Sustainability Engineering by Product-Service Systems

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Abstract
Product-Service Systems offer high potentials for increasing the use productivity of resources. Functionality can be provided in specification how, on place where and in time when needed for the user by modern communication and logistics. Business models change from selling products to selling functionality due to fixed costs of under utilized products being higher than additional costs for communication on demand and supply, and for transport of artifacts to places of performance. Remanufacturing, disassembly and reassembly enables for same products and components performing as required in consecutive different usage phases thus avoiding disposal of valuable resources. Methods for product design with respective components, performance supervision, maintenance of components, configuration for different usage specifications, user's and provider's qualification, ubiquitous access on information about demand and supply to create efficient functionality markets, all represent product related services for the functionality business thus achieving more functionality with fewer resources.

Keywords:
Sustainability Engineering; Value Creation; Product-Service Systems

1 INTRODUCTION

Sustainability Engineering is on exploiting the dynamics of fair competition to achieve the required sustainability of our global living conditions by processes of knowledge creation and innovation. Product-Service Systems (PSS) exploit design potentials for new business models by shaping interrelations between tangible products and intangible services. They enable for innovative function, availability and result oriented business models. These models can help in reducing resource consumption and waste generation by fewer resources providing more functionality. Supplier's motivation is changed from selling ever higher numbers of products to the customer with ever lower costs of manufacturing to selling ever more functionality to the customer with ever lower input of resources. The old manufacturing paradigm of producing big lot sizes for low costs per piece is challenged by providing more functionality with fewer resources. Tangible resources are partly substituted and partly supplemented by intangible services. Sustainability in its three dimensions of economic, environmental and social concern helps in directing the processes of technological innovation. Economic challenge is in market competitivity of resource saving product service design. Environmental challenge is in resource efficiency and effectiveness, e.g. no longer disposing non renewable resources by consequent adaptation for consecutive different usage phases, also in substituting non renewable by renewable resources within the constraints of sufficient renewable resource generation. Social challenge is in establishing the awareness of users and developers for mankind's threat if not adapting ways of living to fair wealth distribution within environmental constraints.

How can PSS contribute to meet the challenge of sustainability by competitive offers of minimal necessary tangible products integrated with required service functionality? The threat of ignoring the conflict potentials of unequal global wealth distribution, the saving potentials in resource exploitation for useful applications is illustrated. Chances of PSS approaches for exploiting these potentials are described.

2 CHALLENGES OF SUSTAINABILITY

Predominantly all over the world industries are still working in source-sink economic patterns relying on resource availability without limitations. Non renewable resources are often exploited for only one usage phase with consecutive disposal. However, there are huge potentials of recycling of products, components and materials. Also, substituting non renewable by renewable resources within their limits of regeneration can help avoiding upcoming shortages in resource supply for a growing population with expectations on higher standards of living.

Earth's resources are limited. Out of the present global population of about 6.7 billion people -9.5 billion are prognosed for 2050-, less than one billion belong to the industrialized world in Europe, North America, Japan, South Korea, Australia, and few islands of wealth. China with its population of 1.3 billion and India with 1.1 as well as other developing and emerging countries are striving to catch up. If the lifestyles of the upcoming nations are shaped by the existing, predominating technologies, then the resource consumption will exceed every accountable economic, environmental and social bound.

The question arises, which production technologies can serve as basis for dealing with this growth, in an economically, environmentally and socially responsible manner. Independent of the exact limits of access to virgin non-renewable resources, alone due to the increasing material demands of more people with increasing standards of living, non-renewable resources worn out after usage phases of products must not be disposed any more but regained in product or material cycles.

Due to limited availability and increasing demand an increasing increase in prices for non renewable resources as aluminum, copper and iron can be observed. Between 2006 and 2009 the costs for import of raw materials to Germany have grown from 31 to 86 billion Euros, including 16 billion Euros for metals. The price for copper e.g. increased from 3300 Dollars per ton in the beginning of 2009 to 6000 Dollars per ton in August 2010, an increase to 10,000 Dollars per ton is expected for 2011. Expanding application areas

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for copper are expected in electrical vehicles and infrastructure for electrical energy supply. Rare earth materials are required for luminous diodes, batteries and photovoltaics, all areas with expected market growth in applications but limitations in raw material purchase. Recycled material becomes the only source of raw material available in the long term [1]. Already 56 percent of copper applied for manufacturing in Germany has been recycled. Keeping ownership on materials to avoid consequences of fluctuating prices for a stable functionality business might be a competitive approach for innovative PSS.

Energy availability is a fundamental premise for any material wealth creation. Nearly one third of primary resources for global energy conversion presently stems from crude oil. Estimates on remaining reserves lie between 1000 and 3000 billion barrels. The date of peak-oil, i.e. the date from when on oil production remains constant or even decreases, is expected for 2020 at latest. Obviously saving primary resources for energy consumption in global dimensions is a huge challenge in responsible management of resources.

The amount of primary resources for energy consumption worldwide has increased from 2000 to 2008 by 25% to over 500 EJ (EJ = 10^{18} Joule) or over 140 PWh (Peta Watt hour = 10^{15} Wh). Germany with 80 million people accounting for one percent of the world's population of 6.7 billion consumes energy of 14 EJ or 4 PWh accounting for about three percent of world consumption. Crude oil with 30%, natural gas with almost 20% and coal with 25% have taken about three quarters of primary resource contribution for energy consumption and caused CO_2 emissions of nearly 30 Gt (10^9 t). Biomass with over 10%, nuclear with 6% and renewable energy are contributing another quarter of world primary resources for energy consumption [2] [3].

Figure 1 shows a gross quantitative assessment of the global energy flow without losses in transformation from primary resources to useful applications. Passenger and goods transport each account for one eighth of consumption in final application, industrial production for one third, and two fifth are for infrastructure with substantial proportions for building, heating and food production.

Between primary resource input and final consumption, there are many different processes and production facilities. The key elements of this transformation are the direct fuel use in machinery and equipment with approximately three fifths and electrical generation with two fifth shares. The movement of vehicles and machinery is generated with about one third, and process heat with about half of primary energy use.

The consecutive steps and different paths in conversion of primary resources to energy driven operations offer big potentials for increasing efficiency and effectiveness. Often these potentials are already baled out within the balance frame of respective entrepreneurial institutional activities. By integrated product and service innovation PSS independently from traditional balance frames can create new business models of providing more functionality in application by less investment in instrumental facilities. E.g. providing customers with energy saving equipment thus saving electricity consumption can be cheaper than investing in additional power stations. Diesel engines directly driven by fuel might save conversion losses of electrical power generation required for electrical drives. Overcoming grown thinking, living and working habits requires new means of convincing people by teaching and learning, by softly integrating innovative artefacts in existing living environments. Mutual dependencies of tangible products and intangible services must be thoroughly considered for successful implementation [4].

The ecological footprint represents a measure for the consumption of renewable resources. About one quarter of earth's surface, accounting for 11.3 billion hectares, can be considered as biologically productive area contributing to the regeneration of resources. The average amount of biocapacity per capita on earth is calculated by dividing the productive area by the number of people on earth, what results in 1.8 global hectares biocapacity per capita. Since approximately 1985, resource consumption on a global level is higher than the ecological capacity. For 2050, an impossible biocapacity of two globes would be required if the trend of increasing renewable resource consumption would be not stopped.

Half of global population is still living without access on electricity and telecommunication, earning less than two Dollars per day. One fifth of global population disposes of four fifths of global wealth. Environmental damages caused by unbalanced resource exploitation and considerable lacks in human education lead to social conflicts and terror. Presently there are 25 local wars on the earth. Culture and education for billions of people have become the dominant social challenge for human survival on earth. PSS approach seems to be promising means to cope with this challenge.

Also the global population growth must be stopped by better standards of living without increasing resource consumption. Social stability can only be achieved if mankind is able to create jobs and living conditions of human dignity worldwide and not only in the technologically developed regions of East Asia, North America and Western Europe.

Rapid technological development, diversity, creativity, entrepreneurship and dynamism in competition and cooperation

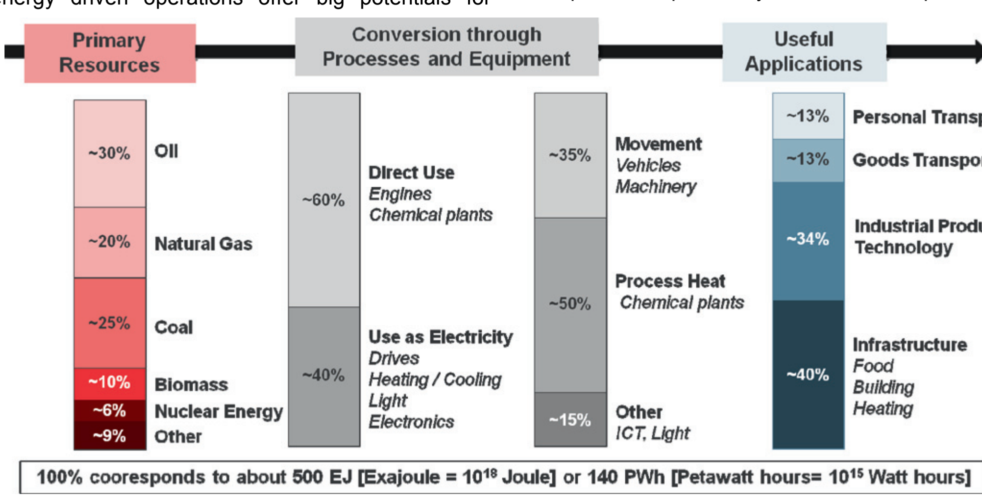

Figure 1: Quantitative assessment of global energy conversion in primary resource shares without losses in transformation.

shape the living environments for the global citizens from the regions of prosperity, but also bring an irresponsible waste of resources. The responsibility of the wealthy minority enables for technological development based on criteria of sustainability in order to harmonize the quality of life and resource use. This challenge offers with great opportunities in sustainable services, products and processes for value creation. Sustainable development with social innovation is also important to open the hungry market of more than 5 billion people who still have not enough purchasing power.

Due to the unbalanced development along developed, emerging and developing countries, it is difficult to reach a new agreement after Kyoto Protocol to reduce the carbon emission. Carbon emission relates with the economic development and environmental protection. Governments are conflicting about individual national wealth development, access on resources and responsibility for climate change. But all of them are concerned about how to reduce the CO2 emissions to protect the environment.

The rationally required sustainable global development can stimulate the forces of human initiative and creativity. Sustainable global development could eliminate the unfair distribution of opportunities by technological and social innovation [5]. Mankind's wealthy minority has the responsibility to identify innovative paths for sustainability engineering. Great opportunities are opened in sustainable services, products and processes for value creation. Social innovation can help to open the new markets of more than 5 billion people. Technologies from developed and emerging countries can empower help for the poor people to help themselves.

Product-Service Systems (PSS) offer chances to fulfill the challenge of sustainable development. The potentials of PSS in resource saving and qualification may succeed to develop economies and civilization in the global discourse.

3 VALUE CREATION

Value creation can be modelled considering both, actual entrepreneurial activities in globalized markets and requirements of sustainable development. Market dynamics can be powerful drivers in achieving sustainable develoment for global mankind along economical, environmental and social criteria by technological innovation. Figure 2 describes an architecture for sustainable global value creation. Value creation factors are integrated in modules to be designed along economic, environmental and social criteria of sustainability. Cooperation and competition among entrepreneurs drive for horizontally and vertically integrating modules thus constituting value creating networks. There are different levels of hierarchy in value creation. From manufacturing tool and operation via value creating cells and systems, whole factories to national and international entrepreneurial conglomerates or knowledge generating educational communities. Each of them from top-down pespective is considered as a network consisting of modules and from a bottom-up perspective as a module together with other modules contributing to a network. Modules or networks can be set up under different infrastructural conditions in industrialized, emerging or developing countries respectively regions within countries. Value creation in an engineering perspective addresses the development of artefacts for useful applications thus shaping areas of human living. From the module view in a bottom-up perspective entrepreneurs try to get their specific value contribution integrated in higher level networks, whereas, from the network view in a top-down perspective entrepreneurs try to purchase original elements enriching their product system from lower level modules. The dynamics of demand and supply in this mutual dependency offers chances for directing global value creation to pathes of sustainability. Referring to requirements of communication, to training and educaton, to maintenance and repair, to knowledge creation and information access for continuous improvement, to setting up competitive offers for resource saving functionality markets, PSS can considerably contribute to sustainable value creation.

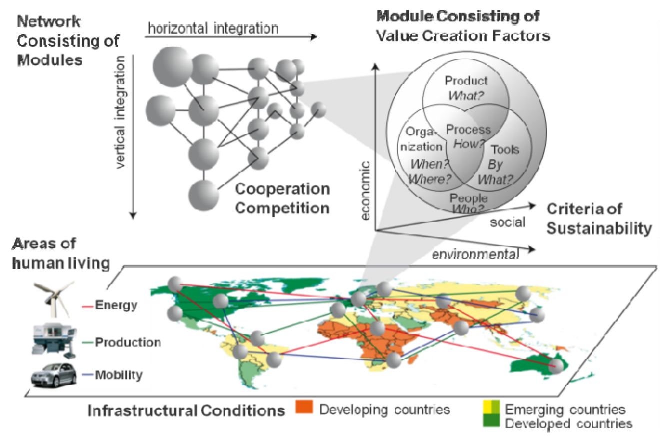

Figure 2 : Architecture of Sustainable Value Creation.

4 POTENTIALS OF PRODUCT-SERVICE SYSTEMS

4.1 Business Model

Product-Service Systems (PSS) are an integrated product and service offering that delivers values in industrial applications. PSS must be understood as a new product consisting of integrated product and service shares, which comprises the integrated and mutually determined planning, development, provision and use. PSS includes the dynamic adoption of changing customer demands and provider abilities. The partial substitution of product and service shares over the lifecycle is possible. There are different models for PSS, the individual business models can be differentiated by further criteria [6]. They differ in the responsibility of production result, personnel, service initiative and finally the ownership of the products, e.g. machine tools. This means the provider takes over responsibilities in the production process by delivering service personal, initiating services and ensuring the production quality, see Figure 3.

	Function oriented	Availability oriented	Result oriented
Production responsibility	Customer	Customer	Supplier
Supply of operating personnel	Customer	Customer	Supplier
Service initiative	Customer	Supplier	Supplier
Ownership	Customer	Customer Supplier	Supplier
Supply of maintenance personnel	Customer Supplier	Supplier	Supplier
Service turn over model	Pay on service order	Pay on availability	Pay on production

Figure 3: Specification of innovative use models [6].

A competitive provider offers product functionality, availability or a result in quality, time and location as required by the user. Multiple usage phases make a PSS competitive by maximizing the utilization of resources and can be achieved by disassembly, component adaptation, and reassembly. The opportunity to optimize the use phase is the key for success in consequence of more freedom of business and engineering development.

The PSS business model takes as its starting point the goal of achieving an integrated functional solution to meet client demands, moves away from phase based servicing and discrete resource optimization, to system resource optimization which is utility based. The resulting PSS can produce synergies in profit, competitiveness and environmental benefits. The potential eco-efficiency of a PSS relies on system optimization in resource use and emissions because of the stakeholders' convergence of interests [7]. Further PSS enables an equipartition for the use of technology. It allows the adoption of the right technology and a competitive production also for low-budget small medium enterprises (SMEs) and emerging countries at the time, place and in the specification which is needed.

PSS can lead to reduced resource use and waste generation. The increase in sales of services can balance reductions in sold products. Employment lost in manufacturing can be balanced by jobs created in services. As a business concept, PSS have the potential to improve access to technology worldwide. With PSS, consumers worldwide would have less need to buy, maintain, dispose of, and eventually replace a product. In fact, the quality of the service, and thus consumer satisfaction, may improve with PSS because the service provider has the incentive to use and maintain equipment properly, increasing both efficiency and effectiveness. The incentive also exists for producers to design closed-loop systems for equipment based on designs for higher durability and recyclability [7]. To be competitive on the market the PSS providers have a strong interest in using a minimum of production resources, which means maximum utilization and usage of products and components. Therefore a provider will use production equipment out of a PSS in a new or other PSS. Resources will have several life cycles. This is possible because of the shift of the ownership in PSS and leads to a cycle economy.

Human beings in the phases of planning, development and delivery of PSS play a major role; especially the human-machine interaction in the phase of delivery is in the focus. Different qualification of technicians and company-spanning cooperation in the field of industry demand a specific support concept during the delivery of services. Figure 4 addresses the economical, environmental and social motivation and technical progress, being sustainability contributions of PSS.

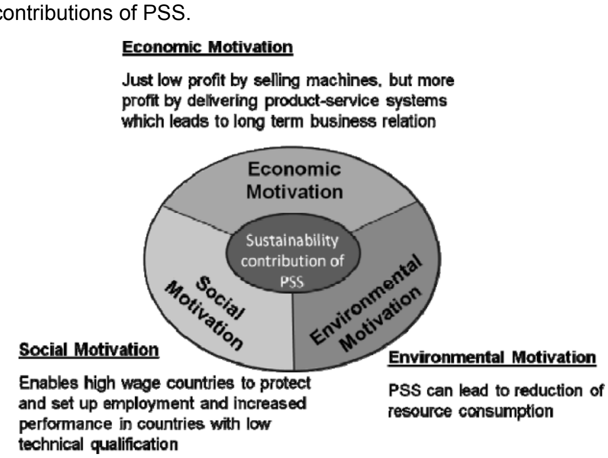

Figure 4: Contribution on Sustainability by PSS.

In developed countries, which already have a large environmental footprint arising from a high rate of per capita resource consumption, PSS can facilitate the transition toward a more service-oriented, sustainable society. The service industry gets the chance to find new and increasing market opportunities. Other benefits include reduced dependance on externally produced resources and reduced load on waste disposal facilities. For emerging countries, PSS may represent a more promising and environmentally sound path to economic development since it enables them to bypass the development stage characterized by individual ownership of goods.

A cycle economy is not only environmentally reasonable but also a chance for new businesses. Selling functionality instead of selling products is advantageous once additional costs for information processing and logistics are less than costs for underutilized capacity (Figure 5).

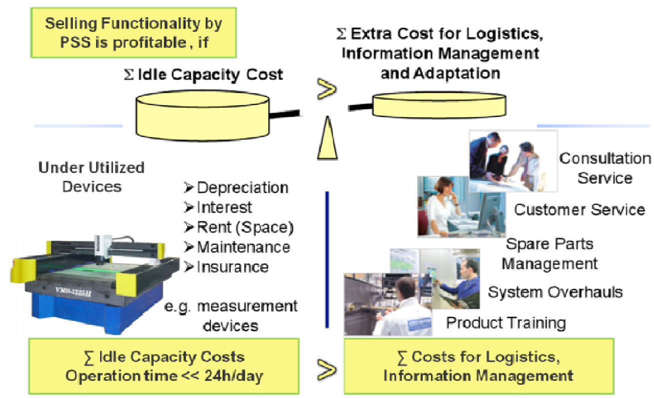

Figure 5: Selling functionality instead of selling products.

From the point of qualification the use of technology is limited. Especially in developing countries the qualification level of worker and technicians is not comparable to the one in the developed world. However, the provider has to take care that his products are usable, as promised in the contract. The challenge is to qualify the local worker and technician from the customer or contractors and supervise their work from distance.

4.2 Knowledge Management

The close co-operation with suppliers and service producers as well as with final consumers can cope with these gaps. While relationships with suppliers are addressed by ISO 14000-series standards and environmentally conscious purchasing practices, downstream practices are addressed by extended producer responsibilities and Product Stewardship concepts. Integrated Chain Management (ICM) specifically addresses the issue of involving several actors in order to improve the environmental performance of products. However, problems associated with ICM are also going to be relevant for PSS due to a similar value chain basis that is extended in PSS into a value creation network. These problems include trade-offs between co-operation and internal environmental management; the problem of choosing wrong actors who do not have the power or knowledge to change or influence events; information sharing and transparency, and barriers from material flows crossing borders and a variety of regulatory frameworks in different countries. By sharing information the provider will be enabled to identify the customer needs and enhance his business relation with new features satisfying the customer needs. By this a long relationship can be established, which has to be seen as a partnership.

Due to the shift in the ownership of products PSS business models give a platform to collect information from every PSS which earlier was only accessible for the customer or by feedbacks of service personnel. This offers providers opportunities to learn more about the PSS behavior and usage by the customer and give the chance to use it for PSS design or redesign. Knowledge generation as well as knowledge and information management is necessary. A definition of knowledge is shown in Figure 6. The adaptation of products and services to the continuously changing technical requirements, application areas and user demands is crucial for the competitiveness of the PSS business model. Different configurations have profound impact on the performance of the system in terms of reliability and productivity, product quality, capacity scalability, and costs. Adapting the functions to the customer needs, the design to reduce idle and operation costs and an ongoing adjusting of service times requires knowledge about the system behavior and prognostics about the system conditions. This knowledge needs to be generated and managed.

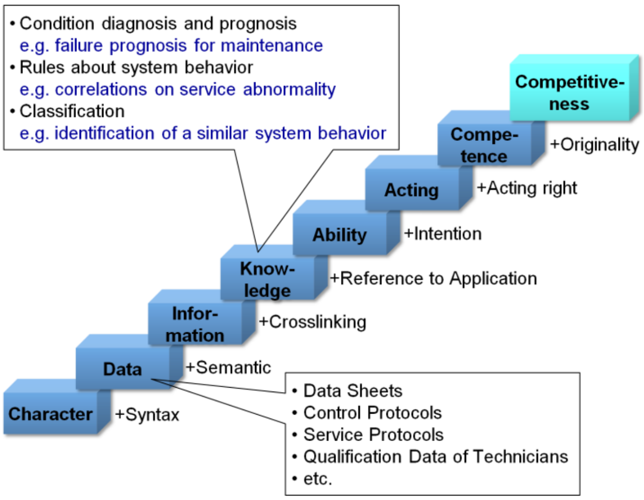

Figure 6 : Definition of knowledge by North [8].

The development of PSS has the challenge to handle the increased complexity of the integrated PSS products and services. To ensure an efficient development of a PSS and to provide decision support, knowledge out of the usage phase or experience from previous developments and PSS provision phases should be used. To support a competitive design of PSS, knowledge needs to be generated about correlations between product and service shares in order to fulfill the required needs and demands. This knowledge is crucial for a successful combination of product and service shares, whose influences are very complex and not always known. The PSS life cycle data, especially from the operation phase, is the source to discover this knowledge.

Due to the modern IT based engineering, business communication and documentation, most data along the life cycle of a PSS are already available in digital form and worldwide accessible via internet, e.g. machine datasheets, service protocols or personal database. Companies offering machine services already document plenty of detailed data about the service processes. Currently this is being used as an information base to compare new situations with historical data. The challenge lies in accessing, acquiring, communicating and finally processing it to knowledge. The continuous supervision of products and processes as well as processing of data by intelligent algorithms is an enabler to do prognostics of the system condition.

Following the Business Intelligence idea an integrated approach for all participations or companies in a supply chain network of a PSS is required. An integrated concept has been developed – the so called Virtual Life Cycle Unit (VLCU). It is an information technology system that supports the supply chain and communication processes in the whole PSS life cycle with knowledge. The VLCU acquires data from the usage phase, communicate and process it with the help of data mining algorithms to knowledge about the system behavior. This includes rules about the process flow of the PSS and its operations, as well as prognoses and classification of the PSS health condition or its components [6]. The processing to knowledge can be done by using data mining algorithm. These algorithms can be used to formulate rules about the PSS system behavior, e.g. a decision tree model. Other algorithms like Support Vector Machines or Statistical Pattern Recognition can be used for condition prognostics based on the actual system condition and wear [9]. In this concept the generated knowledge is available for all actors in the PSS supply chain.

Beside the VLCU concept there are product accompanying information systems, supervising the product or components condition and allow condition based maintaining [6][5]. This is crucial for a PSS as it also facilitates to reduce unseen breakdowns and so a breach of contract, e.g. the promised availability.

4.3 Performance Supervision and Maintenance

In the PSS of aircraft turbines there is a continuous condition supervision to ensure the availability, but also to schedule maintenance planning at the place and the time it is needed. Data from the engine in use are transmitted to the provider. Input factors are planned future running times and available parts on the following destinations of the engine, respective aircraft. While in earlier times the engine was owned by the airline, spare parts and technicians needed to be stationed on every airport from every airline. Nowadays costs could be reduced by having just one team and depot for every airport. An aircraft engine is a very complex machine, the knowledge about it is best on the side of the engine company, e.g. Rolls Ryoce, GE or Pratt&Whitney. Those decide best when wear parts need to be replaced and because of the PSS business model they run today, they maximize use by condition based maintenance (CBM) methods or multiple usage phases, e.g. by running the engine on different aircrafts.

Figure 7 shows the typical parameters measured for engine health management on a Rolls Royce Trent Engine. Aircraft Communications Addressing and Reporting System (ACARS) digital data-link systems are used as the primary method of communication. This transmits the Aircraft Condition Monitoring System (ACMS) reports via a VHF radio or satellite link whilst the aircraft is in-flight. A worldwide ground network transfers this data to the intended destination [10].

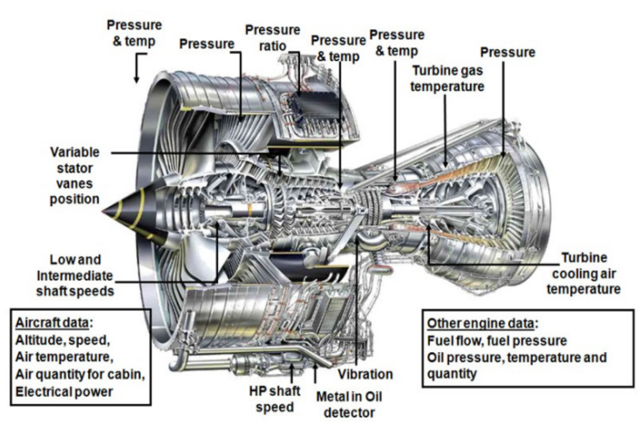

Figure 7: Engine health management sensors RR Trent Engine [11].

4.4 Education

The PSS connect the providers and customers in multifaceted work places at which people determine during their operations the sustainable impact of products and processes. Worker or technicians need knowledge to have the ability in an application do something within the required time and quality. The integrated form of services in the PSS business model also includes the humans. To get access to technology the worker or technicians need to be qualified to do this. Constant availability, different qualifications of users and company-spanning cooperation in the field of industry demand a specific support concept during the delivery of services. Therefore easy and online education systems are required. In order to cope the challenge on qualification the use of modern IT systems offer great solution potentials.

One way is the support of less and insufficiently qualified users. As a part of a support concept, e.g. in a maintenance scenario, the creation of a “shared vision” can be a possibility for the diagnosis and solving of a problem (Figure 8).

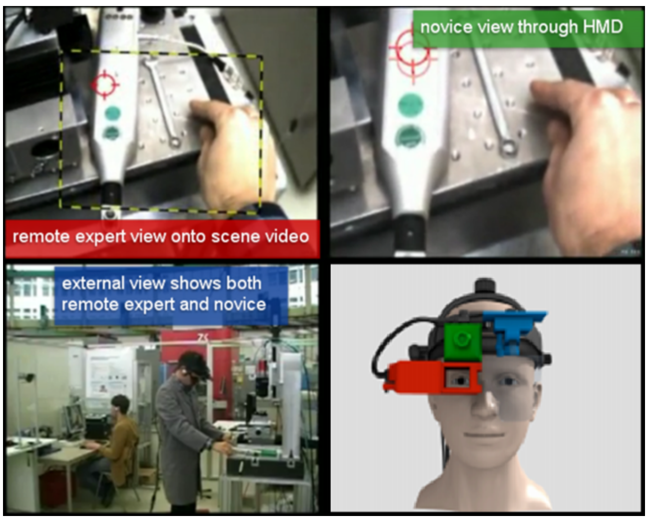

Figure 8: Shared Vision System [5].

During the production of a work piece the machine informs the user about a breakdown. After a detailed inspection the user realizes, that her/his qualification for the removal of the failure is insufficient. To minimize downtimes of the machine, expensive journeys of service staff and last but not least mistakes in the problem diagnosis, the user can establish an audio-visual contact to a remote service expert of the machine manufacturer by a shared-vision system. Now this service expert can analyze the problem in time. Furthermore he can guide the user to a solution of the problem. As the gaze direction shows the focus of attention the visualization of the gaze direction of both involved persons can enhance the communication. Perceiving the mutual gaze movement therefore means an additional intuitive source of information.

To ensure the quality of e.g. a service, the technician might have to be supervised in a way, that his actions are documented and in case of a mistake he/she immediately be informed. This can be done under the umbrella of technician security, but of course also to ensure the quality, economically and resource consumption of the PSS. A wrong installed ball-bearing might wear faster, which means it results in higher lifetime costs because of higher resource consumption. This is not sustainable in economic and environmental way.

Novel tools for education and innovation dissemination guide people during their work to reflect their operations, to gain knowledge and to generate and adopt innovative ideas. They generate stimuli in people of different age, cultural background and qualification to activate interest and therewith initiate a learning cycle.

The state-of-the-art of information and communication technologies (ICT) offers further innovative teaching concepts. By supervising the workers action and give direct instructions to him. So called Teachtools are enablers to incorporate physical and with technical information means to coach and train skills in technological, social, environmental and managerial fields. The learning motivation is addressed and creative competencies are fostered through practical application and project oriented problem solving at the workplace. This environment is ideal for forms of action-oriented- and discovery-learning, which guide the learner through a self-defined learning process. The learner on his learning path meets different kinds of teaching objects, like pictures, drawings, movies or texts. The teachtool suggests learning objects and the learner chooses which teaching objects suites his interest best. His journey will provide him with additional information for a more sustainable design and usage of the products and processes which he is working with. The learning processes can take place in all kinds of value creating activities done in a manual workplace, for example assembly, agriculture or teaching workplaces.

The regional infrastructure, education level and values of various participants are to be hereby observed, in order to indentify deficiencies in the qualification of persons. A variety of best fitting teaching material or objects can be identified, which raises the chance that the learning processes will be performed at a high level of efficiency. Web-based intelligent agents are used to identify the qualification gap of the people and to support the learner with the appropriate teaching contents and highly effective methods.

In [12] such a teachtool has been presented. An image based recognition of manual work processes in combination with an expert system has been developed and verified, see Figure 9.

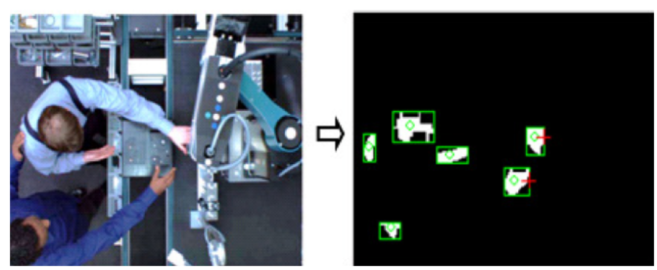

Figure 9: Image-based recognition of a manual work process [12].

With the help of teachtools and shared vision systems, PSS providers are enabled to qualify every person to do services on their machines or use them. This means, that the technology is available to be used for everyone, especially the in the beginning mentioned 5 billion people, having not access to such technology nowadays.

5 SUMMARY

Sustainability engineering meets the challenges of economic competitivity, of responsibly managing environmental resources and of developing social competencies for worldwide wealth generation. Technological innovation can be directed along these guidelines of sustainability. The dynamics of value creation in the framework of global markets enables for network integration of partners under different infrastructural conditions. Product-Service Systems are means to cope with the challenge of more functionality with fewer resources. Selling functionality by service integration substitutes the traditional approach of selling tangible products in innovative business models. Knowledge management and education by modern information and communication technology helps in implementing the new paradigms of resource efficiency and effectiveness.

6 ACKNOWLEDGEMENT

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