TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

ProSeLoNext results | From reactive to proactive with smart data use

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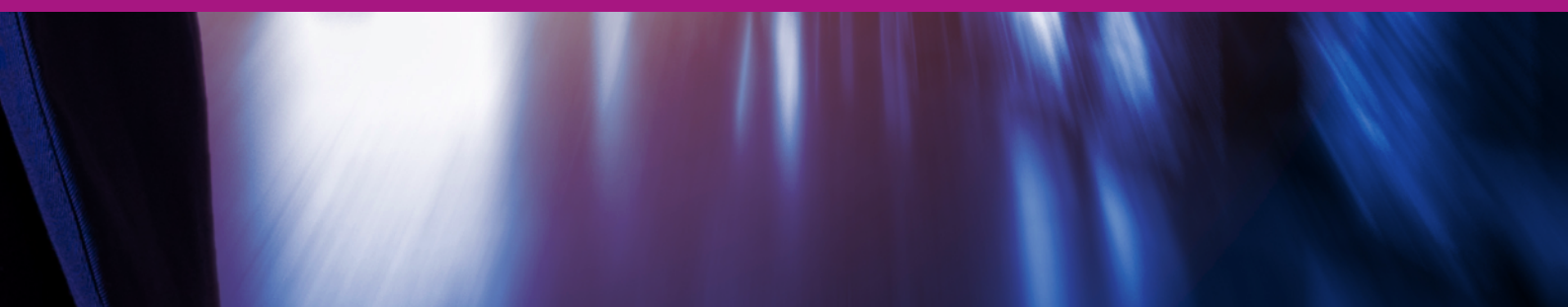
ProSeLoNext results | From reactive to proactive with smart data use

Proactive **Se**rvice **Lo**gistics for capital goods | the **Next** steps



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Preface | Four years of research on proactive maintenance solutions and smart service logistics

High guaranteed uptime and a long-lasting life cycle of machines is not only important for the productivity of capital assets but also for their sustainable use. It reduces the need to produce and distribute extra products, it reduces the use of scarce resources and it reduces the carbon footprint. Smart maintenance solutions and the required smart service logistics can contribute to these reductions thanks to technological and ICT developments.

How magnificent would it be if we could achieve just-in-time maintenance? In that optimal world there would be no waste of labour and materials that have been replaced too early (preventive maintenance) and no downtime costs (reactive maintenance). The road towards finding the right balance and achieving this goal is a long road ahead.

A market-driven research project on proactive maintenance and the required smart service logistics solutions began in the Netherlands in 2005. First at the *Service Logistics Forum* and later under the umbrella of *Topsector Logistiek*. A series of research studies followed one another and still continues to this very day. It is really unique for scientists from three – and later four – top ranking universities in the Netherlands to operate as one team. Most high tech companies that were involved right from the beginning, were also involved in the ProSeLoNext project of the last four years. For the time being, this series of studies has come to an end. This is a wonderful example of team work by universities and the business world!

The interviews in this publication give you a good overview, not only of ProSeLoNext's scientific results, but also of its practical applications at the companies involved. The results are impressive and deserve particular attention for their further application in the high tech industry and in many other industries with capital assets in which proactive maintenance solutions and smart service logistics are at the heart of tomorrow's business.

Now that we have come to the end of ProSeLoNext, we see that the universities involved, and a few of the companies involved and other companies are ready to take smart and sustainable solutions for the service supply chain of complex high tech systems to the next level.

Ben Gräve
Chairman of ProSeLoNext and
Chairman of Service Logistics Forum

Looking back on ProSeLoNext | From reactive to proactive

By collecting data with sensors in machines, the Internet of Things makes it possible to predict when maintenance is necessary. Smart use of data in combination with tools such as a service control tower allow us to introduce predictive maintenance and better service logistics, provided that the business model changes accordingly. Research project ProSeLoNext (Pro-active Service Logistics for capital goods – the Next steps) gave us a wealth of tools and practical experiments, thanks to the close cooperation between researchers and seven companies. Rob Basten (Eindhoven University of Technology), Matthieu van der Heijden (University of Twente) and Ramon Caanen (Gordian Logistics Experts) look back on the project. Rommert Dekker (Erasmus University Rotterdam) and Henk Akkermans (Tilburg University) were also part of the scientific core team.

Matthieu van der Heijden takes us back to the beginning of the journey that has resulted in ProSeLoNext: 'It was in 2005 at the *Service Logistics Forum* – the well-known network organisation of professionals in the Netherlands and Belgium – when the idea occurred to us to conduct research ourselves. Jan Willem Rustenburg worked hard to form a consortium with companies and universities. The companies were enthusiastic, and they were convinced of the added value and wanted to contribute to the research. The cooperation was so successful that we were soon able to formulate research proposals for programmes of *Topsector Logistiek*. That's how we could raise funding for ProSeLo and ProSeLoNext.'

The future of service logistics At the heart of ProSeLo and ProSeLoNext is service logistics of the future. Rob Basten, project leader of ProSeLoNext: 'More and more data is available about how machines and parts are functioning. Think of large copy machines, big computer systems and even airplanes. Smart data analysis makes it possible to plan maintenance better. The supporting supply chain of spare parts, service engineers and service tools can be managed by service control towers. A service control tower is a central hub with real time data enabling smart planning. These new developments open up new possibilities for Original Equipment Manufacturers (OEMs) to develop new business models. Not only selling machines and changing broken parts is part of their business, they can also develop a whole range of services for maintenance and repairs. ProSeLoNext focused on these three aspects: smarter maintenance, management by service control towers and new business models.'

From reactive to proactive At logistics consultancy Gordian, Ramon Caanen supported the research project. For example, he monitored the landing of knowledge and the tools developed by the companies who took part. 'ProSeLoNext consists mainly of research that has been conducted in close cooperation with the seven companies involved in this project: Canon Production Printing, Marel Poultry, IBM, Thales Nederland, Fokker Services, ASML and Vanderlande. In most cases, the goals of the companies and the researchers were well aligned, which led to fruitful and practical results. Basten: 'In general you could say that the companies went from a reactive to a proactive state of mind when it comes to maintenance policies. The role of data has increased enormously. Even five years ago, not all companies had a data science team yet. Now almost all of them do. Sensors are being placed on both current as well as new machines. By using service control towers, customers have a shorter downtime for broken machines and their equipment is becoming more reliable. This is how OEMs can stay competitive in their market. Salaries are quite high in the Netherlands, however, you have smarter maintenance and smarter logistics.'

Ramon Caanen

Rob Basten

Matthieu van der Heijden

Knowledge in practice ProSeLoNext did not only provide us with scientific articles, but also with many improvements in practice. Basten: 'Canon now has a tool for predictive maintenance that has been rolled out in two countries and it is still being developed even further. Other companies have a better overview of their future business model.'
Caanen continues: 'Companies do have a better understanding of the possibilities of their data. They now know what predictive maintenance could look like in their company.' Van der Heijden adds: 'A Master's student's project at Fokker Services is still going on. It's about signalling the risk of repaired parts being delivered too late. Machine learning is used to better anticipate these cases. At IBM we also applied artificial intelligence. And at ASML we contributed practically by signalling an imbalance in stock levels of spare parts. If you look globally there is enough stock, but there can be too much stock in one area and hardly anything in another. In that case, redistributing parts could make sense to reduce the risk of a stockout.'

Learning from each other Caanen: 'Working together with the companies made the research very result-oriented. This was strengthened by the fact that some companies used this programme to work on their internal innovation goals.' Basten: 'Something that has been really good about this way of working is that participants exchanged ideas and experiences at consortium meetings. This new way of maintenance planning means, for example, that companies have to be available 24/7. Although this wasn't officially part of our research project, it was something that a few companies frequently talked about among themselves. The research projects of the Master's students were actually applying scientific research in practice. Their projects were very practical, which made them very useful for the companies involved. The fact that we are planning a follow-up project with part of the consortium shows how pleased everyone is with this university-business cooperation.'

ProSeLoNext (2015-2019) consisted of four main work packages and many smaller follow-up research projects (some of them conducted by Master's students):

1. Work package 1 produced models to plan **predictive maintenance and service logistics.** The companies involved were Canon Production Printing, Fokker Services, Marel Poultry, Vanderlande and Thales Nederland.
2. The subject of work package 2 was **business models.** The companies involved were Vanderlande, Fokker Services, ASML, Canon Production Printing and Thales Nederland.
3. Work package 3 resulted in **decision making supporting models for service control towers.** The companies involved were ASML, Fokker Services and IBM.
4. Work package 4 was all about **valorisation**. A 'cookbook' resulting from WP2 guides service providers on how to take over the responsibility for maintenance and service logistics activities by aligning their interests with those of their customers. The Control Tower Demonstrator, resulting from WP3, was built and implemented, based on an IBM case.

The results of the Master's student's projects at the companies taking part in ProSeLoNext can be found on the website of the Service Logistics Forum: *https://platformservicelogistics.nl/project/proselo-next/*

Key insights

On predictive maintenance

1 Maintenance optimization models that were developed earlier, f.i. in ProSeLo, can successfully be applied in practice. Application in various companies turned out well and gave meaningful results.

2 Sensor information available in practice is often imperfect. Partially observable Markov decision processes (POMDPs) are a way to deal with this. One drawback is that solving such problems is time-consuming, although there are techniques from computer science that may help. Another drawback is that determining the underlying degradation process is difficult, requiring further research.

3 The value of applying partially observable Markov decision processes (POMDPs) can be huge, depending on the characteristics of the problem at hand. For example, having full information is more valuable for cheaper, less reliable components than for more expensive, more reliable components. It is also more valuable if components' deterioration characteristics are only somewhat different from each other.

On business models

1 Business models for smart condition based monitoring (CBM) driven services can be developed for a broad range of maintenance contexts. Following a 'cookbook' approach of a fairly uniform method of system group model building and simulation analysis tailored to specific supply chain parameters works well in a variety of practical settings. Main components of a generic system dynamics model can be reused and modified, reducing modeling time and required modeling skills.

2 OEMs that are eager to develop CBM-driven smart services follow similar paths on their servitization journey, moving from initial exploratory pilots with a small group of key customers to an expansion of commercial offerings, only followed by wide-scale adoption several years later on.

3 Growth of these smart services is driven by two interrelated reinforcing feedback loops:

- CBM service quality loop: as more failure data becomes available, better data analysis leads to better degradation models which improve the quality of the CBM service, which leads to more applications with customers, which leads to more failure data coming available and so on;
- CBM market growth loop: as more customer applications are started, market awareness of these smart services grows, leading to customers being more willing to share equipment performance data and install specific smart sensors, which further grows the number of customer applications and hence the awareness in the market.

Vision of the future

On service control towers

1 Service control towers would benefit from selective alert generation and automated prioritization of alerts if the supply chain status becomes less healthy. Planners are often already struggling with an overload of alerts and set their own priorities. Artificial intelligence in alert generation may help them.

2 Service control towers benefit from intelligent decision support tools. Planners can process more alerts as well as find better interventions if they are supported properly by data driven decision logic, showing them some options for interventions with the expected impact in the service control tower. Proactive operational interventions improve the performance, when possible using advance supply and demand information.

3 Artificial Intelligence techniques are promising for alert generation and reduction, but much more difficult to apply for decision support in service control towers. A combination of AI with traditional operational research-based methods looks promising, however.

4 Operational interventions in service control towers make most sense in the downstream part of the supply chain, close to the locations where customers really need resources. Think of proactive lateral transshipments between forward stocking locations or expediting resupply to forward stocking locations. Expediting return of failed parts or repair of parts that are delivered to a central stock location appeared to have minor impact.

5 Service control towers could benefit from managing more resources than service parts only. To prevent or solve a defect in the installed base, more scarce resources are often necessary (e.g., tools for diagnosis and repair, service engineers). Additional gain is possible by adding all scarce resources to the service control tower.

> By 2030, there are strong financial incentives for companies in the high-tech industry to act more sustainably. Carbon emissions cost hundreds of euros, availability of raw materials is limited, and qualified people are scarce. It is key for companies to minimize resource consumption. At the same time, high-tech equipment is becoming ever more complex and by 2030 users aim to have lights-out operations (i.e., factories that are fully automated and don't require human presence on-site).

> This requires 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, spare parts and expensive tooling.

> To facilitate this, equipment is connected to operations control centres in which data are shared, activities are continuously monitored, and pro-active interventions are proposed to avoid downtime.

> With techniques from artificial intelligence and machine learning, big data is transformed into predictions on, e.g., failures and supply disruptions but also into advice. These are typically used by human decision makers who select the best option supported by key relevant information.

> Service supply chains that enable maintenance are pro-active and resilient: Supply disruptions are predicted, and all supply possibilities are used, including 3D printing of parts.

> The control centres are typically operated by original equipment manufacturers (OEMs), since they have most technological knowledge on a wide installed base. This requires servitization with the right contracts and collaboration modes. It also enables the OEMs to maximize the useful life of equipment, and to reuse scarce materials at the end of the life cycle.

Predictive maintenance | From break & fix to sense & respond


Mark ten Have


Lonneke Teeuwsen


Dirk ten Hartog

Predictive maintenance is maintenance based on analyses of data of spare parts: When do machine parts tend to break? And what is usually the cause? And how is essential maintenance and repair being noticed? If these aspects of critical parts in machines can be identified, machine maintenance can be planned in a much smarter way. Several Master's students have taken predictive maintenance to the next level at Canon Production Printing (CPP) and Marel Poultry, amongst others.

Rob Basten, associate professor at the Eindhoven University of Technology, led ProSeLoNext and the work package on predictive maintenance. 'The basis for this work package was laid in ProSeLo, which preceded ProSeLoNext. In ProSeLo we looked at maintenance planning by combining different policies: A number of parts are maintained once in a while (time-based maintenance) or after a certain period of use (usage-based maintenance), while other parts are only maintained as soon as they break. A third type of parts are maintained by predictive maintenance, meaning based on the condition information received from the machine, which predicts possible failure of those parts. The goal of predictive maintenance is to prevent these failures without acting too early in order to prevent unnecessary costs. It is highly complex to combine three different maintenance policies for many components in a smart way. This theoretical preliminary work has been further developed at several companies involved in the ProSeLoNext project. These companies are not only CPP and Marel Poultry, but also Vanderlande and Fokker Services, for example. We attracted over twenty Master's students and a PDEng candidate – Felipe Ramos Gaete – who integrated the different study results at CPP.'

A completely different service concept Mark ten Have is Service Product Manager at CPP and responsible for the global support and service profitability of a number of products. 'We were developing an entirely new product for a new market in 2011. This meant a shift from printers in 8/5 office environments to 24/7 industrial printers, used for example by book printers. This had quite an impact on our service concept. For the office environment a 'break-fix' concept suits perfectly. If a machine breaks down, a serviceman will arrive to fix it. The customer usually has other equipment as a temporary backup. It's inconvenient for a while, but not too much of a problem. The corresponding business model is based on turnover and profits from parts and consumables.
At a large printing company, our machine is part of its core business, so an unexpected downtime has great impact with immediate financial consequences. Such printing companies need to be able to deliver quickly to their customers. Books are being ordered on demand: Customers order in the morning and books have to be printed and sent in the afternoon, in order to have them delivered to the customer the next day. What we sell our customers is reliability and uptime. So, for our high-end products we had to go from break & fix to sense & respond in our maintenance concept.'

Fifteen Master's students To acquire knowledge for this change, Ten Have was looking for good people to work with. This was the start of first ProSeLo, and later ProSeLoNext. 'Together with the students we were able to obtain knowledge we did not have yet. We determined which direction we should take with CPP and which topics fitted that purpose. This was how the roadmap for research projects originated.' These

Marel produces machines for poultry, meat and fish processing. The poultry division is the largest and represents half of the total turnover, followed by meat with one third of the turnover. The company has multiple sites around the world and half of its turnover is realised in Europe, the rest is equally divided between North America and the rest of the world. The turnover in the Netherlands is less than 5% of the total turnover, but one third of all staff is employed in this country. In 2019 Marel had 6,300 employees. *Photo: Marel*

projects were carried out with about fifteen Master's students, one after the other, each solving a part of the puzzle. By doing so we did not only acquire the new knowledge we needed, but we also found the young people we needed for the company. This led to a positive chemistry and to innovative ideas that we could link with the already available experience in the company.' As a result, CPP started using the Maintenance Scheduler. Ten Have: 'We are still working on rolling out this system to all our products and sales organisations. This requires a culture shift and that takes time. What's more, our Japanese parent company is operating much more in the consumer market and office market, where break & fix is still a valid concept.'

The Maintenance Scheduler Lonneke Teeuwsen, Service Product Specialist, was one of the Master's students. She graduated in 2016 after which she joined CPP. Initially, she continued to work on the Maintenance Scheduler, but currently she is part of a product group that does not make use of it yet. 'It was good to see how all the individual projects came together in the Maintenance Scheduler project. At first it was still a theoretical model: What if we had all data of every part? Then this could be the result. We made a simplified version to put into practice. The more data on parts we can collect, the more we will develop this simple version. For example: A trigger for a specific belt developed by a student. The belt is driven by motor power and if it wears out, more motor power is needed. In the past, replacement was based on an error in case the power volume reached a certain value. This led to unnecessary errors since powers can also peak for other reasons. A much more advanced algorithm can be used in this case. By collecting more data on failure behaviour we were able to develop a trigger that gives a notification two weeks before failure occurs which leads to fewer unnecessary errors.'
Teeuwsen is pleased that the Maintenance Scheduler is still being optimized. 'It's a platform that can be built out with new options, so we can incorporate new triggers and parts in the same framework. It has been a good way to introduce predictive maintenance with small steps into a company. You shouldn't wait until a tool is 100% finished and is in full working order, but in stead you have to try things out in small groups and in pilots to gain experience with all kinds of implementation issues.'

Eager to find the answer Ten Have: 'So, ProSeLoNext has given us quite some concrete results. This was also the challenge I gave my students: Deliver something we can use immediately. And it has to be academically sound too! But we succeeded very well, actually. The brilliant thing was that all those students on the floor didn't take us much time at all. The more there were, the easier it got. The first student supported the other students, and I could focus on the subject. And all my other colleagues became used to the students as well and supported them like I did. It is important to be eager yourself to find the answer to a specific question. If you can share >

Canon is a leader in consumer and professional imaging. It was established in 1933 and has grown into a strong brand with a global presence in the Office, Imaging System and Industry business segments. Canon's powerful R&D is known around the globe for its high number of patents awarded yearly. Canon has more than 195,000 employees (2018). Canon Production Printing is founded and headquartered in Venlo, the Netherlands, in the heart of Europe's high-tech corridor. Canon Production Printing has multiple sites around the world and has more than 3,000 employees (2019). *Photo: Canon*

that enthusiasm with your students, then it will be a success. Having students in your company? I can recommend it to everyone!'

Spare tyre in the back of your car Dirk den Hartog is Service Director Poultry at Marel. Marel is global market leader in machines for poultry, meat and fish processing. 'In contrast with Canon, we have always worked in a B2B market and in an industrial environment. Our machines have a lifecycle of ten to twenty years so maintenance is an important aspect. We are constantly working to keep our machines up and running. Our customers need to deliver daily fresh products at supermarkets, so on time delivery is crucial. It comes down to hours. You really don't want any unscheduled downtimes. The shift to predictive maintenance has been going on for somewhat longer at Marel. 'In ProSeLoNext we focused firstly on coding all parts on the basis of several characteristics. For some parts we say to the customer: You'd better have a spare one yourself. You can compare it with a spare tyre and a spare set of lights in the back of your car. We have to adjust our logistics supply chains to that behaviour. If the customer used this spare tyre, we have to arrange a new one. For other parts we say to our customers: You have to let us carry out regular servicing and replace it on time. You can compare it with a full servicing of your car. And finally, there are also a number of parts that need to be controlled according to a specific rhythm. Based on all these codings we were able to develop several service products.'

From output to outcome Looking back, project leader Rob Basten is very pleased. 'All the research that has been done turned out to work well in practice – sometimes with minor adjustments. As a result, the customers of the companies taking part in ProSeLoNext are suffering from fewer unscheduled downs. These unscheduled downs are the main difficulty when running a business. One could say that we delivered the scientific output in ProSeLo and the societal outcome in ProSeLoNext. We also started with a follow-up study. In this study we look at maintenance planning models that can be used when signs of wear and tear are hard to detect. For example: We see temperature rising in the maintenance box of CPP, but what does it mean exactly? It may well have three causes. Which models can be used in this case? These kinds of processes are only partially observable, and you will have to act on a hunch, an idea of what you think is going on. I would love to test our theories on this subject at companies in a future project.' <

The researchers involved were all at Eindhoven University of Technology: Rob Basten, Sena Eruguz (currently VU Amsterdam), Geert-Jan van Houtum, Oktay Karabag (currently Erasmus University Rotterdam), and Felipe Ramos Gaete (currently KLM).

Rommert Dekker

Kaveh Alizadeh

Service Control Tower | Making Fokker Services fit for the future

Fokker Services (FS) has been involved across the entire scope of the ProSeLoNext project: from studying condition-based maintenance, to adjusting new business models with the 'cookbook' and developing various aspects of its service control tower. Not everything that was developed could also be implemented. However, being involved in this project has provided Fokker Services with many new insights. 'It's important for us to be part of the ecosystem. We are taking every small step forward that we can.'

Rommert Dekker, professor at Erasmus University Rotterdam, supervised Master's students, a PhD researcher and a postdoctoral researcher. Dekker: 'First the building blocks were laid for the control tower. Two fascinating tools were developed: one for Dynamic Inventory & Pricing and one for Obsolescence. Fokker Services is, when it comes to service logistics, in a different market compared to the other companies taking part in ProSeLoNext. It's a highly competitive second-hand market. For example, we looked at the pricing of parts related to the expected market share, linked to uncertainty about market size. Our postdoctoral researcher, Sena Eruguz, calculated what the implementation of this model with an optimal tactical control would mean in terms of cost efficiency. Strangely enough, this turned out to have a rather small effect. The savings are smaller than you would expect. However, everyone does appreciate having all the information in one place, so planners can make accurate analyses. Sometimes people make assumptions about the parameters in tactical planning that are not quite correct. These can then be corrected by using the service control tower for operational control.'

Characteristics of suppliers Kaveh Alizadeh is System Improvement Manager at Fokker Services and he worked closely together with many researchers on the service control tower. He joined the project for the obsolescence tool when it was already underway. This tool helps to predict the moment when suppliers will not be able to supply a certain part any longer. 'Based on the information from our obsolescence management team, the researchers looked at certain characteristics of suppliers. Some characteristics are strongly correlated with the chance that a part can no longer be supplied.' Dekker adds: 'For example, how long ago did we order something at this supplier? That was a clear indication as to whether it would still be available or not. The longer ago it was, the higher the chance that a certain part would be unavailable. When there's lots of variety in the delivery times, that's another clear indicator of the risk that parts become obsolete. This has resulted in a Top 10 of 'risky suppliers'.'

More and more data driven decisions The obsolescence tool was partly implemented by FS, but as for the Dynamic Inventory & Pricing tool that didn't really work out. Alizadeh: 'I would have liked to further operationalise it. Various >

‘We are taking the first step towards automated decision making’

Wouter van Dis

Martin de Jong

researchers worked on it and, in the end, a full prototype of the control tower was completed. We did not implement it, but certain aspects of it are certainly relevant to put to use. Student David Chi developed a tool to collect market data and we are using the 2.0 version of it. We’re also working on improving our tactical planning. When it comes to tactical planning, there is a large amount of generalisation and this causes a gap between tactical planning and how this is carried out in practice on an operational level. Two Master’s students did some work on our alert management and intervention management systems. Using machine learning, a prediction tool was created that can estimate as to how high the chance is that a supplier will deliver too late. This includes a simulation model that looks 10 days ahead into future changes and stock levels. This is how we want to make the transition from intuitive decisions to data driven decisions. We are taking the first step towards automated decision making.’

Towards different relationships between players
Wouter van Dis is Advanced Analytics Manager. The applications developed by ProSeLonext are also on his ICT platform. ‘In 2016 I set a future goal: I wanted to know which of our clients’ aircraft components would break tomorrow. In the case of condition-based maintenance, you remove the part before it really breaks down. I always compare it with the timing belt in your car. It’s very expensive to repair it if you wait until it has broken completely. So, it is replaced after a certain mileage – to prevent the major breakdown and high costs. At FS we don’t do this based on a certain mileage, but based on the condition of each part. Since we have introduced condition-based maintenance, we are doing more repairs than before but the repairs are cheaper. This does mean, however, that we have been discussing with our Sales colleagues for some time now as to what we should charge our clients. They want to keep the costs low, but we argue that the client should actually pay a bit more. Each player is taking up a new position in the field now that we are implementing condition-based maintenance. I keep a close eye on all the trends and developments – also in other research projects – as to what this could mean for FS. Our biggest challenge continues to be to get hold of the data. I don’t need to own the aircraft data, as long as I can see and use them. We’re now looking at block chain technology in this context.’

Learning with others Martin de Jong is Manager Quality Assurance & Analytics. He succeeded Menzo van der Beek as steering group member at ProSeLoNext. ‘We look at which new knowledge development is relevant for FS and how we can turn that new knowledge into research projects and how we can find funding. These kinds of projects – whether they are successful or not – show us how we can improve – and also where we

Fokker Services is an independent aerospace service provider of tailormade solutions for regional, commercial and military aircraft. From supplying parts and offering exchange programmes to modification programmes and maintenace of parts. Carrying out maintenance, modification and repairs for many different types of aircraft, Fokker Services is based in Hoofddorp in the Netherlands. Employing 550 people, it is also located at Schiphol airport, in the United States and Singapore. *Photo: Fokker Services*

should *not* be looking to make improvements. It's great for us, which is why so many of our employees are involved. And it's also very valuable for other companies. We are in a different product cycle compared to the other companies in ProSeLo-Next because they are all Original Equipment Manufacturers (OEMs) and we carry out maintenance. This is the reason why they focus on the data of their own products, while we need to convince our clients that we can see and use their data.'

Valuable eye-openers for the ecosystem Kaveh Alidazeh: 'Learning from and with other companies and conducting scientific research is making us fit for the future. A project like ProSeLoNext encourages us to keep going.' Wouter van Dis: 'ProSeLoNext has provided us with various eye-openers: Where are the issues that we should be working on? What is going to change in the future and how can we work on this with the entire ecosystem all at the same time? The small steps that we *can* take, we are definitely taking already.' Rommert Dekker: 'ProSeloNext has been a valuable testing ground. It has allowed us to work on problems – both in theory and in practice. It was also very valuable for the many students who were involved in this project. They had a fascinating environment to study in, which gave them the opportunity to develop new skills. However, we do need a great deal of patience. But if we stay at it long enough we can achieve so much.' <

This study on various elements of the service control tower at Fokker Services was conducted by a number of researchers: Rommert Dekker (Erasmus University Rotterdam) and Sena Eruguz (currently VU Amsterdam), Mathieu van der Heijden, Engin Topan and Nils Knofius (University of Twente).

Service Control Tower | ASML keeps a proactive grip on 20,000 parts

Ruud van Sommeren

Engin Topan

Every day, ASML – the company that builds machines to produce computer chips –makes sure that its customers' machines are working. Every minute when a machine is not working can be very costly. It is a major challenge for ASML to balance stock levels and urgent deliveries and to prevent longer down-times, because ASML works with more than 20,000 parts in various centres around the world. The ProSeLoNext research study and the application that was implemented offer support in this complex process of finding the right balance.

Ruud van Sommeren is Senior Manager Supply Chain Services. 'ASML not only builds machines for customers, but it's also responsible for keeping these machines in good working order. We have parts in stock spread throughout the world close to our customers. One of the clauses in many of our contracts states that we need to make sure that a machine needs to be back in action within one hour after it breaks down. One hour of downtime can cost our client as much as 100,000 euros. One of the tools we are using to keep this promise is the supply chain control tower.'

From reactive to proactive The failure rate of ASML components is generally low, but *if* something happens we must be able to act very quickly, explains Van Sommeren. 'This means that we have parts in stock in various warehouses located around the world. As the demand varies, it may well happen that a region is out of stock while another region still has plenty in stock. Are we going to wait until the next delivery from a supplier arrives? Or do we redistribute the stock between the different regions? If a new delivery is expected within a few days, we do nothing. But if it's going to take a month, then it's better to redistribute the available stock in the best possible way. By doing so, we reduce the risk of longer downtimes of machines due to certain parts being unavailable in a region. What's the best possible moment? How does this relate to other options in terms of costs? We must ensure that Asia, for example, is not suddenly faced with a shortage. These kinds of decisions can only be made if there is a very good overview of and a clear insight into risks and costs.'

New steps in science Fortunately, this clear overview and insight is offered by researcher Engin Topan (University of Twente) who has now been appointed assistant professor. Master's student Ite Jan Muller developed this application in more detail. Topan: 'By developing a method for proactive shipments, the transition is made from tactical to operational planning. Not much research had been conducted on this topic yet. I began by studying the existing literature in close cooperation with my colleagues at Erasmus University Rotterdam. The first goal was to confront the theory with the practice of ASML. The second goal was to create one planning method that integrates all the various strategies that Original Equipment Manufacturers (OEMs) can use to reduce downtimes. One of these strategies is the proactive redistribution of parts. This is a rather complex system, because we also wanted to minimise the risk of certain parts being out-of-stock.'

Generating alerts Topan: 'The scientific paper we published was unique, partly because we also incorporated all the stock levels – locally, centrally and what's still in the pipeline – to decide what the best proactive shipments are. The research looked very promising as to what it could potentially contribute to the practice of ASML. However, we had to test our assumptions in the real world. Ite Jan Muller implemented a simpler

ASML is a Dutch high tech company and the world's largest supplier of machines for the semiconductor industry, in particular steppers and scanners, which are used in the production of computer chips. Their main customers are chip producers. The global headquarters and business complex of ASML is located in Veldhoven, in the brainport region of Eindhoven in the Netherlands, where both research, development and assembly in clean rooms take place. The company also has 60 service points in 14 countries to support the installation and delivery of machines and spare parts. *Photo: ASML*

version of this planning method at ASML and added alert generation. An alert is generated when a certain part is about to go out of stock. It's like an alarm clock so you can act on time. This should not happen all too often, because otherwise the planners can't handle it.' This research project is still being carried out. Master's student Kirsten Brands has added operational planning of tools for failure diagnosis and repairs to the control tower at ASML. Topan hopes that more aspects of the research paper can be implemented at ASML to further confront the theory with the practice of ASML.'

No 'ping-ponging' Ruud van Sommeren: 'We have now been using Ite Jan Muller's application for over two years for all our parts. This immediately added a lot of value for us. The application generates a 'snap shot' of all our stock levels of parts in all regions. We compare this with our expectations: Which parts will we need in the coming month? If we see that a shortage could arise somewhere, then we must consider which risks we run and whether it is worth it to ship a part from another region. There are other options. We must make careful decisions. An operational planner always evaluates the alert and takes the best possible action. We have made some adjustments to this application ourselves. There are 'thresholds' for when an alert is actually given and we adjust these thresholds regularly. This is because we don't want the planners to receive alerts all the time whenever small changes occur. Neither do we want for parts to be sent back and forth all too often, 'ping-ponging' around the world. We can generally conclude that redistributing components between regions helps to further reduce the downtime of our customers' machines.'

Not gathering dust Matthieu van der Heijden, associate professor at University of Twente and workpackage leader: 'It feels very good to see that scientific research has actually produced a very useful tool for the practical world in this case. My biggest concern as an academic, is that a perfectly good theory ends up in a desk drawer gathering dust because it turns out to be too complicated in practice. But in this case it has worked out really well. However, it does still happen that parts are pro-actively moved to another warehouse, when those parts *do* arrive there in time from the regular source after all.' Van Sommeren: 'Yes, that happens, but proactive redistribution is worth it for ASML.' <

The research project on proactive shipments at ASML has been conducted by researchers of the University of Twente, namely Matthieu van der Heijden and Engin Topan. Their Master's students Ite Jan Muller and Kirsten Brands – now graduated – made important contributions. Jacky van de Griendt guided and supervised them at ASML.

Business Models | A cookbook for OEMs and their customers to find solutions

Henk Akkermans

Marco Vijfvinkel

Service logistics is about what happens after a product has been delivered. It's about servicing and repairs. You don't want to do too much maintenance, but not too little either. When machines break down this leads to business interruption. Predictive maintenance is the ideal solution – if it has been cleverly planned based on data analyses of failure behaviour and based on other aspects of components and systems. But how can we prevent a situation in which only Original Equipment Manufacturers (OEMs) are investing and their customers are merely enjoying the benefits? Well, by working closely together on new business models using the cookbook: 'The development of Dynamic Business Models for Smart Services'.

Henk Akkermans is professor at Tilburg University and director of the World Class Maintenance foundation. He has been developing strategic logistics models for many decades, and he initiated the work on business models within ProSeLoNext. Initially, this topic only played a minor role in the entire research project. Akkermans: 'The research on predictive maintenance was mainly technologically oriented. However, we discovered that the technology can only work well if the finances are taken into account as well; the money side of things. If there is no financial incentive, predictive maintenance will never really get off the ground. So, we decided to make the topic of business models a much more important part of this research project. This turned out to be highly relevant for all the companies taking part in ProSeLoNext.'

The benefits are not shared equally Technologically, smart and proactive maintenance is a good option. Akkermans: 'Most companies usually manage to find the necessary data about their machines and components: How often are they used, what is their wear and tear, what is their expected life cycle? You can decide whether or not to use that data to smartly plan servicing and maintenance.
However, something that is much more complicated is the business side of this. It seems that only the OEM is the main investor: No more fixed servicing and maintenance appointments so no more certainty of that type of regular income. By using smart maintenance, fewer parts are sold. The customer using the machine seems to be the only one enjoying the benefits. The machine is available for longer periods of time, and there is less unexpected downtime. This means that it's not in the OEMs' financial interest to implement predictive maintenance. So, in practice, this prevents predictive maintenance from being successfully introduced.'

A major challenge Akkermans explains: 'The key question is how we can divide the costs and benefits more evenly and more equally, making it more attractive for the OEM to implement predictive maintenance. It's about making the right calculations together, and making a fair deal. This means a

Vanderlande is global market leader for future-proof logistic process automation at airports and in the parcel market. It is also a leading service provider for process automation in distribution centres. Vanderlande works at 600 airports, including 12 of the top 20 airports in the world. With more than 6,500 employees in various locations on every continent, the annual turnover of Vanderlande is 1.6 billion euros.
Photo: Vanderlande

performance-based contract, rather than a cost-plus contract. It sounds simple, but it's not an easy calculation to make. Costs and benefits change over time. And then there is the organisational side of things. It all begins within the companies themselves. The Sales department has different interests compared to the Production or Services departments. To start with, you need to agree with the other departments first. And then you also need to agree with the customer, which also has various departments with different interests.'

Being more open and transparent First the researchers developed a calculation model. Akkermans: 'Technology is at the heart of this: How do machines break, how often, how long does it take to fix them, how often do you need to service the machines to prevent failure? In addition, there is the capacity that is required, such as the service engineers, the sensors, and what they cost. The longer periods of uptime mean better revenues. You can change various elements and see what the effects are. Imagine that you want to know the impact of condition monitoring on the profitability of a new smart service. You can change the sensitivity in the model to see if the annual profit changes and what any unforeseen side effects may be. This is how both the OEM and the customer have a shared insight into what is possible with a different business model. It's new and perhaps scary for companies to start sharing information about their business and their earnings – information that was never shared openly in the past. So, companies need to become more open and transparent, and this makes them more vulnerable. Combining this hard and soft side is incorporated in the business model method in the cookbook that we have written. It's not new in itself, but it has been entirely adapted to service logistics.'

Working with departments across the organisation
Marco Vijfvinkel heads the competence center for digital and IT services within Vanderlande. 'We have been working on the topic of predictive maintenance for quite some time now. It was important to us to take part in a research project like ProSeLoNext because it allowed us to get to know other companies that are working on it too. Two years ago, Henk Akkermans, Quan Zhu and Roland van de Kerkhof approached me with their method to calculate business value. It was precisely about an issue that we were struggling with at that time. As a joint project, we then worked out the model in more detail in a series of workshops. We added all our data about failure behaviour, when parts break, financial data and more. This meant that we had to work closely together right across the organisation with various departments. So, we didn't only take the technological perspective, but also the service proposition into account, including Finance, R&D and of course the service engineers who will be using the predictive maintenance solution.'

A journey The model was tested in practice in the real world of Vanderlande. What was the outcome? Vijfvinkel: 'The biggest >

Thales Nederland is the largest defence company in the Netherlands and it produces advanced radar and infrared systems and fire guiding technology. It is also known for the servicing and maintenance of the public transport smart card system *(OV chipkaart)* in the Netherlands. The Thales Group works globally and is located in 56 countries with nearly 64,000 employees and a turnover of nearly 15 billion euros in 2016.
Photo: Thales Nederland

problem turned out to be the availability of the correct input data. Are we certain about how often a part is not working and what the cause is? Which failures are we going to prevent exactly when we implement predictive maintenance? However, we also immediately saw the benefits and advantages. No need to carry out inspections, for example. The maintenance costs go down. But the model didn't allow us to make predictions. It only indicated a trend. Something else that became clear was where the added value was, both for our customers and for ourselves. If you go down this path, you will really make a journey together, because you discover that the knowledge of and insights into your own servicing and maintenance processes need to be better. For example, we found that we had to more clearly define all kinds of service and maintenance activities to be able to collect data.'

The data challenge Akkermans: 'Vanderlande was the fourth business case we did within the context of ProSeLoNext. Even though the method we used is the same as everywhere else, the problems in each company are different. At Vanderlande, it turned out that reducing the number of inspections would be the real benefit. There was one problem that all the companies faced: the data. Keeping track of everything that happens to the parts, the servicing, maintenance and repairs. Preferably digital and if possible automated so employees don't need to do much by hand. You see, they need to describe time and time again what was wrong, and how it was solved. It would be great to use machine learning algorithms.'

A step-by-step plan After simulations with the calculation model at various companies, the method and findings were collected in the cookbook. Feng Fang, university lecturer at Tilburg University who also works at Asset Health Dynamics helps companies to make smarter decisions, by using simulations, for example in logistics. He is the author of the cookbook together with Roland van de Kerkhof and Laurens Lamper. Fang: 'The aim of the cookbook is to teach companies how they can develop good business models for the service logistics. It is a step-by-step plan. One business case is included in the book – the case of ASML – so companies can read how applying the method worked out in practice. The cookbook can be used to learn and play and see the impact of various changes to the business model on the entire system. We used the cookbook for workshops at companies including Fokker Services, Marel Poultry and Thales Nederland.'

Defence is different Berend Jongebloed is Product Manager Service at Thales in Hengelo in the Netherlands and one of his colleagues was his ProSeLoNext predecessor. Jongebloed: 'I work on research projects that Thales is involved in. The goal is to learn what other companies in other sectors are doing and to assess how we can apply that new knowledge in the field of defence. I joined ProSeLoNext when the cookbook

Feng Fang

Berend Jongebloed

had just been published. We had started our, what we call 'servitization journey': Exploring what it would mean for Thales if we don't only sell products, but also service them. We tried to familiarise ourselves with this new way of thinking. For example, we were working with methods for business modelling and value proposition design.
The defence industry has a completely different dynamic compared to everywhere else. By taking a workshop with the cookbook we discovered that servitization in the field of defence is indeed difficult. The roles are divided differently compared to other sectors. We are OEM, but who exactly is the service provider? The navy or Thales? And how do we go about obtaining and sharing data? It's complicated, so we continue to explore this.'

A radar or aerial images? Jongebloed emphasizes that for performance-based contracts, the relationship between the OEM and the customer is even more important than in the case of short-term transactions. 'You enter into a long-term agreement together. This requires more mutual trust than other situations. The element of time is always an important issue for us as well. We deal with ships that need to last at least 30 years. Recent new orders for Thales mean that we are playing the more traditional OEM role again. Just like in the past, we are supplying radar systems and not aerial images yet, as we would say in servitization terms. We are, however, asked more frequently to give a guarantee on life cycle costs. And the life cycle approach with more attention for sustainability, well that's certainly something that's here to stay.'

Covid-19: maintenance from a distance Vanderlande works for airports, distribution centres and package sorting facilities. Vijfvinkel: 'Customers will increasingly demand predictive maintenance to be able to keep a grip on total cost of ownership. But it will take many years before we have completely left the operational performance system behind us and have fully implemented total cost of ownership. Since the outbreak of Covid-19, it has become even more important for airports to investigate which aspects of maintenance need to be carried out to achieve various business results. We are now mainly looking at existing technological systems, to be able to learn quickly in an operational setting. One of the effects of the Covid-19 outbreak is that we will provide more support from a distance for servicing, maintenance and repairs so our customers can do it themselves. This leads to different requirements for the business model.'

A look behind the scenes What have researchers learnt from all these different situations and from working with the cookbook? Akkermans: 'At least we now have one generic method that is applied slightly differently in each business case. Companies must all take roughly the same steps. We have the proof of concept. As a scientist I would say: We're still working on it. But as a consultant I would say: We're more than ready to implement this more widely. We see that predictive maintenance is an increasing trend in society that is here to stay – so this isn't just an ICT but a business issue. Even though there are large differences between companies and products, the number of similarities are surprisingly large. It always reminds me of the first sentence of Tolstoj's *Anna Karenina*: 'Happy families are all alike; every unhappy family is unhappy in its own way.' What makes this project so special is that we have been able to follow the developments at five or six companies. This is usually private and confidential information. So, we have truly been given a look behind the scenes.' <

The researchers involved were postdoctoral researcher Quan Zhu alongside professor Henk Akkermans, and Akkermans' PhD candidates Feng Fang and Roland van de Kerkhof, Tilburg University.

Demonstrator | ‘Playing’ with a service control tower provides new insights and more options

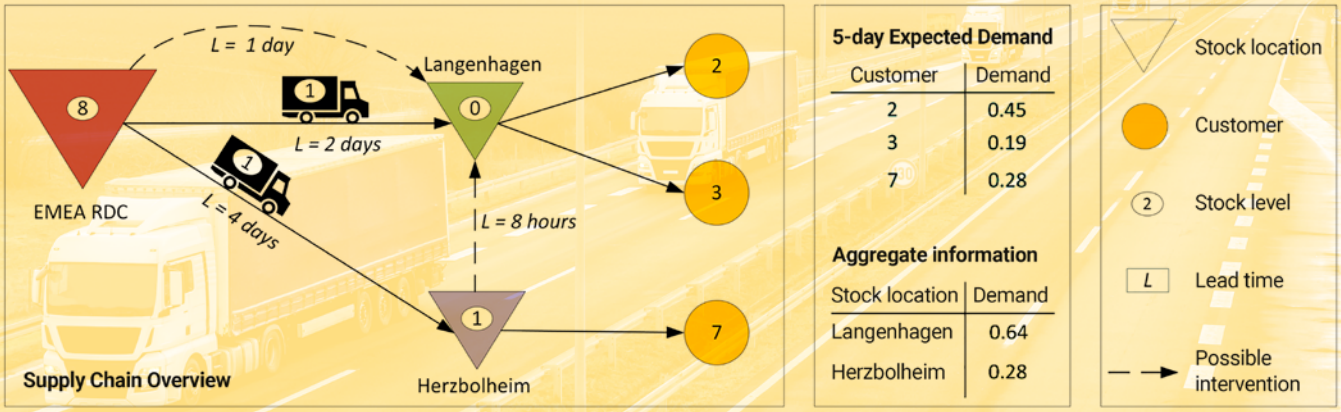
Berry Gerrits

Jaap Hazewinkel

Imagine a tool that helps planners in parts logistics to decide more easily. The tool gives these planners a number of options for which the implications have already been calculated. This allows the planner to quickly see what would or would not be a good decision. Should they proactively ship a spare part from one warehouse to another, or not? The Demonstrator is a simulator of a service control tower that offers a realistic case thanks to the data from IBM. It provides valuable insights, both to scientists and to the logistics industry.

Berry Gerrits of *Distribute builds simulation tools for innovations in logistics* is an entrepreneur and a PhD candidate. He developed the Demonstrator with the aim of familiarising the industry with the options of a service control tower. Jaap Hazewinkel is manager of Strategy and Transformation at IBM and internationally involved in innovations in parts logistics for this ICT company. ‘We supplied real data from a small section of our supply chain for the Demonstrator. We also helped by offering our practical knowledge and experience. This allowed the researchers to build a rather realistic case, which was manageable enough to experiment with. In real life, the logistic processes at IBM are much more complex.’ Gordian Logistics Experts, valorisation partner at ProSeLoNext, worked both on the content and on the experiments. Ramon Caanen: ‘My former colleague Maarten Driessen made sure that the data from IBM ended up in the Demonstrator correctly and completely. We provided the tactical content, as it were. We also organised workshops so logistics experts in the business could find out more about the Demonstrator.’

Shipping parts proactively or not? Gerrits: ‘Planners are often faced with the question whether they should proactively make adjustments to the logistic process or not. They need to know the implications of their decisions. The Demonstrator is a dashboard showing the effects of various decisions in the short term and elsewhere in the supply chain, or in the entire network. During the workshops we played a game with the logistics professionals. We gave various teams of planners various levels of information and looked at the effect on their decision-making behaviour.’ This example provided by Matthieu van der Heijden explains the simulation: ‘Imagine that a company has distribution centres in various German cities. At one of these centres a certain part is no longer in stock. What to do? One colleague says that it’s not such an important part and that new stock will arrive in time. Another colleague says: Let’s ask another distribution centre to send one of their parts. But wait: Suddenly information arrives that this part was shipped from the central warehouse a few days ago. Perhaps it would be better to wait for that after all. This is how planners can experience the added value of information flows.’



Alert! Zero stock of part 8 at Langenhagen

Figure above: The demonstrator presents an event in which stock is running out at a particular warehouse. Immediately relevant information about the condition of the supply chain and possible interventions is provided.

Inconsistent and indecisive Caanen: 'We saw that planners who had little information at the beginning were likely to behave inconsistently and indecisively. As they received more information about the implications of the option they chose, they became more consistent and decisive. However, we also saw a clear turning point: At some point the volume of information becomes so overwhelming that planners lose sight of the big picture and benefit much more from a clear recommendation by the system. That's a completely different ball game.' Van der Heijden: 'Companies should carefully weigh how much the information is worth to them. Perhaps it's enough to know the stock levels. Knowing exactly when new stock will arrive, will cost more. On the whole, people like being able to make their own context-specific decisions. It could well be the case that a planner in a certain branch gets a lot of hassle from a certain colleague, but this is not the case in a different branch. These kinds of things are very difficult to include in the automated systems, of course. It's better to give a number of suboptimal options rather than only one solution that is theoretically the best.'

Valuable new insights The researchers also experimented with adding a few intelligent control rules to improve the system's performance. For example, priority rules for dealing with orders that need to meet conditions such as same day delivery and next day delivery. Gerrits: 'Interventions lower down in the supply chain, so closer to the customer, turned out to be most useful. And obviously, the situation with short distances such as between the Netherlands and Germany is different from longer distances, for example between Europe and Asia. This has not been included in the scope of this research project yet.' It also turned out that it pays to proactively monitor 'leaks'. Gerrits: 'What I mean by leaks is that it sometimes takes too long for information about return flows to end up back at the central warehouse. Imagine if someone throws out a certain part because it can't be repaired after all, it would be very useful if the central warehouse is informed immediately. This would prevent a shortage at a later date.'

A positive experience Ramon Caanen: 'We as the ProSeLoNext consortium, noticed that the approach with a tool like the Demonstrator worked really well in this project. We should use it more often as a valorisation tool. There was also the social aspect of it. People who played the game had noticeably more and more fruitful interaction with others. They were really figuring out their options as a team.' Van der Heijden: 'There were many lively debates and we should have allowed more >

time for this.' Has the Demonstrator also been useful for IBM itself? Hazewinkel: 'Not directly, no. The interventions have not been implemented. IBM makes its decisions based on the type of contracts and the costs of, for example, proactive shipping of parts. There are contracts with penalties for us if we don't deliver in time: In those cases we intervene 'manually'. The Demonstrator does not distinguish between types of contracts. Still, I do see added value in the overview that planners get. I believe that if we had had a service control tower during the Covid-19 lockdown in the spring of 2020 when there was a sudden drop in the number of aeroplanes taking off, then we would have had much less work planning the logistic processes between the Netherlands and South Africa, for example. These destinations have long lead times, so it can pay off to proactively move parts.' <

The Demonstrator has been developed by Berry Gerrits in close cooperation with Gordian Logistics Experts and researchers of the University of Twente and Erasmus University Rotterdam. The research-based work was carried out by PhD candidate Berry Gerrits, Matthieu van der Heijden and Engin Topan (University of Twente) and by Rommert Dekker (Erasmus University Rotterdam). Important work has also been done by Master's students Pim Schultz, Sofia Kyriazi and Justin Fennis.

IBM stands for International Business Machines Corporation and it designs and sells computer hardware, software and technology and it is an important service provider in the ICT industry. Operating in more than 160 countries with more than 350,000 employees around the world, IBM had a turnover of 79.7 billion US dollars in 2018.
Photo: IBM

Colophon

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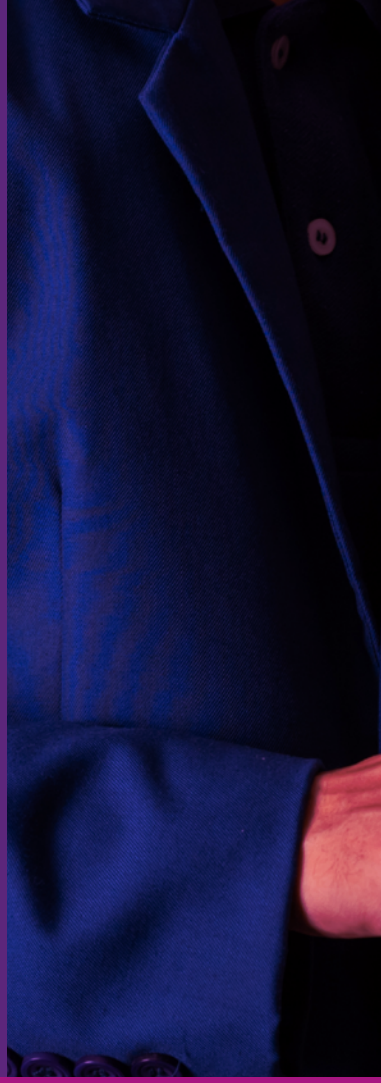

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