Design and Governance of Collaborative Business Processes in Industry 4.0

Frank Schoenthaler **Dominik Augenstein** **Thomas Karle**
PROMATIS Group
Ettlingen (Karlsruhe TechnologyRegion), Germany
frank.schoenthaler@promatis.com dominik.augenstein@promatis.de thomas.karle@promatis.de

***Abstract*— The ongoing adoption of cyber-physical systems and the Internet of Things (IoT) is accompanied by incredible business process improvements fueled by ground-breaking innovations. Industry 4.0 with smart factories, smart supply chains and smart customer experience has become reality. And Industry 4.0 is also driving business process innovation. This paper deals with the design and governance of those innovative business processes.**

Keywords*—4th Industrial Revolution; Industry 4.0; Internet of Things (IoT); Internet of Services (IoS); Social BPM; Social innovation lab; collaborative business processes; business process design; governance, risk, and compliance (GRC)

I. Introduction

More and more people today can be reached at any time and anywhere in the world via mobile devices and wearables. At the same time, progressive global networking is taking place across organizational, national and cultural boundaries. After all, network users want to communicate more with partners and increase the efficiency of doing so. In addition, they are driven by human curiosity and the desire for consumption of needs-based products and services at the lowest possible cost. The amount of personal data that is submitted when using the Internet is inconceivable. Sometimes it happens involuntarily, but more often it is surrendered voluntarily. This is often driven by the desire to better tailor products to the specific needs, or a product that is actually designated as a free product is paid with the net currency "knowledge" instead. Or shall we name this currency precisely "personal data"?

From people's accessibility at all times and in their various roles as citizens, consumers, employees, business partners, opinion leaders, and so on, and from the knowledge of important personal data, including the interests for purchases, preferences and behaviors, companies can obtain immense potentials to improve and extend their supply chains. There is hardly any major company today that does not pursue the goal of developing this potential for itself. Digitization is the magic word that is associated with this development. Companies have long understood that it is not sufficient to tackle only a few processes occasionally, in cases where potentials are assumed for fast conversion, but that there is a need for an enterprise-wide digital transformation that takes all business processes to the test and checks them with regard to their suitability for digitalization. Critical to the continued success of the transformation program is a holistic perspective on business models, strategies, processes and enterprise architecture, combined with consistent planning and implementation of transformation projects.

II. The 4th Industrial Revolution and the Internet of Things (IoT)

In a period in which many companies are still in the midst of or only starting to plan complex transformation programs, a new dimension of digitalization opens up: Now objects and machines are digitally addressable anytime, anywhere via sensors and SIM cards, too. Cyber-physical systems (CPS) network in the Internet of Things (IoT), and they are the building blocks of a new industrial revolution.

A. Cyber-Physical Systems (CPS)

A cyber-physical system (CPS) is a system of collaborating IT elements, designed to control physical (mechanical, electronic) objects. Communication takes place via a data infrastructure such as the Internet. Traditional embedded systems can be considered as a special case of a stand-alone CPS. In a modern CPS, however, networking between multiple interacting elements with physical input and output stands in the foreground. The CPS communicates with both machines and also with people (graphical displays, pick-by-voice ...) based on simple questions such as "Who are you?", "Where are you?", "What are your contents?". It is able to make autonomous decisions and to control logistical processes. Thereby it refers to ambient conditions, which it constantly monitors.

B. The 4th Industrial Revolution

With the possibilities of networking between people and machines, both within the respective groups and with each other, unsuspected new opportunities open up for collaboration in the context of social networks. This results in disciplines such as Social Manufacturing and Social Logistics, which will be the effects of the 4th Industrial Revolution. In the following we will use the term “Industry 4.0” as a typical application of the 4th Industrial Revolution. Industry 4.0 is a future-project in the High-Tech Strategy of the German Federal Government (cf. [1]), which promotes the digitalization of traditional industries such as manufacturing and logistics. Technological basis are CPS and the IoT. Further reading can be found in [2], [3], [4], [5], [6], [7], [8].

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The 4th Industrial Revolution opens new potential for the automation of existing production and logistics processes with the application and networking of CPSs, but above all it creates the conditions for completely new processes and services. The revolution is accompanied by an increase in complexity and new security challenges, but on the other hand also by the increasing degree of decentralization and self-organization. As will be seen later, this is precisely what creates the considerable requirements for new business processes.

C. Collaborative Business Processes on the Internet of Things

An industrial revolution will not take place in one day, but takes place over a period of years or even decades. This is also true for the 4th Industrial Revolution. And it will not only take place in industrial manufacturing, but also extends across the entire value chain. It is revealed by the more and more increasing collaboration across organizational boundaries, to the establishment of virtual organizations in which the value creation process is implemented consistently by a global network of highly specialized companies. And it does not end in business networks, but increasingly involves consumers, too, directly or through their social networks.

Let's look at a business scenario in Fig. 1, as it can be found in large parts in reality already. And with the expected progressive spread of Industry 4.0 we will already be able to speak of a typical business scenario in a few years. In the figure, intelligent CPS communicate with each other and with conventional IT systems based on the Internet of Things (IoT).

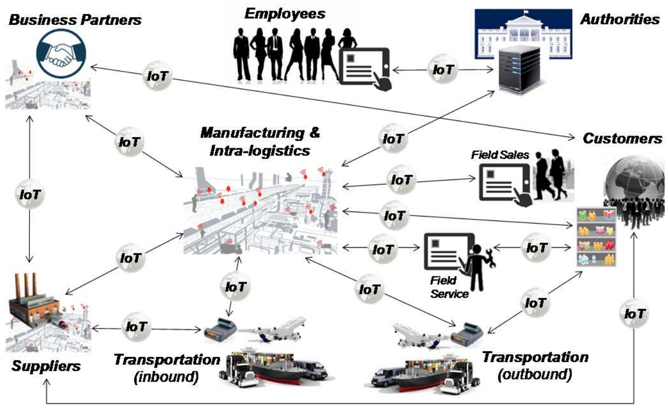

Fig. 1. Typical business scenario in the Internet of Things

The figure shows IoT-based communication along the value chain, i.e. that between supplier and carrier, then between shipper and producer, and finally between the producer and his customer. Already by this type of communication a digital transformation of the value chain takes place that results in enormous improvement potentials. However, perhaps even more important are the newly emerging communication channels such as between supplier and customer, which give the supplier an insight into inventory of salable products directly on the shelf at the point-of-sale, so that he can proactively respond to the producer's anticipated needs to his own pre-products. In this example, a new form of collaboration arises from the digitization, which eventually results in a transformation of the value chain itself. The improvement potential of such a transformation is obvious. However, to exploit this potential conditions have to be created that are not of a technical nature, but mainly of sociological nature. To discuss them at this point is beyond the scope of this paper. We only want to point out the trust among business partners, which will have to gain a whole new quality. In addition, issues such as governance, risk, security, and compliance (cf. Section VI and [9]) must be considered.

Just to enhance this view on the IoT we would like to recommend the look forward of J. Rifkin (cp. [10]): Rifkin describes how the Communication Internet is converging with a nascent Energy Internet and Logistics Internet to create a new technology platform that connects everything and everyone (Internet of Everything, IoE). Billions of sensors are being attached to natural resources, production lines, the electricity grid, logistics networks, recycling flows, and implanted in homes, offices, stores, vehicles, and even human beings, feeding Big Data into an IoE global neural network. Prosumers *(producers + consumers)* can connect to the network and use Big Data analytics and algorithms to accelerate efficiency, dramatically increase productivity, and lower the marginal cost of producing and sharing a wide range of products and services to near zero, just like they now do with information goods.

D. Fundamental Changes ahead of us

Before we take a closer look at the characteristics of business processes in Industry 4.0, we want to shed some light on the most fundamental changes along the entire value chain, which we will be facing, or that in many cases are already taking place directly in front of us:

- *Self control*:
  Things (e.g. CPS) will operate and interact autonomiously.
- *Self organization*:
  Agents will negotiate with each other on the global IoT. This will lead to a decentralization of decisions.
- *Less complex decentralized algorithms*:
  Complex algorithms for centralized supply chain planning have to be replaced by less complex decentralized algorithms.
- *Tight integration*
  of customers, suppliers, and business partners along the value chain.
- *Responsiveness*:
  Transparent decisions in decentral control cycles enable fast reactions to changes and disruptions.

Intelligent products:
Here, intelligent production systems will create intelligent products that can be identified at any time and that can be localized. They will know their current status and they will be able to submit this information as well as their entire history, so all states that they have been in as part of their life cycle. Important for the self-organization is that they know their options on the way to completion, i.e. to a certain extent, they carry their own production plan within themselves.

New qualifications:
Although primarily technical aspects have been considered so far, it is to be expected that the 4th Industrial Revolution will also bring about a revolution in the working world. Reference [11] postulated a technological unemployment that arises when jobs are replaced by intelligent machines. But it will also create new jobs and other jobs will change considerably.[1] But what all changes have in common is the need for a generally high level of education by all concerned walks of life. And the 4th Industrial Revolution demands - just like all the revolutions before it - new skills that were previously have not necessarily promoted in our current education systems, but perhaps even inhibited:

- advanced requirements for working independently and self-organized
- ability to collaborate intensively and effectively with external partners
- business transaction processing is replaced by approval, monitoring, planning, simulation tasks

III. Orchestration of Standards-based Business Processes

Industry 4.0 comes along with intensified corporate-wide collaboration, which presents businesses that operate in a global context with many different partners with an unprecedented challenge. How can such businesses prevent continually spiraling costs when they try to meet the system requirements of their business partners, while the potential benefits of collaboration are reversed? The answer is standardization, which is also driven by Cloud deployment, which is technically simple and does not cost much. Companies will - as consumers always have - focus more on standardized services that they receive from an Internet of Services (IoS) and pay based on usage (cf. Fig. 2). At the same time global industry standards prevail for cyber-physical systems.

Does this mean that due to the ongoing standardization of the used business services there will no longer be any competitive advantages in business processes? Does Industry 4.0 lead to less competition or a competition, which preferably is decided in the price war? This suspicion is justified, but can be easily dispelled, because it will show that for economic success, in addition to a highly qualified staff, the intelligence in the design of business processes will be crucial. And in this business process intelligence, the competitors will differ considerably in conjunction with the ability to quickly and economically adapt business processes to the rapidly changing market requirements.

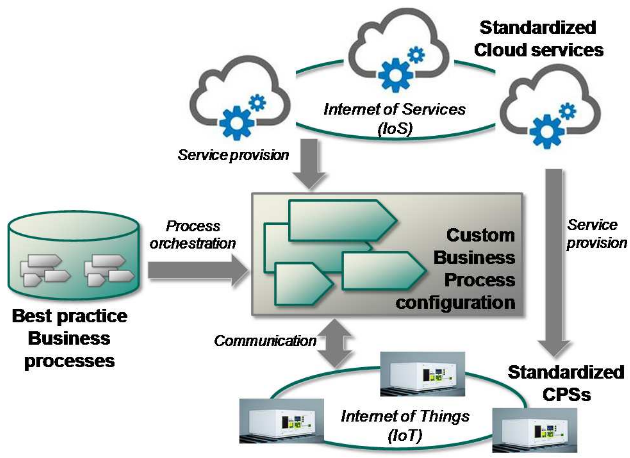

Fig. 2. Orchestration fo standards-based business processes

In Fig. 2 it is shown that companies do not differ in the use of standardized services, but use it in the way they configure their business processes and services in these processes. In the sense of speed in the orchestration of processes and the quality of the process configuration, we recommend proven best practice business processes, which can then be reused in future process configurations. Techniques for the creation and reuse of best practice business processes are described in [9]and [12].

IV. Decentralization of Transaction Processing

Today's enterprise applications, in the core, assume a central transaction processing through the application user, as shown in the top area of Fig. 3.

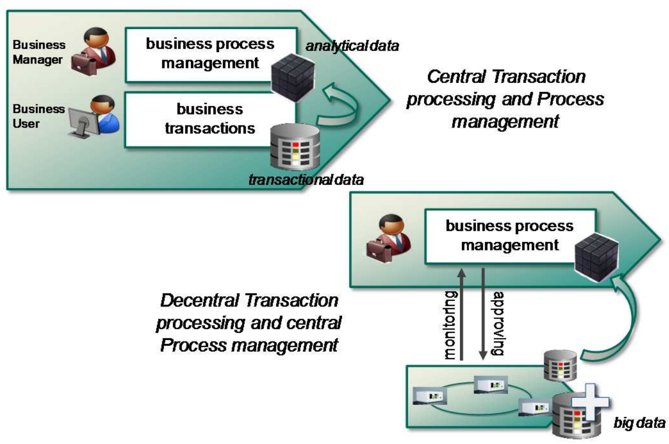

Fig. 3. Decentralization of Transaction processing

Through the increased use of mobile devices and by increasing the provision of self-service portals in line with an evolutionary process there will be a certain amount of decentralization. However, the responsibility for business transactions still remains with the business user. For the overall management of the business process, a business manager is responsible, who is also the disciplinary superior of the business

[1] A detailed discussion of the effects of the 4th Industrial Revolution on the world of work, even on our entire economic system and onto society is urgently needed to create the right conditions. However, this would be beyond the scope of this paper. Instead, we would like to refer to two interesting publications and recommend reading them: [10] and [11].

user in general. This two-stage model in the figure may be, of course, of more stages in practice. As part of the operational implementation of business processes transaction data arise (structured and unstructured, e.g. documents) that are compressed for analytical processing in the context of litigation and often for faster Slice & Dice access, and are stored in multidimensional data marts and data warehouses.

In Industry 4.0, the central transaction processing will still be found in the back-office area, e.g. in financial accounting or sales office. However, in areas that will be dominated by CPS it will be a matter of the past. There it will be replaced by a distributed processing by self-organized and self-controlled agents. They produce and process the transaction data, but also generate a wealth of additional sensor data, which will mostly be stored in so-called NoSQL[2] databases. Sensor data are an interesting class of big data (cf. [13], [14]), from which valuable business knowledge can be extracted with big data analytics tools. In this model and in the context of management responsibilities, the distributed transaction processing business process management is focused on the monitoring of business activities including the measurement of business performance as well as on approving of operations and results.

V. DESIGN OF BUSINESS PROCESSES 4.0

As shown above, some business processes differ in the Industry 4.0 considerably from conventional business processes. While the increasing standardization of used cloud services poses significant potential for cost savings, especially through cost-saving deployment cost, these can be easily reproduced by competitors in the market. In this respect, saved deployment costs are not suitable for achieving sustainable competitive advantages. Companies are therefore faced with the challenge to achieve sustainable competitive advantages through product innovation, but also by means of intelligent business processes. We want to show these business processes with the suffix "4.0" to make it clear that they have a higher adaptability, advanced options for managing communication relationships encountered in the IoT, and procedural support for innovative Industry 4.0 technologies.

A. Strategy- and Architecture Modeling

In practice, the Horus® Method™ has proven to be convenient for the design of Business Processes 4.0 (cp. [9]). The method provides a phase-oriented structured approach taking into account all relevant aspects of modeling. In addition, it is supported efficiently through the tools of Horus[3] Enterprise.

Fig. 4 illustrates the Horus approach in Phase 1 of the strategy and architecture phase. This phase aims to provide a strategic technical framework for detailed business process modeling. It includes a contextual analysis, a strategy analysis and the enterprise architecture modeling. In the context analysis, the system framework to be analyzed is defined. In this framework, the business goals, a performance model and the real context model, in which the system to be analyzed is placed in relation with its external entities, are created. Here, you already have to keep in mind that collaboration among various companies within the framework of an integrated value chain is typical for Industry 4.0. Insofar, the system framework usually includes not just one company, but a composite of cooperating enterprises, which have formed a "virtual company" in the context of the value chain.

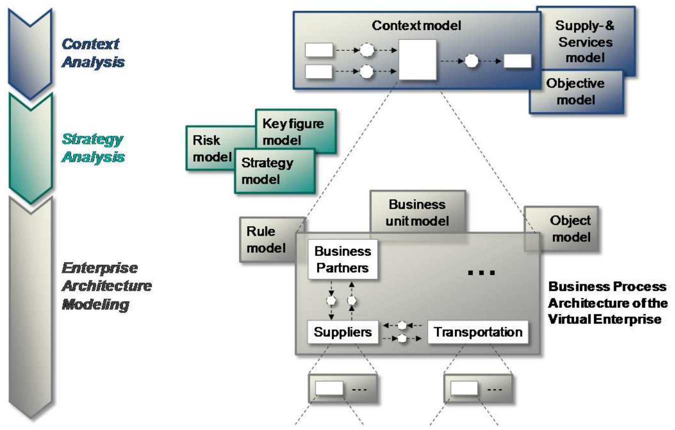

Fig. 4. Horus® Method™ *Phase 1* – Strategy and Architecture

Based on the business goals of the virtual company, the mix of strategies to be implemented is developed during the strategy analysis supplemented by a risk and a performance measurement model. The result is a reliable and binding framework that is available for all collaborative partners, in which the business process architecture for the virtual enterprise can be developed. Here, where appropriate, applicable reference models in the form of Horus Knowledge Bases (cf. [9], [12]) are used, which greatly enhance the productivity and quality in modeling, especially if they reflect industry-specific standards, such as SCOR®[4] or eTOM®[5] *(*enhanced Telecom Operations Map).

The liability of the models for all partners in the virtual enterprise, which were elaborated in the strategy and architecture phase, has already been mentioned. For this reason, it is essential for the network's success, that the partners participate early on in the modeling phase. For this, the Social BPM tools (cp. [9], [15]) of the Horus method have proven to be effective. As time-limited (a few hours up to max. 2 days), focused labs they allow to bring together a large amount of participants from different organizational units and companies in web-based sessions with little efforts in terms of time. The

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2 The term NoSQL stands for "Not only SQL" and is used for data models that do not use the tables common for storage and retrieval of structured data.

3 Horus is a family of business process engineering tools, sold by the software manufacturer Horus software GmbH and a global network of business alliance partners. You can find a freeware version of the modeling tool at http://www.horus.biz/en/products/horus-enterprise/freeware-download/, available for download. Interested institutions active in public research and teaching can use the complete product range in the Horus Cloud upon request.

4 The Supply Chain Operations Reference model (SCOR®) of the APICS Supply Chain Council is the world's leading supply chain framework, linking business processes, performance metrics, practices and people skills into a unified structure.

5 The Business Process Framework (eTOM®), which is maintained by TM Forum, is a business process framework for telecom service providers in the telecommunications and entertainment industries.

work is often done by interdisciplinary groups across organizational, corporate, national and cultural boundaries. The labs are suitable for tuning and training tasks as well as for the development of process and service innovations (cp. [16]). In addition to working in labs, participants can work in web-based social networks for prolonged periods of time in an asynchronous way to prepare results, deepen, rework, review and approve them.

In addition to the business process oriented fixation of a collaboration framework for the virtual organization, the parties usually also agree on a quantitative framework. In practice, sometimes the determination is made based only on a collaborative financial planning by the partners involved. Here, we have had positive experiences in the interaction of Horus with the Oracle enterprise performance management product Hyperion Strategic Finance (HSF). In most cases, however, collaborative planning of required quantities, resources, personnel requirements, sales volumes, investment and financial figures are made. Here, in practice, Horus is used together with the Hyperion Planning Suite by Oracle and Oracle's cloud-based Planning & Budgeting Services.

B. Business Process Analysis

In the framework, which has been created in Phase 1 of the Horus Method in collaboration of the cooperating partners, the details of the business processes are developed in Phase 2. These are derived from the communication relationship examples shown in Fig. 1. Business processes can move either in the context of a single partner or across two or more partners. Of course, the Social BPM tools are used again, especially in multi-partner cases. Similarly, whenever possible, reference models are used.

As an example for the business process analysis, Fig. 5 shows a model structure in which a company engaged in Manufacturing & Intra-logistics cooperates with two different suppliers. The suppliers pursue two very different policies with their participation in the virtual enterprise: Supplier 1 acts as a "black box", i.e. they allow the partners no insight into their internal business processes. Supplier 2, however, understands his policy "100% transparency" as a real competitive advantage in being considered by his business partners. In practice, both extremes are rarely encountered, but usually more or less transparent hybrid forms. For this reason, it has been proven sensible not to proceed with the communication relationships mapping in an integrated model, but in clearly defined model structures as exemplified in Fig. 5. Basically, the entire process is broken down into sub-processes that take place in the context of an enterprise and those that represent the relationships between these sub-processes. This latter class of sub-processes describes the communication and the performance flows between the partners. For this reason, such sub-processes can be interpreted as service & commission level agreements, upon which commercial agreements between partners can be made in practice.

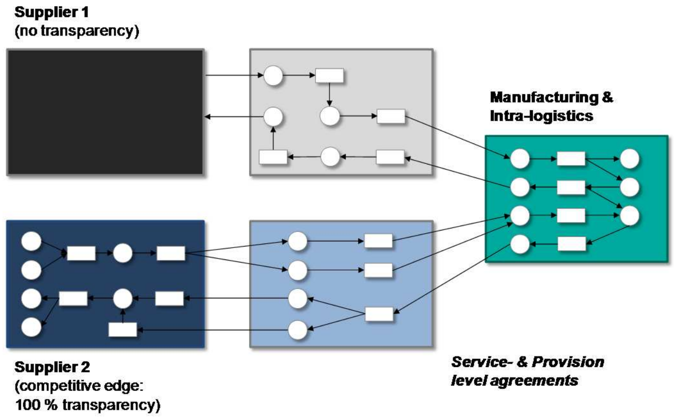

Fig. 5. Horus® Method™ *Phase 2* – Business Process Analysis

C. Process Simulation

In practice, the analysis and design of Business Processes 4.0 show a complexity that should not to be underestimated. Making this complexity manageable is an object of modeling methods and tools used. Communication and decision making processes can usually be very well supported with Social BPM, even with a large number of partners involved. The results obtained in practice are quite encouraging. Complexity also arises from the challenge of having to make quantitative statements on the expected performance of the business processes in the context of modeling. Will the process be able to process the required quantity in the required quality and within the given budget and time frame, and across organizational and corporate boundaries? And if not, what action (capacity increase, change of supplier, adapting the quality specifications, etc.) can be taken to make this possible? These and similar questions must be answered with a reasonable time and cost effort in the context of modeling.

The Horus Method proposes the use of simulation methods (cp. [9], [12]). For procedure modeling Horus XML nets are used which come with operational semantics and are directly simulated. The passive model elements are assigned to identifiable objects that are moved through the net by executing the active elements. This is how the model is tested "under load" for its correctness and performance. The simulation results (changes in the net and assignments of the passive elements, each over time) can then be recorded in a multidimensional data mart and analyzed with data analysis techniques. An animation of the nets based on the simulation results complement the quantitative analysis of a visualization component that brings the modeled dynamics vividly to life.

In practice it is often found, in connection with the simulation, that it is not the modeling itself that represents the core problem, but "feeding" the models with realistic parameters and simulation data and the subsequent interpretation of the simulation results. Fig. 6 illustrates typical classes of simulation data, which are used as parameters within the simulation models. The spectrum ranges depending on the practical application of customer behavior on product quality to environmental conditions.

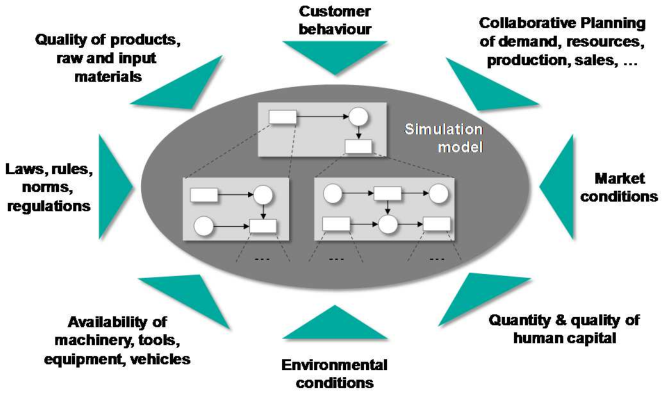

Fig. 6. Simulation model and important parameters

Simulation tools such as Horus offer various possibilities for parameterization. For the XML nets used in Horus, parameterization takes place through the instantiation of the passive model elements and the object stores with objects. Technically, this instantiation is done with the implementation of web services, which insert CSV tables, database tables, or results from business analytics and big data analytics as objects into the simulation model. Due to the fact that future behavior needs to be simulated, technologies such as predictive analytics and data mining are used (cp. [17], [18]). Particularly worth mentioning is the growing importance of big data analytics in the context of Business Processes 4.0. For example, social data from social networks can be used to forecast customer behavior, or the sensor data from cyber-physical systems can be used to evaluate the performance of intra-logistics networks.

VI. Business Process Governance

A. GRC – One of the Key Challenges in Industry 4.0

The days where an enterprise could be led entirely in an autocratic "lord of the manor" fashion are long gone. And this is especially true for virtual enterprises like in Industry 4.0. Regulators respond with increasingly complex regulations to the global escalation of economic, environmental and computer crimes. The crux here is that for a globally active enterprise, it no longer suffices to consider only the national regulations at enterprise level, but rather all regulations must be considered which are affected in the context of transnational business processes. These regulations are not even compatible in many cases. In short: Governance, Risk and Compliance issues (in short: GRC) are at the top of the management's agenda; and the same holds true for virtual enterprises as in Industry 4.0. But first a short disambiguation (cf. [9]):

- *Governance* is running a business on the basis of clearly understood and formulated business objectives and instructions. Important conditions are legal compliance and completeness. Governance thus extends across all business units and levels.

- *Risk management* is the sum of all measures for dealing with known and unknown internal and external enterprise risks. These include the establishment of early warning systems to identify risks, as well as measures to eliminate potential risks, and for the treatment of incurred risks.

- *Compliance* denotes conforming to a rule, correspondence or conformity with a specification, policy, standard or law with (ethical and moral) principles and procedures, including standards (e.g. ISO) and clearly defined conventions. Compliance fulfillment can be both forced (e.g. by law) and voluntary (e.g. adherence to standards).

B. Influencing Factors and GRC Mechanisms

In corporate practice, it has been proven to treat Governance, Risk and Compliance management in a cross-thematic context. The reasons are obvious: Very many interdependencies exist; synergies arise during implementation that on one hand enhance the effectiveness of planned actions, contributing to cost reductions on the other. By the way, companies that see GRC not primarily as a burden, but above all as an opportunity to improve business processes, achieve genuine cost savings and improve their competitive positions.

Fig. 7 shows the typical structure of a GRC approach. The number of external requirements seems overwhelming for the observance of and compliance with corporate records-management, in many cases setting forth personal liability.

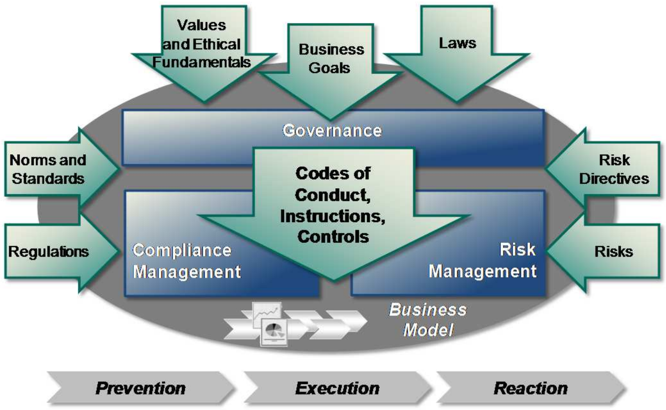

Fig. 7. Influencing factors and GRC mechanisms [9]

Their task is to formulate appropriate instructions, to communicate and to monitor their compliance. Even more: The directives should be complete, efficient and effective, therefore consistent in itself. It is also necessary to implement mechanisms that monitor and control the execution of the directives. In addition, reactive mechanisms are to be provided for, ensuring that the enterprise immediately takes proper measures, in the case of imminent or an actual violation of regulations, to limit damage to the periphery as well as the enterprise itself. Responsible enterprises pay the highest attention to preventive mechanisms. With the avoidance of risks and compliance violations lies the key to significant cost savings and prudent market trade, often resulting in interesting competitive advantages.

However, it is clear from these considerations that the drafting and subsequent implementation of a comprehensive GRC approach bears a high degree of complexity. This is actually manageable only if the enterprise connections are represented in a consistent model. Analyses and optimization are possible based on this model, as well as development of an effective GRC system. In this respect, GRC is one of the most important fields of application of Horus. GRC is covered by the Horus Method and the dedicated GRC tool Horus GRC.

VII. CONCLUSION

In the present work it was first shown what the conditions and the drivers are for the 4^{th} Industrial Revolution and Industry 4.0 and what changes arise for the people, businesses and finally society. Based on a typical business scenario typical communication and performance relations between different partners have been identified, which form the basis of collaborative business processes based on the Internet of Things.

The standardization of IT functionalities in the form of cloud services that are cost-effectively deployed via an Internet of Services characterizes the Industry 4.0. Sustainable competitive advantages can be achieved by individually orchestrated business processes. In conjunction with the increasing decentralization of transaction processing, this leads to a new class of business processes, which we have designated as Business Processes 4.0.

The core of the present study were the concepts and methods for the phase-oriented modeling of Business Processes 4.0. Here, particular attention was paid to involving the entire business community through the use of Social BPM tools. Driven by the decentralization of decision-making, simulation as an important tool in forecasting and business processes planning has become increasingly important. Here, parameters are progressively included, which are obtained from big data analytics (including sensor data and social data).

Finally, the subject of Governance, Risk and Compliance was discussed, which has a significant importance for virtual enterprises in Industry 4.0.

VIII. OUTLOOK

The present work is based on practical experience of strategy- and business consulting as well as IT consulting, solutions and systems integration projects, which PROMATIS has carried out in recent years. Here, Enterprise Applications - preferably Oracle Applications (Oracle Cloud Applications, E-Business Suite, CRM On Demand, Hyperion EPM, …) - were used, as well as the entire Oracle Middleware stack. In addition, research results from Horus Innovation Partners have been incorporated, a research alliance bringing together PROMATIS and Horus software GmbH (cf. Fig. 8).

Fig. 8. Horus Innovation Partners

The Horus Innovation Partners work in research and development projects on various topics related to the 4^{th} Industrial Revolution. For these projects, interesting and actionable results can be expected for the coming years:

- Best Practice Reference Models for business processes in smart factories, smart supply chains, and smart customer experience
- Social BPM and Social Innovation Labs
- Gamification for modeling and execution of smart business processes
- Governance, risk, security, and compliance in smart factories
- 100% process flexibility with schema-less Business processes

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