IFAC

SmartFactory – from Vision to Reality in Factory Technologies

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Abstract: *In our daily life we are more and more dependent on the latest technologies in electronics and communication. Our mobile phones become powerful multimedia systems, our cars computer systems on wheels, and our homes will turn into smart living environments. All these advances must be turned into products for very cost-sensitive world markets in shorter cycles than ever before.*

The resulting requirements for design, setup, and operation of our factories become crucial for success. In the past, we often increased complexity in structures and control systems resulting in inflexible monolithic production systems. But the future must become "lean" – not only in organization, but also in planning and technology! We must develop technologies which allow us to speed up planning and setup, to adapt to rapid product changes during operation, and to reduce the planning effort. To meet these challenges we should also make use of the smart technologies of our daily life.

The advances in wireless communication will allow us to avoid cables. Powerful mobile computers or smartphones will replace many of the traditional control panels and abstract services will replace bits and bytes in control. These advances will not only lead to mobility for machines and people but also to new challenges in system design.

The SmartFactory[KL] initiative was founded by many industrial and academic partners to create and operate a demonstration and research test bed for future factory technologies. Many projects develop, test, and evaluate new solutions. This presentation describes changes and challenges, and it summarizes the experience gained to date in the SmartFactory[KL] approach.

1. THE ROCKY ROAD IN PRODUCTION TECHNOLOGY

In the past few years, our daily lives are characterized ever more by advances in micro electronics and communications technology. Our telephones are mobile and crammed with add-on functions. We not only talk on our telephones, but we nowadays use them also to make photos, listen to MP3 music, manage data, navigate through foreign cities, wake us up or even surf the internet. The same applies to our cars, which are more like computers on wheels than vehicles. Not to mention our homes, equipped with more and more intelligent devices and systems, designed to simplify our lives or at least, make them more comfortable.

Mark Weiser, one of the pioneers in computer technology, has coined the term *ubiquitous computing*—often also referred to as pervasive computing or ambient intelligence—for this new world: "*Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives*" (Weiser, 1991). In reality today, we are still quite a distance

away from this vision. We focus too much on the technology and hope to attain a market advantage by combining a greater number of functionalities in each single device. Unfortunately, this "Swiss army knife" strategy leads to products that customers are unable to master. The manufacturers also encounter a growing number of problems: The cost efficient production with suitable quality requirements becomes problematic when products with increasingly short life cycles shall be equipped with an ever growing number of options (Zuehlke, 2004).

The production plants also become ever more complex despite all efforts at improving this situation. This in turn, results in longer planning phases and unacceptably long times-to-market. At this point, let's look back to twenty years ago. In the 1980's, we witnessed the first wave of integration of IT technologies into the factories—computer integrated manufacturing (CIM), as it was called then. The hope was that fully automated plants would solve cost and quality problems on the basis of state-of-the-art computer technology. Since humans would no longer fit in there, the visions of the future aimed at deserted factories with no human workers. The reality arrived quite differently than imagined. These CIM systems were extremely complex in planning as well as in construction, operation, and maintenance. The technologies were not yet mature and the

humans were overstrained. At the beginning of the 90´s, when the crisis was obvious, a milestone was represented by the popular book by Womack, Jones and Roos: "*The Machine That Changed the World: The Story of Lean Production*" (Womack *et al.*, 1991), which explained to the high-tech addicts in the western industry, how Toyota was able to build high quality automobiles with very simple production principles. These principles were known from then on as lean production, which became the paradigm of the beginning decade.

Lean production meant networks, not hierarchies; dynamic, self-coordinating work teams instead of monotonous assembly line jobs; and, most importantly, the personal responsibility of the individual worker. But this philosophy is directed primarily on the organization and less on the technologies.

1.1 Where are we today?

Today, computer integrated manufacturing is a reality, but we are still wrestling with the challenges of extreme complexity in planning and operations. Our planning processes are just as before: too sequential, too comprehensive in content, too much hardware-oriented and too product-specific. At the same time, we are facing new challenges: our products need to be more individualized and be offered in more variants, they must be adjusted to the market requirements in less time, the product life cycles are shorter than ever before and the global competition ever stronger. But definitely we can rely on the old remedy: "Don't make things fat, think lean!" Create and use lean technologies now as you created a lean organization then! Lean means reducing complexity, avoiding waste technologies and information and strictly supporting the humans in their daily work. Here, we have the help of many new smart technologies that we take for granted in our daily lives which, in the meantime, have reached a level of maturity that makes them useful under industrial constraints. This is illustrated in the following short scenario:

John is enjoying the sun outside the company's cafeteria when suddenly his smartphone rings, informing him about a problem at assembly line #5B. He checks several parameters on his smartphone screen and decides to better inspect the problem personally. On his way from the cafeteria to the assembly building his smartphone guides him automatically to the place of the malfunction. There, John switches to his laptop, links it to the unit controller by a wireless connection and performs several checks. Finally he learns that one of the conveyor belts has a defect. Now he seamlessly switches back to his smartphone and makes a video call to the spares department. He makes a photo of the broken device and sends it to his colleague who can now check the availability of a spare part. Unfortunately, no such part is available, so he decides to replace the complete assembly module by another one with comparable functions. He pulls that one from the machine module storage and installs it within minutes.

Thanks to the complete wireless control architecture he simply unplugs the power supply and connects it to the new module. When powering up, the new module automatically links itself to the line controller transferring its exact place and offered services and downloads the necessary production parameters. Seconds later, the assembly line is running again and John can think about continuing his break in the sun and watching the latest sports news on his smartphone.

Isn't that a desirable vision of the future? Without doubt, there have been great advances since 1991 that can help us come closer to realizing the goal of lean technologies. Let us look in more detail into some developments which will affect the factory of the future.

1.2 Smart devices

Everything, down to the smallest piece of equipment, will have a certain degree of built-in intelligence. We see RFID technology here as a pioneer. A highly integrated, low-power and low-cost processor is extended with a memory and a wireless communications interface and affixed to each component in a mass market. In effect, the "intelligence" of a central system is moved into every product. Products know their histories and their routes, and thereby not only greatly simplify the logistic chain but also form the basis for product life cycle data memories. When this technology is mastered and can be manufactured for just a few cents, the next step will be to couple sensors and actuators on the chip and turn it into an autonomous actuator-sensor network.

1.3 Everything is networked

Due to their communication capability these smart devices will form networks which allow them to set up and maintain a very reliable communication infrastructure. Based on the Internet Protocol (IP) these networks will be highly redundant and therefore reliable. On the higher levels of communication the already proven network technologies like UWB, ZigBee or WLAN will take over offering high communication capacities at low installation cost. So we are moving towards the *internet of things* where every single piece has an IP address and can communicate. But with today's standards we will reach the technical limits soon. The IP address space must be enlarged. The IPv4 standard can not supply enough addresses for today's technology, but IPv6 will bring us relief and even far more: IPv6 will provide each of us roughly 60 thousand trillion addresses (Garfinkel, 2004).

1.4 Mobility of devices

The advances in low-power electronics together with high-resolution LCD screens and the wireless communication capabilities will bring mobility forward. Our mobile phones will become multifunctional and multimodal tools which offer us permanent access to all sorts of technical equipment.

We will be able to work anywhere and anytime using any device we like. But general solutions for this kind of interaction are still far away. The plant IT structures today are either strictly centralized (thick servers, thin clients) or strictly decentralized (thin servers, thick clients). Both alternatives need a powerful network infrastructure to route the task data between the devices in real-time and are furthermore still device-dependant. What is needed in the future is device-independent mobility at the task level. But this will require a standardized task description on a still to be defined meta-language level (Satyanarayanan, 2004).

Another important problem concerns knowledge about the place of interaction. When we operate today's wire-based systems, the wire installation gives us implicit information about the place of interaction. In nomadic systems we will never know exactly where this place is. The user may be seated in front of the machine as well as in the local tavern. To keep the nomadic devices lean and up-to-date, we cannot store every possible front-end software in the devices; instead we should use the network connection to download an abstract HMI representation depending on the users place and task which will be used to generate a hardware-specific HMI on the dedicated device. Therefore we need location sensing systems, which can track the nomadic devices precisely also in indoor environments. The initial positioning solutions that are already available on the market still lack a broad coverage of industrial requirements. Furthermore, they are not standardized in terms of the required hard- and software interfaces, which makes their integration in large company-wide installations a non future-proof decision.

1.5 Standards must emerge

As indicated above, industrial solutions for many of the described applications will only be successful when they are based on vendor-independent open standards in order to keep cost and development effort low and guarantee for high availability and reliability during their lifetime. But many of today's standards, e.g. in wireless networking are often lacking regulations which are essential for process control applications. Therefore, in the first phase of industrial applications vendors are forced to develop their own extensions. But in the next phase, appropriate general solutions are likely to follow. A good example is wireless HART, which emerged from analog wire-based (4-20mA) via digital standards and is widely accepted as well by users as by vendors.

In addition to the hard-/software and communication standards for devices we also need design standards, e.g. for model representation which are needed to link the various planning systems (CAD, VR, CAE, CAM etc.) in order to achieve a seamless planning, design and operation environment based on device, process, communication and HMI models. Here the evolving ISA-95 standard (Fig. 1) seems to cover major requirements on the higher levels, while EDDL (Electronic Device Description Language) will bring solutions to the lower device levels.
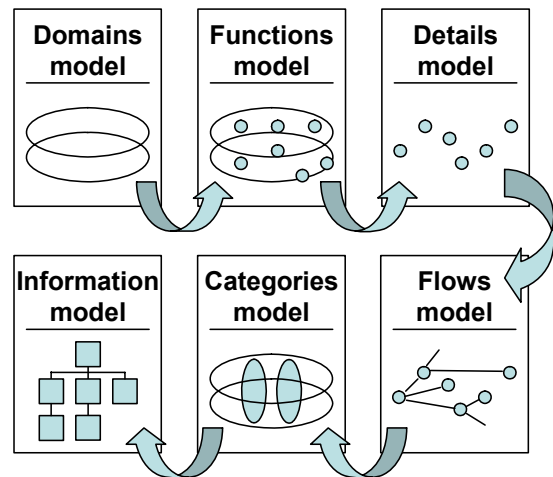

Fig. 1. ISA-95 models

However, before we can employ these technologies in our operations, we must be able to certify their reliability and safety under industrial conditions. No user will substitute the well-established control cables by a wireless connection unless he is convinced of their safety and security—no user replaces a machine panel by smartphone services as long as nothing works anymore when the smartphone is replaced by a newer device. For this reason, it makes great sense to test these technologies first under near-industrial conditions and to develop them further in order to ensure their suitability in industrial environments. It was for this purpose that in Germany for the first time in the year 2004, representatives of manufacturers and consumers met with people from academia and developed a vision for the intelligent factory of the future. This became the basis for the *SmartFactory*[KL] in Kaiserslautern, the very first multi-vendor research and demonstrator facility for smart production technologies in the world. The next section provides a brief introduction to this facility.

2. THE *SmartFactory*[KL] APPROACH

Based on a feasibility study, a non-profit registered association named "Technology Initiative SmartFactory KL" was established in June 2005. The founding partners numbered 7 at that time and represented various sectors of economy and research. Their common goals were the development, application, and distribution of innovative, industrial plant technologies and to create the foundation for their widespread use in research and practice. The number of partners has since grown to 21 and includes producers and users of factory equipment as well as universities and research centers. Support is also provided by industry associations and political organizations (Fig. 2).

Funding for the establishment, operation, and expansion of the infrastructure primarily stem from membership fees and donations by members of the initiative. Additional funding was provided during the build-up phase by the Minister of Economics and Science of the State of Rhineland-Palatinate. Beyond this, there are advanced projects that are funded

solely by the participating industrial partners as pure research projects or as sponsored joint projects. These projects benefit from the use of the *SmartFactory*[KL] infrastructure and contribute to its upkeep as well as expansion.

Fig. 2. Partnership circle of the *SmartFactory*[KL]

In a series of workshops for the partnership circle, the intentions and research focus of the members are regularly solicited so that new work groups can form and devote their efforts to current topics of interest. The group activities and the moderation of meetings are coordinated by a core team from the *SmartFactory*[KL] to ensure that the synergies between development subjects and research projects are realized for all participants. This continuously leads to new approaches for projects to be pursued internally by the partnership circle or to serve as the basis for requesting public funding for research grants. The initiative lives to this extent from the active participation and contributions of all members in joint research and development projects. In the process, the circle is always open to new partners, who bring in innovative products, projects, or ideas and have a desire to actively join in the work on further developing the platform. A framework of information forums introduces interested companies to well-known representatives of research and business who present the current state-of-the-art and invite an exchange of ideas about trends and smarter technologies. Furthermore, *SmartFactory*[KL] regularly presents itself to the public at major industry events, most recently, at the CeBIT and Hannover Messe 2008 fairs.

A hybrid production facility has been built as a demonstration and development platform for the production of colored liquid soap. The product is manufactured, filled into dispenser bottles, labeled, and then delivered by customer order. The plant has been designed strictly modular and it consists as well of a process manufacturing part as of a piece goods handling part. The machinery and components are identical to those found in modern industrial plants and stem from various manufacturers so that the result is a multi-vendor production and handling facility available for research purposes, absolutely comparable in its complexity with real manufacturing plants (Fig. 3 and 4).

The research focuses clearly on the use of innovative information and communication technologies in automated systems and on the resulting challenges in the design of such systems. Several different wireless communications systems are employed in the demonstration facility (Fig. 5). As a consequence, a permanent WLAN connection has been implemented for the decentralized control systems of the components in the piece goods part to the higher level control center. Bluetooth, ZigBee and RFID systems are deployed

among the components, which serve as an extended link at the sensor/actuator level. The wireless communication guarantees new freedoms in plant layout and reduces the planning effort in that cabling is no longer required. However, the robustness of the radio communications in such a heterogeneous environment must always be proven.

Fig. 3. Photo of the *SmartFactory*[KL] facility
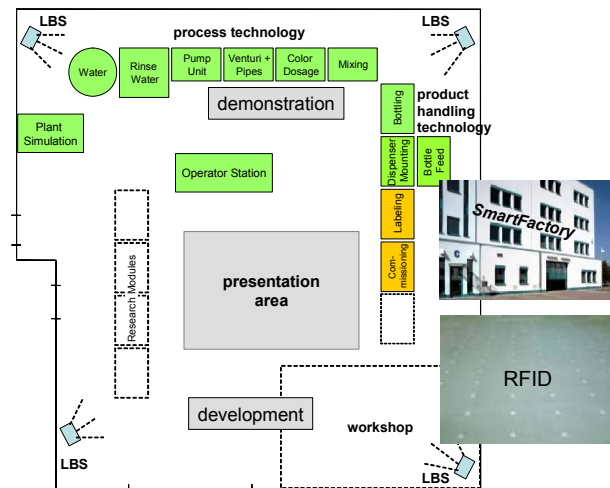

Fig. 4. Floorplan of the *SmartFactory*[KL]

The wireless communication in combination with the modular construction allows the facility to operate according to the "plug'n work" principle. Every element takes on a clear, well-defined function within the process chain. Because no physical connections exist between the components other than the power supply, it is relatively simple to replace or add individual components for a modification or extension of the production processes. The components recognize their function and position themselves within the process chain and integrate automatically into the control systems for plant management. The configuration of the information flow becomes ever simpler because the components identify their tasks from the manufacturing situation and attune themselves to the surrounding components.

The logical continuation of the "plug'n work" principle is the transition from traditional function-oriented to service-oriented control architectures (SoA). The *SmartFactory*[KL] has converted a sub-area of the plant control to SoA architecture. The purpose of this was to gain experience in the handling of this new architecture for industrial control processes. The present system is based on a Business to Manufacturing Markup Language (B2MML) model according to ISA-95, a Web Services Description Language (WSDL) model, as well as the Business Process Execution Language (BPEL) for system administration. While this test case reveals the fundamental advantages of a SoA architecture, it also clearly shows the far ranging effects of this paradigm change on the overall information structure of a company.
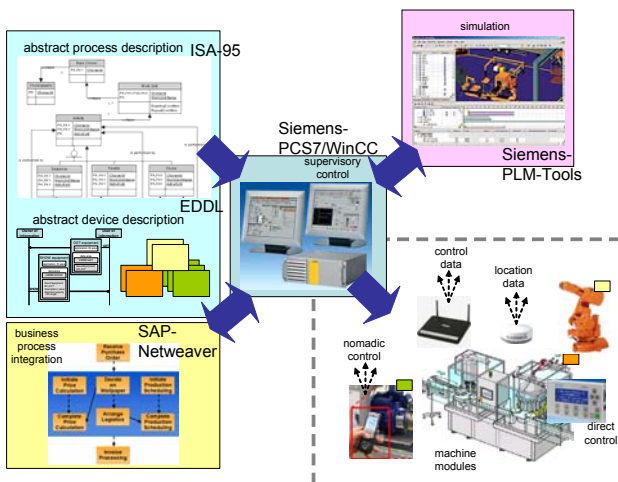

Fig. 5. *SmartFactory*[KL] -ICT-structure

Using radio technologies it is also possible to employ new, mobile and flexible systems for the operation, maintenance, and diagnostics of the production facility. Today, most sensors and actuators as well as more complex mechatronic units are equipped with stationary, inflexible control panels that range from those with just a few buttons and lights to those with complete PC-based, color LCD panels. Due to the lack of standards and the increasing range of functionalities, the complexity of these device operating systems is rapidly growing, a fact which not only leads to higher costs but also to problems in familiarization training and maintenance service. One solution to this problem is the physical separation of the devices and the control panels. Radio technologies enable standard control devices such as PDA's or mobile telephones to access different suppliers' field devices. A widely standard, consistent control concept raises the learning conduciveness of such systems and prevents operational errors. Location independence and the advanced display and interactive possibilities enable a significant increase in the flexibility of device operations.

The integration of location sensing systems with production and logistic processes is a major condition for meeting the demands for greater flexibility and shorter production cycles. The effective use of location data allows for flexible context-related applications and location-based services. Various positioning systems are deployed at the demonstration facility of the *SmartFactory*[KL]. For example, the floor is fitted with a grid of RFID tags. These tags can be read by mobile units to determine location data. Other systems for three-dimensional positioning based on ultrasonic as well as UWB technologies are also installed and currently tested, especially in terms of the accuracy achievable under industrial conditions.

The installed systems cover the full range of components within the automation pyramid (Fig. 6): from field devices (sensors/actuators) and programmable logic controllers (PLC) through the process management and manufacturing execution systems (MES) to the enterprise level (ERP) software, the entire spectrum of control technologies for industrial manufacturing is represented in the *SmartFactory*[KL].
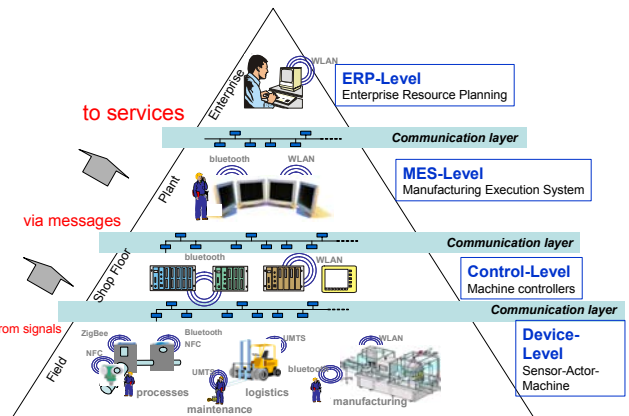

Fig. 6. Automation pyramid

The platform offered by the *SmartFactory*[KL] served as a research and development basis in numerous projects with various partners. For example, a demonstrator has been developed, that shows the usability of commercial mobile telephones for radio-based parameterization of components (Görlich, 2007). Using Java software, which runs on the mobile phones of several different brands, it is possible to monitor and configure a multitude of field devices in the *SmartFactory*[KL]. The available devices and wireless links are automatically identified. Furthermore, a uniform operating philosophy facilitates handling of field devices and enables access to any device from any location on the shop floor, thereby speeding up parameterization, diagnostics, and control of field devices. Rapid switching from one device to another is possible without changing location.

In a government funded project, a very basic and general method for the description of human-machine interactions in an abstract and hardware-independent way is currently being developed. This is a prerequisite for decoupling HMI engineering from hardware design, respectively the actual hardware used.

Beyond this, a group of industrial partners has developed a dedicated, radio-control system using the Bluetooth technology that meets the requirements of the production environment. As the project continues, additional wireless technologies and a greater number of device platforms will be

considered in an examination of the configurability of control interfaces of individual suppliers and the self-descriptive abilities of today's field devices.

The goal of the project, "Decentralized parameterization of the production processes via RFID" is the installation of a modular manufacturing plant that can adaptively react to changing conditions for the production of versatile products. The necessary flexibility will be achieved by storing the relevant production data on mobile storage devices attached to the products, which serve as the input for the parameterization and configuration of the production processes. The R/W-capability allows for updates of the product memory during production.

A digital record of the life cycle of high value products, continuous monitoring of a product's status, product location tracking as well as ubiquitous access to all relevant product data are topics of increasing importance to manufacturing and trade companies. In the framework of the government funded research project "SemProM" (Semantic Product Memory), an innovative, basic concept for a *Digital Product Memory* will been developed and implemented at the *SmartFactory*[KL]. As a visionary technology of the future, it is based on the next generation of mobile, embedded, and radio-based elements for semantic communication between everyday objects. The goal is to develop "intelligent" products, with capabilities far beyond the pure identification function of today's RFID features. Besides the evaluation of the various embedded sensors (e.g., temperature, brightness, humidity, speed, acceleration, location), they record all relevant product and operating data and, in the sense of an *Internet of things*, exchange this information with other products, with their surroundings, and even with their users.

3. THE LONG ROAD STILL TO GO

Despite the success stories already discussed, it is still a long and winding road from the vision to the reality of a smart factory, but just as it is constantly being walked by the consumer product engineers, it must also be taken by the factory planners. Along the path there are not just technical challenges but also multi-dimensional problems to be solved:

3.1 The technical dimension

The technical dimension most likely poses the least difficult challenges. Here, devices suitable for industrial use are to be developed. For reasons of economy they will likely be based to a great extent on the technologies from the world of consumer goods. For example, just as it took many years for the PC to become suitable for industrial purposes, so too will smartphones or wireless PLC's make the jump. In the process, we must always strive to use the existing standards from the world of the consumer whenever possible, for that is where the high production volumes are which lead to acceptable prices. But these standards also need to be adjusted to the conditions of the industry.

3.2 The organizational dimension

Many of the envisioned changes can only develop their maximum benefit when the surrounding organizational situation changes accordingly. This is especially true for the service-oriented architecture (SoA). It requires more than just renaming today's control functions "services" and leave everything else as it is. SoA is a powerful decentralized architecture that relies on company-wide task and service models. The services themselves are encapsulated and retrieved over a standard interface. The various levels of aggregation must first be identified and defined for such services. What makes the implementation so difficult is that initially the company-wide services must be defined semantically, and then step by step refined down to the unit level. Furthermore, the SoA architecture is not a strict hierarchical structure as is typical for plant construction today; rather it is a loosely linked distributed network architecture. This implies a need for new engineering methods and tools to be satisfied before any employment in an industrial setting can be considered promising.

The use of nomadic devices is also far more than just a substitution for the fixed installation of control panels. One problem here is the variety of different devices, which are also designed with significantly shorter life cycles as the rest of the plant. Additionally, there is the problem of user permissions, which must ensure that only authorized users can access a certain device within the plant. And, as device tracking enables permanent monitoring of the user, there are privacy issues of data protection to be clarified prior to use.

3.3 The planning dimension

A large portion of the problems in plant engineering have their origin in the planning methods commonly used today, which are closely associated with hardware factors. As a rule, today's planning procedures normally start with an initial, top-down rough planning in which the structures, components and production methods and parameters of the product are defined. Thereafter, the bottom-up detailed planning begins, in which the required machine parts and components are selected and engineered, wiring schemes planned in detail, and finally, the control hardware and software is developed. Today there are many advanced CAx systems used for this. With CAD, for example, STEP models can import and integrate mechanical data; CAE tools for SCADA development like PCS7/WinCC (Siemens) facilitate the design of control software, and visualization (or simulation) tools allow for the simulation of the entire plant already in early design planning stages. Unfortunately, these systems often lack adequate data integration: Although they are internally model-based, the models are often incompatible with one another. It is precisely this model-based integration that takes on increased significance in the lean planning process of the future. Here, solutions are most urgently needed to create an improved planning situation.

Model-based planning needs device models on the basic levels. Today, most industrial devices are already delivered to the customer with electronic CAD and product data in the

international STEP format. In the future, this data must be transformed into comprehensive device models including communication and even service models (Fig. 7).
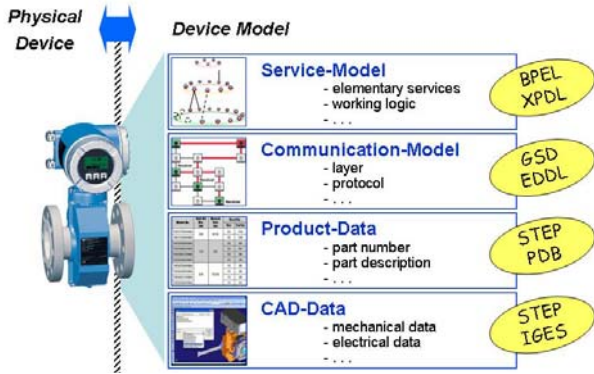

Fig. 7. Device modeling

3.4 The safety and security dimension

The daily frustration of having an empty battery for your mobile phone or having a virus sneak onto your PC is certainly annoying, but very seldom threatening. This is quite different for an industrial application. There, we must be able to ensure under nearly every normal condition, that the systems stay constantly under control. Today, while wired controls can provide a satisfactory safety guarantee, there are still many open questions concerning the mobile and wireless solutions. It is not only the technical issues like the power supply or the availability of channels that can present problems; there is also the risk of criminal attacks—the tiresome hackers—that not only cause severe problems but will be much harder to be traced.

Another problem area is fast approaching and with it come challenges we will be confronted with in the near future: As more and more devices are becoming smart and equipped with wireless communication interfaces, the frequency bands allocated for this purpose will quickly reach their capacity limits. Already today, e.g. at industry trade fairs, the WLAN links often break down, simply because there are too many users in a relatively small, enclosed area. New access protocols can certainly lead to a far better use of the frequency bands, but for the long term, there will be the need to release additional radio bands.

In spite of such problems, the first wireless systems are now being sold by several of the large vendors in the field of process automation. However, these are still custom solutions, which serve mainly to gather experience and test the market. Most customers have not yet been convinced of these systems' safety and security. But just as it took years for the PC to overcome the skepticism of industry as a reliable control component, the wireless systems will need a bit more time before they can assert themselves (Welander, 2007).

3.5 The social dimension

Finally, we should not forget the lessons learned from the CIM era. Whatever technical system we design, we always should put the human in the center! The factory devoid of humans is an aberration. We need humans in all phases of factory operations from the planning through the operation to the maintenance and repair services. While our human cognitive and sensomotor abilities have not significantly improved within the last thousands of years, future systems should focus on humans and their abilities and not conversely demand that the humans adjust to whatever technology.

The new technological possibilities will further provide a level of mobility for humans which has never been reached before. The place of work will be increasingly decoupled from the physical location of the worker. The wireless communication technologies make it a reality to remotely perform portions of the plant monitoring and operating functions, for example, from the cafeteria or even the sidewalk café. This brings up not only issues of job security but also of the boundaries between work and leisure and certainly even the compensation models.

As we have learned from today's smartphones, the short life cycles of such operating devices in comparison to the long life cycles of the production equipment require an independency of the HMI software from the hardware. This can only be achieved by replacing the device-dependant HMI software by abstract HMI models to describe the interaction independent from the actual hardware realization. Such models will have to be developed and then implemented in appropriate engineering tools.
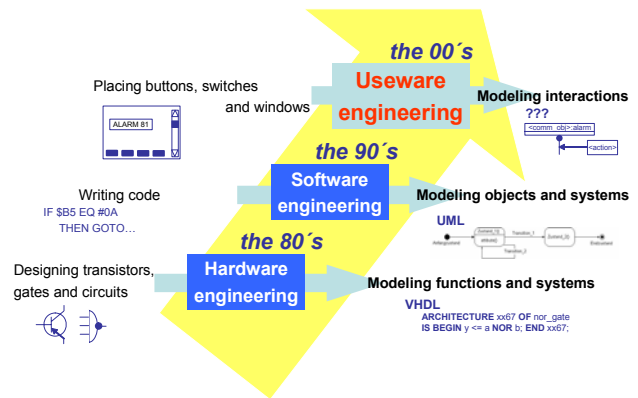

Fig. 8. Engineering development

Taking all this into consideration, the engineering of the HMI takes on a whole new significance. We are following the path we already walked long ago in the development of hardware and especially software: namely, from the direct design or programming to abstract engineering methods. In current software engineering, we are able to model systems using abstract, object-oriented methods. Similarly, we must now

develop Useware[1] engineering methods that describe the interaction in abstract, object-oriented ways (Fig. 8, (Zühlke, 2007)).

There have been many advances in the IFAC over the past years towards achieving designs in technology that are well-suited for human use. This is true both for the ergonomic design as well as for the social design of the work environment. It is important to continue to travel down this road to the new worlds of technology while making certain that human beings remain the measure of all things.

4. CONCLUSIONS

Today we are in a comparable situation to twenty years ago. New ICT technologies and products offer a broad range of new applications not only in the consumer but also the industrial world. A simple adaptation of existing technologies from the area of consumer goods appears tempting but, this would be inappropriate for industrial use in most cases. Instead, we should remember the lessons learned from the CIM crisis:

- reduce complexity by strict modularization, abstract modeling and lean technologies

- allow for a really concurrent engineering by decoupling process, mechanical, electrical, and control design on the basis of abstract models

- create and apply standards to all levels of the automation pyramid in order to reduce planning effort

- allow for self-organization wherever possible

- strengthen the interdisciplinary teamwork on all levels

- check the advantages of new technologies and architectures like SoA and their implication on the organization as a whole

- and in the end: develop technologies for the human!

The path we have taken in Germany with the *SmartFactory*[KL] initiative, to examine, test and develop technologies in a physical factory test bed, has proven itself so that we can recommend it for imitation elsewhere. However, the resources required are not to be underestimated and, in the last analysis, success can only be realized through strong, interdisciplinary cooperation among industry, academia and government.

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[1] USEWARE comprises all hard- and software components of a technical system that are related to human-machine-interaction, the term USEWARE was introduced in 1999 to emphasize the independent significance of HMI design compared to the traditional fields of hard- and software (Zühlke, 2004).

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