Systems Engineering in the IoT Era

Interviewees
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Dr. Martin Becker

Interviewer
Dr. Takaaki Matsumoto

Fraunhofer IESE is an institute of the Fraunhofer-Gesellschaft.
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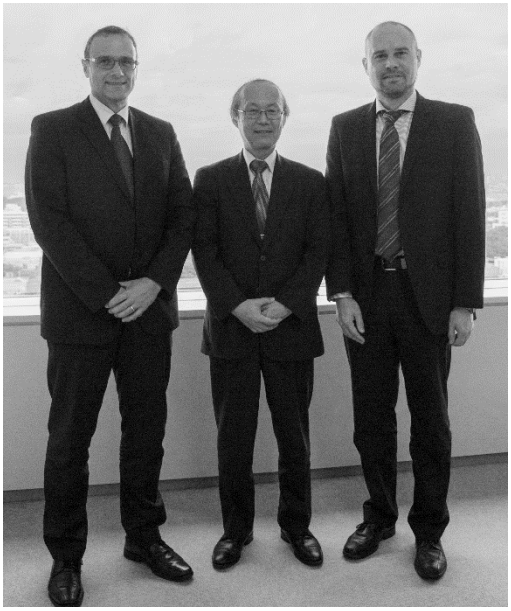
Introduction

The amount of software in formerly largely hardware-dominated products has continuously increased over time. Software is perceived as an enabler of new, innovative services and business models in all sectors of industry and society. Systems Engineering is an interdisciplinary approach that considers both the business and the technical needs of all customers. Being able to establish appropriate Systems Engineering practices in the organization is crucial for staying competitive and for developing innovative products on time, within budget, and with a high level of quality.

In summer 2016, Fraunhofer IESE conducted a study about challenges and best practices in the area of Systems Engineering across innovative companies in the German-speaking region. The results of the study were presented in Japan at the end of October 2016, as many Japanese companies are interested in sharing experience on how to successfully establish Systems Engineering in the organization and make it sustainable.

Within that context, the president of the Software Reliability Enhancement Center (SEC) of the Japanese Information-technology Promotion Agency (IPA), Dr. Takaaki Matsumoto, conducted an interview with Dr. Jens Heidrich and Dr. Martin Becker from Fraunhofer IESE, who presented the results of the study in Japan. This article presents a summary of the conversation.



Interview

***Matsumoto**: We have invited you to get your input and views about the influence of Systems Engineering in the era of IoT. First, can you explain to us why this is important for companies and what activities IESE is pursuing in this context?*

Heidrich: What we see in recent years is an increased trend towards system integration. Companies are seeking new business models and new opportunities. For instance, the company Adidas, a sports company, recently bought Runtastic, a company in the area of fitness applications for smartphones. We observe that formerly more product-, hardware-oriented companies are going towards completely new products, completely new business models. Digitization/IoT is a kind of enabler in order to discover new markets. We go from formerly closed monolithic systems to highly integrated systems of systems. A so-called smart ecosystem integrates information systems for controlling some business processes and embedded systems for controlling some technical processes as one unit to achieve a common, superior goal. One huge application field of these smart ecosystems in Germany is Industrie 4.0. Another important application field for IESE in recent years has been in the area of Smart Rural Areas. A great number of people in Germany live in rural areas. In the project Digital Villages, which is sponsored by the German state of Rhineland-Palatinate, we are building up two model regions for investigating the opportunities of IoT and digitization in rural areas.

***Matsumoto:** What is the focus of the Digital Villages project? Is it in Smart Farming or Smart Agriculture?*

Heidrich: There are different potential application fields of Smart Rural Areas. In the Digital Villages project, we are focusing on concepts around Smart Delivery and Mobility. For instance, we evaluate the efficient delivery of local goods supported by people who live in the countryside – as a kind of crowd-based delivery approach. In other projects in the context of Smart Rural Areas we also work in the areas of Smart Farming and Smart Health (e.g., tele-medical services or ambient assistant living).

***Matsumoto:** There is one big problem that we have in Japan, because especially in rural areas the average age is high, so there are many elderly people. Mobility is very important, especially in the rural areas because those elderly people cannot easily move around. The same is true for healthcare as well.*

Becker: Some years ago, there were large programs on Smart Cities in Europe, and while we were attending such a conference on the EU level, it became clear that we have to do something

for the rural areas. The majority of people in Germany and also across Europe lives in rural areas with less infrastructure compared to cities and a higher number of elderly people, who want to live in their familiar environment for as long as possible. Therefore, the key question was how concepts we know from Smart Cities can be brought to the more rural areas.

Matsumoto: *Talking about Smart Farming in Japan, the average age of the people who are working in the agriculture industry is over 65 years – and that average age is still growing. Therefore, it is very hard for those elderly people to do agriculture work and we do not have enough people or workforces in the agriculture industry. This is becoming a very big problem and there is a lot of discussion going on about how to make agriculture smarter and reduce the workload that is required for agriculture so that we can actually do agriculture with less people. Are there any concrete examples of initiatives in Germany for that?*

Heidrich: In Germany, the agricultural area is largely machine-driven. Especially if you have big, large fields, you need high-tech equipment for doing farming in that area. We have a strategic collaboration with John Deere, a very large US company in the area of farming. They have their European Research Center in Kaiserslautern and we are working on different concepts related to smart farming. On the one hand, it is about making it easier for people who operate a farm by providing smart machinery for efficient farming. On the other hand, it is also about increasing the attractiveness, also for younger people, to operate such farms again.

Matsumoto: *That is a very good point. Going back to the topic of system integration, we are now in the era of IoT, and various objects and services are connected and many different systems are integrated. In the past, the boundary between hardware and software was very clear, but that boundary is getting unclear. So, you talked about Adidas as an example, but I think the recent trend is more for former software companies moving into the hardware area, such as Google, who started to build automobiles.*

Heidrich: I would say you have it in both directions. On the one hand, the formerly hardware-oriented companies are thinking about the opportunities from IoT and digitization, and for them there is a high risk that a former pure IT company goes into their established market and takes away a substantial share.

Becker: The underlying trend is that across the different application domains, more and more product innovations are enabled by software. The classically more hardware-oriented companies have to invest in building up capabilities for efficiently providing the software. This also opens the field for more software-related companies who then buy in the hardware competences.

Matsumoto: *In addition to systems integration, are there any other topics that IESE is focusing on?*

Heidrich: For us, system integration is an underlying trend that drives many different topics that are related with Systems Engineering. I mentioned Industrie 4.0 as an important application topic for us. For instance, in the BaSys 4.0 project, which is sponsored by the German Ministry of Education and Research (BMBF), we are working on a base platform for Industrie 4.0. In the PRO-OPT project, sponsored by the German Ministry for Economic Affairs and Energy (BMWi), we are working on the usage of Big Data for Smart Production. In the IUNO project, which is also sponsored by BMBF, we are working on IT security for Industrie 4.0. As you can see, we bring in many different competences in this application field.

Matsumoto: *Does that mean that the platform for Industrie 4.0 is already established and that it is ready for the providers to develop products on top of that?*

Heidrich: That would be nice, but the BaSys 4.0 project just recently started in the middle of 2016. In Germany, the platform Industrie 4.0 oversees all the related activities and pursues many parallel threads. One thread is to develop this kind of base platform. We expect to have first results early in 2017, but it is a 3-year project.

Matsumoto: *So if vendors would like to develop products for Industrie 4.0, or by complying with the standards for Industrie 4.0, will there be a common API for communicating with the platform?*

Heidrich: Yes, the BaSys 4.0 project will provide the necessary specifications and a reference implementation for a base platform for Industrie 4.0. For instance, you need ways for describing abstractions of concrete machines such as digital models (digital twins) of machines.

Becker: The first steps towards this were initiated by the Industrie 4.0 platform. They developed a reference architecture for Industrie 4.0, which is called RAMI. And now, BaSys 4.0 is about to develop a concrete "operating system" for Industrie 4.0 along this reference architecture, which can be shared across the different application areas.

Matsumoto: *That operating system is going to be embedded or implemented into the product, which complies with the Industrie 4.0 standards?*

Becker: The product will be built on top of that. Industrie 4.0 applications or products will require new capabilities, such as being more aware of the respective context and surroundings, being capable of self-organization and self-adaptation. They have to take care of safety and security at the same time. These properties have to be built in. Currently, there are no suitable approaches at hand that provide this in an open fashion.

Matsumoto: *But there are so many existing products that people are using already, and if we have to scrap them all and build everything new? That is going to be very costly. What is your view of that?*

Heidrich: I think the major idea is that you do not have to throw away everything, but try to make machines smart – also existing machines. So you must find ways for properly integrating also legacy hardware into that kind of systems. Otherwise, I think this vision of Industrie 4.0 cannot come true quickly.

Becker: There are already existing platforms or operating systems from commercial companies, such as Siemens, who offer their products in an Industrie 4.0 context and companies can actually use that right away (even though it is proprietary). This will most probably not change due to these newly available infrastructures. It is more the idea of making it easier for companies that are not there yet, or maybe smaller and mid-size companies who want to dive into Industrie 4.0, to provide them also with technology that facilitates the adaptation of new technologies for their products.

Matsumoto: *I think that is a very important paradigm shift because current IoT seems to work like objects starting to connect with each other on their own. There is no discipline or no order. In that sense, we have to decide on the architecture to actually make sure that safety and security issues in IoT and Industrie 4.0 are sufficiently addressed. Such mechanisms seem to be very important.*

Becker: For instance, there is a large-scale European project called EMC^2, which is about embedded multicore systems. There, besides the architecture, especially some engineering mechanisms for engineering safety together with security are being developed. For instance, we are leading the respective work package there, where these safety and security integration approaches are developed. The challenge is not only in combining safety with security. An additional challenge is that the systems are changing at runtime. This means that we have to shift the final assurance of safety- and security-related properties from the development time to the runtime of the systems in the field. This requires new approaches from the engineering perspective.

Matsumoto: *I think it is very difficult to have dynamic adaptation, especially during runtime. How are you trying to achieve this, and what kind of concrete mechanisms are you thinking to use?*

Becker: There are dedicated models. We have a technology called ConSerts, which allows us to model system behavior or system properties. When these ConSerts models are composed at runtime, the system is able to check if the overall qualities required can be guaranteed so that, for instance, the composition of two systems would be safe. This requires that the kind of models we have of the system at development time today are pushed into runtime in the future. So that the system, once it is reconfigured, can reason about its properties.

Matsumoto: *Then the key question is how effectively and accurately you can actually model the systems?*

Becker: That is true. With that we come back to the overarching topic of model-based or model-driven Systems Engineering, which provides us with these models. It is important to note that it is not just a model about the system itself; we must also model the context surrounding it, including the humans for instance.

Matsumoto: *I think that is a good introduction, which leads us to Systems Engineering, which has drawn a lot of attention recently for coping with the fast changing IoT world. In your seminars held in Tokyo and Osaka, you talked about the current status of Systems Engineering in Germany and concrete case studies. Could we say that Systems Engineering in Germany is quite advanced and is widely adopted or that its usage is expanding.*

Heidrich: Nowadays, many companies carefully think about Systems Engineering and how to adopt it for their specific purposes. The maturity of companies is rising and according to our study, the vast majority really sees that it is a key topic for coping with future challenges. So especially for small and mid-size enterprises, it is still a challenge because they have limited amounts of resources to build up Systems Engineering competences.

Matsumoto: *I think that Systems Engineering is a very broad concept because it is often said that it is interdisciplinary and goes across multiple domains. That means, people need to build up high skills and high capabilities. If that is the requirement for the companies, it is going to be a big burden for them building up these competences.*

Heidrich: Of course, there is an investment in building up Systems Engineering capability. But, as you have said, the term Systems Engineering is a very broad term. It is less about a single person having to know about all the different disciplines. It is more about communication and letting the different disciplines in the organization have appropriate interfaces, talk to each other, and collaborate. If you have integrated products, the software engineers need to understand the hardware part, but also the hardware engineers need to better understand the software part. It is a big challenge for organizations to establish that kind of interaction, which is also related to the fact that previously you had pretty isolated processes.

Matsumoto: *So does that mean that a Systems Engineering concept does not only require technical changes, but also organizational transformation?*

Heidrich: Yes, you are absolutely right. That is one of the most important topics that we also saw in our study, that organizational change management is most challenging for the companies be-

cause, in order to be competitive, to set up efficient processes, you need to have the right organizational structure for doing so. Therefore, it is much more than "only" talking about technical aspects.

Matsumoto: *Did you see any particular concrete examples of companies in Germany who went through organizational transformation or reorganization?*

Heidrich: I think especially the bigger organizations in Germany initiated that kind of change. For instance, you find bigger companies that are very active in Systems Engineering such as Robert Bosch GmbH. In general, we also observe that it takes a certain time for initiating all these changes and it is also challenging to find the right resources. In Germany, there is a great demand for software engineers or people who have software engineering competencies.

Matsumoto: *That is a very important point because Japanese companies tend to think about Systems Engineering only from the technical perspective. Obviously there are lot of technical discussions about Systems Engineering, but not about other areas. And when we ask Japanese companies: "Are you using Systems Engineering?", the answer tends to be, "yes we are, because we use SysML".*

Becker: That is one part. But, on the system level it is important that you connect Systems Engineering with some business goals of the companies. There should be a clear driver or some new functions or new features in your products, which actually demand this more interdisciplinary collaboration. And from there, you would typically first have a look at how the system is structured and you would maybe start to establish some cross-sectional teams who do the Systems Engineering in a first run. Over time, once you see that you require more and more Systems Engineering capabilities, it could then also be a wise decision to reorganize the company.

Matsumoto: *In that sense, maybe the word Systems Engineering is not correct. Especially in Japanese, the word "engineering" has the connotation of technical engineering or mechanical engineering. We get the perception that engineering is that sort of engineering. So maybe a better word can be System Thinking or System-oriented Thinking.*

Becker: System Thinking is already a kind of term, which implies that the engineers think about system aspects on a broader scale. Therefore, I think that system thinking is part of Systems Engineering. What is required in addition, besides requirements engineering, is especially system architecting.

Heidrich: Maybe it starts even earlier, because as you have said, it has a lot to do with the business models – with finding the right opportunities for my organization. Starting from these opportunities you need to think about what competences do I need, what architecture should my system have, and so on.

Becker: You are absolutely right. For this, companies have to ensure that their business marketing and their engineers talk with each other and work closely together in order to exploit these business opportunities together with some technical opportunities. Typically there is no role who can do this alone. So again, a kind of interdisciplinary collaboration is required for really exploiting the potentials there.

Heidrich: It is important that companies think about how to open the established silos in the organization and let the people talk with each other. This is also about building up a good environment for innovation, which requires technical expertise, but you also need business expertise to think about the direction in which a company should go.

Matsumoto: *That is exactly what is happening in this area of IoT because existing closed innovation is not going to work anymore. If you stick with this closed innovation, you cannot have competitiveness. Therefore, we have to shift to open innovation.*

Heidrich: Absolutely.

Becker: And open innovation not only inside a large-scale organization, but also beyond! So more and more companies think about what we call smart ecosystems, where they maybe provide just a platform where other companies can provide additional hardware devices or software applications.

Matsumoto: *So after hearing our discussion, I think my image of Systems Engineering is that it has very broad definitions or connotations. In the past, we focused on "how" to make things, but I think "what" to make is also part of Systems Engineering. When Systems Engineering becomes that broad in its nature, it is not limited to only hardware or software. It will encompass the human actors, the people, as well. Is that, you think, the correct understanding?*

Heidrich: Yes, that is true. I think it is more about seeing the human in the center, because at the end, the human is the one that needs to be supported and uses the services provided by the systems, and it is important to see that as a central component.

Matsumoto: *In that sense, human actors can be very, very difficult because often, I think, making a model of the human is going to be very difficult or almost impossible. Therefore, when we model systems, the challenge will become how to model the human actor.*

Heidrich: Yes, I think that is a very big challenge. It is also related to the privacy topic, when collecting and analyzing data about human beings. In order to model human behavior, you also need to analyze what a human is doing in which situation and let the system react accordingly. Especially in Germany data privacy is a hot topic.

Matsumoto: *What you said is true, because when we try to model people, we have to understand the historical behavior of a person. Where did that person go and what did that person do? That is privacy information. Is there any particular direction that Germany is heading to in terms of privacy and also human factor modeling?*

Heidrich: The topic of data privacy is very intensively discussed in Germany. In general, the individual should be able to control what is allowed to be done with the provided data, and what is not allowed to be done. I think there are basically two solution approaches there: First, we have a technical solution. So, you can try to model some kind of data usage policies. For instance, at IESE we are working on the IND^{2}UCE framework, which tries to provide better control mechanisms regarding what is allowed to be done with data in a certain context/environment. Second, there is a non-technical solution, which is to create a higher awareness among the people regarding what kind of data they provide, and to educate them so they can make more informed decisions.

Becker: From a technical perspective, there is also the trend in different industries to not push all the data into the cloud so that it can be processed in a centralized way, but rather to bring these functionalities, which help to understand what people's needs or interests are, into the machines. So the function is somehow rendered in these embedded systems. That means that valuable or sensitive data can be stored locally in the machines and do not need to be "shared" with everyone in the cloud.

Heidrich: I think that also fits nicely to the general principles of analyzing Big Data, bringing the functionality to the data and not the data to the functionality.

Becker: And this does also open some market opportunities for companies that are able to build "smart" embedded systems, who can understand the needs of their users in a better way, or maybe which could even learn their behavior while they are out in the field. Such systems most probably have a higher market potential than fairly stupid embedded systems where all the intelligence is somewhere in the cloud.

Matsumoto: *Yes, I agree with that. Especially when wearable devices become prevalent, we can actually track and measure the physical data of people such as heart rate or pulse or blood pressure. We need to have a mechanism for the users to control what data should be passed on to the cloud so that better healthcare can be provided, or what data should be stored locally in the devices for the sake of privacy.*
So, when the system needs to have dynamic adaptation itself, the existing waterfall type of development methods may not be good enough. Mainstream development may become more agile. What do you think about that?

Heidrich: Nowadays, companies are driven by shorter innovation cycles demanded by their customers. This requires a certain agility on the company level to react to changing customer demands. Therefore, I think a lot of companies in Germany are trying to establish a highly iterative process in order to react to these changing customer demands. Agile development as a process is very popular in Germany, especially in the area of information systems. However, for the development of embedded systems, interest in these approaches is also growing. We made a study some time ago about what kind of agile approaches companies apply. We saw that companies do not just use Scrum or Extreme Programming as they are described in a textbook, but they adapt that to their specific needs. For instance, Scrum does not say anything about security or functional safety and other system properties that need to be guaranteed. And even though you are applying an agile development process, you need to think about how to bring these aspects in and how to make the process a little bit more mature with respect to these aspects. At IESE we try not to be a process evangelist advocating either plan-based or agile development. You should think about what goals you have as an organization and then design a proper development process.

Matsumoto: *In Japan, the agile development method is not commonly used yet. I think the biggest reason for that is because of the Japanese industrial structure. Most of the software development is done by vendor companies and not end user-oriented companies. For agile development, both types of companies need to work together in an integrated manner, but that is very difficult in the current Japanese industrial structure. How about the situation in Germany in that perspective? Do many companies have the development functions in their organization?*

Heidrich: That depends a little bit on the company. You have a lot of externally developed and supplied software and companies that are specialized on that kind of model. But, in general it depends on the IP and the USP. If the USP of a company is in software, they normally should try to have in-house development capabilities. If its USP is not in software, they could outsource these parts.

Matsumoto: *In a case when a company outsources to do the Systems Engineering, there are various challenges, such as contract challenges or other issues. Are there any good solutions for that?*

Heidrich: If you again take agile development as an example, you need to have a certain trust between the supplier of the software and the company that orders the software, because you typically pay for a number of iterations instead of having a huge, previously worked out requirements document as a basis. This requires a different kind of collaboration mode.

Becker: What can also be observed is that companies that shared textual requirements in the past, share parts of their system model with their suppliers in these days if model-based Systems Engineering is followed. Collaboration between the two is no longer just document-based, but if there are additional models, they can also be provided to the supplier and facilitate their development. This helps both sides to have a common understanding of what is going to be developed. And this is not just about structural models that define the system elements and the interfaces. It is especially about behavioral models, which allow so-called virtual engineering. There, a kind of heterogeneous simulation could be executed as soon as there are first models of central system elements available, which maybe combine parts from the OEM and from the supplier.

Matsumoto: *That is a very good suggestion and I think that is a very promising methodology in the future.*

Becker: In automotive, this is already quite heavily exploited these days.

Matsumoto: *And now I would like to move on to the last question. You have done this study about the situation in Germany. Based upon that, could you please give some recommendations or suggestions to the Japanese industry?*

Heidrich: I think what we are seeing in the study is that it is important first of all to think about what your opportunities are in the area of IoT and digitization. Then come up with a strategy on how to change and structure your organization appropriately. When you have established this strategy, you must think about what kind of competences you will need to build up in the area of Systems Engineering, and specifically software engineering. Then you need to also think about the engineering process that you will follow, so how to integrate the different stakeholders. We talked a lot about interdisciplinary development. Companies need to know how to integrate all

the stakeholders into the development process in order to efficiently and effectively deliver products of high quality. We found three areas for practices to be established initially: The first one was in the area of model-based development, the second one requirements engineering, and the third one system verification and validation. These are good areas to start with for establishing concrete techniques, methods, and tools. Further areas of interest include the topic of virtual engineering and having integrated toolchains.

Becker: It is important to have an understanding of what the added value is, and from this perspective then identify the areas where the companies maybe require additional capabilities and then see how these capabilities could be added. And the answer lies not in just buying a tool and hoping that people will use it properly.

Heidrich: I think the most difficult part is at the very beginning, because if you do not know "what" you want to do, it is difficult to say "how" you want to do it.

Becker: I think there is some good help there. In Germany, there are roadmap documents on embedded systems and cyber-physical systems, and also Industrie 4.0. Typically, they include many new application scenarios. I think that could be quite a helpful source of inspiration for companies to understand what could be value-adding new application scenarios, and from there then derive the necessary capabilities they would require for Systems Engineering.

Matsumoto: *Do you have any suggestions or recommendations in terms of human resource development? How to build and foster the people who would understand and have the skills and capabilities for Systems Engineering?*

Heidrich: You have to distinguish two branches there. First, to educate people earlier at the university level, to also motivate the topic of Systems Engineering and provide corresponding courses and curricula. Second is continuous training on the job, to provide company-internal and external training. This was mentioned by nearly all the companies in the study as being beneficial. Participating in special distance learning programs on Systems Engineering can also extend the capabilities of people in an organization. It is probably also a good idea to not limit that education to within the company, but to also think about how to exchange your experience with other companies. For instance, become active in communities that deal with Systems Engineering and try to acquire some knowledge from these communities. I think that would be a very good strategy for an organization.

Matsumoto: *So in Germany do you have many communities of that sort? Of course, there is INCOSE, and we have JCOSE, which is the Japanese branch of INCOSE, but the number of members of JCOSE is not so high. Do you have active communities for that in Germany?*

Heidrich: We also have this top-level organization in Germany, which is called "Gesellschaft für Systems Engineering", which means the Association for Systems Engineering. That's the German chapter of INCOSE. I would say the most active exchange takes place at specific topic conferences, such as focusing on systems requirements, systems architecture, system implementing, or verification and validation.

Becker: And within INCOSE and the national chapters, there are dedicated working groups on specific topics in Systems Engineering. For instance, in Germany, there is a working group on how to model functional architectures. In these groups, typically universities are involved, but also a lot of industry companies who share their experience and also their needs. It is very fruitful to engage also in these working groups.

Matsumoto: *This was a very insightful and informative session. Thank you very much! I understand that it is very difficult to actually teach the textbook-type concept of Systems Engineering because the concept is very broad in nature. Therefore, it is very important to share experiences or best practices in the form of maybe seminars or conferences. Thank you very much!*

Heidrich: Thank you very much!
Becker: Thank you very much!

The interview was conducted on 25 October 2016 at the headquarters of the Japanese IPA/SEC, Bunkyo Green Court Center Office, Tokyo, Japan. The questions and answers were translated consecutively from Japanese to English and vice versa.