Capital goods are machines or products that are used by manufacturers to produce their end-products or that are used by service organizations to deliver their services. Capital goods have a life cycle consisting of 5 phases; see Figure 1. In the first phase, based on feedback from the market and knowledge on technical possibilities, needs and requirements are defined. Next the system is completely designed. After that multiple units of the system are being produced. Then, in the exploitation phase, the systems are used, and finally the system is disposed of.

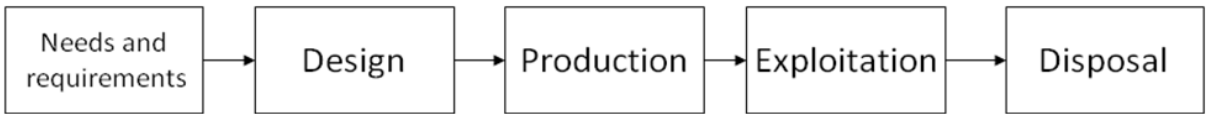

Figure 1: Life cycle of a capital good

The focus of this proposal is on *advanced capital goods* like lithography systems, large-scale computers, baggage handling systems, and so on. These capital goods are technically complex, they are expensive, users are completely dependent on their availability, downtimes may be very expensive, and they have long life times (20-40 years, say). For these advanced capital goods, there is a long-term trend that users are interested in getting a function rather than a product, and they look how expensive the function is per unit of product/service that they produce themselves. E.g., an airport like Schiphol is interested in buying the function 'handling of baggage' rather than in buying a 'baggage handling system', and they are interested in the cost per handled bag. It is also known that for advanced capital goods, only a fraction of the Total Cost of Ownership (TCO) consists of the buying price of a new system. The largest part of the TCO consists of maintenance and downtime costs.

In this project, we aim to investigate innovations that lead to lower TCO for a given downtime objective, or equivalently, lower downtime for given TCO. We distinguish three research areas (Work Packages)

I. Shared parts for performance-based contracts
II. Last buy and re-use
III. Proactive Maintenance via remote monitoring

The University of Twente is leader of Work Package 2 and participates in Work Package 1. The total research capacity of the project is 3 PhD students and 3x1 year Post Doc. The work content by the UT is 1 PhD student and 1 PostDoc (1 year). Below we give a brief explanation of each work package.

WP I: Shared parts for performance-based contracts

Increasingly, service logistics of capital goods is outsourced to the OEM-s using service contracts in which service levels agreements (SLA's) that should be achieved by the service supplier are well-defined. The OEMs face many uncertainties when they sell service contracts, for example about the system failure behavior due to limited information on component failure rates and system use by the customer. OEMs have several means to influence its service contract performance, such as

- choosing the right amount of spare parts at the right locations in the network,
- influencing throughput times in the service process, such as repair of modules and components, transportation times to the operating sites and return times of failed parts; for example, this can be achieved by adjusting resource capacities (tools for diagnosis and repair, service engineers) or by priority setting of specific jobs in the service processes.

The OEM can improve his service by *sharing* parts, especially the case if the service chain is not fully controlled by one player. Sharing parts has advantages, because due to pooling lower safety inventories can be maintained. We will deal with questions on the way to execute it in such a way so that the costs and benefits are balanced over the parties involved.

WP II: Last buy and re-use

Spare parts are important to service capital goods throughout the system life cycle. In general, spare parts can be sourced from:

1. failed parts that are returned from the field and that are technically and economically repairable (parts that have been replaced by a spare during corrective maintenance);
2. complete systems that are returned from the field (for example, at the end of a lease period) and that cannot be sold or leased anymore to a new customer; these systems can be disassembled and useable parts may become available as spares ("asset recovery")
3. new parts as manufactured by the own production department or external suppliers.

Unfortunately, the timing and/or quantity of spare parts from the first two sources is usually not adequate and highly uncertain. Therefore, an OEM buys new spare parts for servicing its systems at the start of and during the system life cycle. At a certain point in time, production may be discontinued, and then the OEM has to decide about a so-called “last buy”, such that sufficient spare parts are available to cover the total demand over the remaining life cycle with high probability. This decision is generally hard, because the length of the remaining life cycle (“final phase”) tends to be long (at least several years in the capital goods industry).

Because a stock-out of a spare part may have serious consequences (expensive alternative solutions, long downtimes at customer, service contract violation), it is common for companies to buy an excessive amount of spare parts at the “last buy” opportunity with the goal to have a low out-of-stock risk. Usually they succeed, but that comes with a price: Each year a companies like Océ and IBM scrap spare parts with a total value of millions of Euros, representing an enormous waste from both a financial and an environmental perspective. Furthermore, reusable parts are often not repaired and re-used anymore in the last years of the system life cycle, even though this could be technically and economically feasible. We aim to improve the sustainability and efficiency of the service supply chain by developing approaches to reduce the Last Time Buy and to take more advantage of re-use.

WP III: Proactive Maintenance via remote monitoring

Unexpected failures are the main source of unscheduled downtime of a capital good. The yearly unscheduled downtime is equal to the number of unexpected failures times the average downtime per failure. By preventing unexpected failures, or keeping them to a minimum, expensive downtimes and system interruptions can be significantly reduced.

Reducing unexpected failures of capital goods can be achieved through two key aspects:

1. Accurately predicting their failure times:
2. Performing maintenance actions to restore them to good conditions

This can be enhanced via remote monitoring. In remote monitoring, some quantifiable measure that characterizes the degradation of capital goods is captured, in real-time, using condition monitoring techniques (e.g. sensors). This measure can be very useful to assess the condition of the operating capital good and the degree of degradation it has undergone up to the moment of measurement. By assessing the underlying degradation state of a capital good, we will be able to:

- Predict the evolution of this degradation state, and estimate the time at which it will cross some pre-determined critical/alarming level or failure threshold.
- Develop optimal condition based maintenance policies based on its actual state of health.