistics is an important capability of the army, including among others transportation and maintenance of military systems in an effective and efficient manner. Guaranteeing a high availability of the systems is crucial, but at the same time the costs to achieve that must be kept at an acceptable level.

In addition, the MoD is striving to a smaller (logistical) footprint to reduce vulnerabilities, increase efficiency and to meet requirements related to reducing the overall CO^2 footprint. Sustainability and circularity are therefore important themes.

Another development is that the MoD is striving to create a logistical ecosystem in which it will cooperate with companies. This should lead to more efficiency because we can share personnel and material, but this demands a better planning and organization.

The theme addressed by the OpsCenter proposal, i.e. the development of a new operations control center for sustainable after-sales (i.e. maintenance and logistics) services using various new technologies, therefore directly aligns with these challenges.

As developments in some of the topics (e.g. additive manufacturing, condition monitoring) already started within the MoD, the proposed project and the associated collaboration with other industries, is expected to accelerate these developments.

As Ministry of Defence we are therefore very interested in the research described in the OpsCenter proposal. We have been actively involved in formulating the vision of success and problem statement through discussions during consortium meetings and a smaller break-out-session with the project leader.

If the program design is selected to be worked out to full program proposal, we intend to contribute 40,000 Euro in cash and 80,000 Euro in-kind. During these hours we will use the (preliminary) results of the project to build a (prototype) tool within our company based on our use-case. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal, and will actively contribute to its success.

Yours sincerely,

Commander Logistics Training Centre

G.A.M.M. van Kuijck
Colonel RNLA

Eindhoven University of Technology
De heer Rob Basten
PO Box 513
5600 Mb Eindhoven
Nederland

Date	30-11-2020
Regarding	Servitization
Reference	WaMe
Attachment	-

Dear dr. ir. Basten, Dear Rob,

PDM is a technical service & consultancy company with more than 200 consultants and engineers. PDM is dedicated to helping the high-tech Manufacturing and Process industries excel. To driving industrial excellence. We increase the lead in technological innovation and optimize the production environment. Industrial excellence is invaluable for our economy. Only by constant innovate you have to want to stand out, to optimize, maintain, or even increase your lead. Through the continuous development of your product and production environment PDM will help you achieve this.

At PDM we will be focusing on align with customers towards Servitization, from product-led tot service-led. Therefore PDM adjusts the customer business model with top level commitment, we adapt the customers organization with decision-making powers at the right level, we convert the customer product proposition into a viable service proposition and we change your customer approach. This requires a strong relationship with customers, creativity, and innovative power. We will focus on improving the service logistics by a higher uptime, more efficient processes and reducing costs.

As PDM we are very interested in the research described in the OpsCenter program. If the program design is selected to be worked out to full program proposal, we intend to contribute over a period of 5 years 40,000 Euro in cash and 80,000 Euro in-kind (approx. 775 hours at 103 Euro/hour) to this proposal. During these hours we will use the (preliminary) results of the project to build a (prototype) solution and tool within our company and the customer companies we work for. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Best regards,

PDM Industrial Excellence BV
W.M.H.P. Mesterom
Owner / Commercial Director

From:
Stichting Service Logistics Forum
Postbus 1058
3860 BB, Nijkerk
The Netherlands

To:
Dr. ir. Rob Basten
Eindhoven University of Technology
PO Box 513
5600 MB Eindhoven
The Netherlands

Subject: Letter of intent OpsCenter research proposal

December 8, 2020

Dear Dr. ir. Basten, Dear Rob,

The foundation Service Logistics Forum (SLF) is a network of approximately 90 companies and universities in Netherlands and Belgium to exchange know-how and knowledge and to stimulate innovation and talent in the service logistics domain.

The Dutch Topsector Logistics looks to us for the service logistics vision and innovation agenda. The research described in the OpsCenter proposal is clearly addressed in this agenda and we have been actively involved in formulating this research proposal. If the program design is selected to be worked out to full program proposal, we intend to contribute 5,000 Euro in-kind. During these hours we will contribute to disseminating the intermediate and final findings to the companies in our network and even wider. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Yours sincerely,

Ben Gräve

SLF chairman

VANDERLANDE

From:
Vanderlande
Vanderlandelaan 2
5466 RB Veghel
The Netherlands

To:
Dr. ir. Rob Basten
Eindhoven University of Technology
PO Box 513
5600 MB Eindhoven
The Netherlands

Subject: Letter of intent OpsCenter research proposal

24 November 2020

Dear Dr. ir. Basten, Dear Rob,

Vanderlande is the global market leader for value-added logistic process automation at airports, and in the parcel market. The company is also a leading supplier of process automation solutions for warehouses. Established in 1949, Vanderlande has more than 6,500 employees, all committed to moving its customers' businesses forward at diverse locations on every continent. With a consistently increasing turnover of 1.5 billion euros, it has established a global reputation over the past seven decades as a highly reliable partner for value-added logistic process automation.

On predictive maintenance and service logistics we expect to increase the level of Condition Based Maintenance by (remotely) monitoring assets, organize timely maintenance and consequently increase the efficiency of service logistics. Secondly we will look for an extension of Service Logistics activities through smarter business models. Thirdly, we will invest in organizing a Operations control tower by focusing on improving operational decision making in order to optimize performance to our customers while optimizing inventory levels.

As Vanderlande we are very interested in the research described in the OpsCenter proposal. We have been actively involved in formulating the vision of success and problem statement through discussions during consortium meetings and a smaller break-out-session with the project leader. If the program design is selected to be worked out to full program proposal, we intend to contribute 40,000 Euro in cash and 80,000 Euro in-kind. During these hours we will use the (preliminary) results of the project to build a (prototype) tool within our company based on our use-case. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Yours sincerely,

J. Rijswijk

Jelle Rijswijk
Managing Director Global Services

Boschstraat 35
4811 GB BREDA
Tel:076-7631553

info@worldclassmaintenance.com
www.worldclassmaintenance.com

Dr. ir. Rob Basten
Eindhoven University of Technology
PO Box 513
5600 MB Eindhoven
The Netherlands

Date:	9th december 2020
Reference nr.:	WCM2020/16
Subject:	**Letter of intent OpsCenter research proposal**

Dear Dr. ir. Basten, Dear Rob,

The World Class Maintenance Foundation (WCM) is the network for Smart Maintenance in the Netherlands. Our goal is radical: towards 100% predictive maintenance in Dutch Industry. We do this by developing, distributing and applying smart maintenance knowledge.
Our smart maintenance projects contribute to an extended asset lifetime, better mobility, the necessary energy transition, knowledge development and last but not least, Dutch competitiveness.
In short, we believe that Smart Maintenance is an important step towards a guaranteed quality of life in the future. We carry out cross-sectoral innovation projects, develop educational programs and work in an active network in which asset owners, service providers, knowledge and research institutions and the government participate.

As WCM we believe the OpsCenter research proposal results contribute towards our goal.

Therefore we are very interested in the research described in the OpsCenter proposal. We have been actively involved in formulating the vision of success and problem statement through discussions during consortium meetings and a smaller break-out-session with the project leader. If the program design is selected to be worked out to full program proposal, we intend to contribute 5,000 Euro in-kind. During these hours we will contribute to disseminating the findings to the companies in our network and beyond. In this way, we strengthen the valorization of the project results and provide a feedback loop towards the researchers for the ongoing (and future) research projects.

We are strongly committed to this proposal and will actively contribute to its success.

Yours sincerely,

ir. A.C.J. Besselink
Chairman