Production process stability – core assumption of INDUSTRY 4.0 concept

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Abstract. Today's industrial enterprises are confronted by implementation of INDUSTRY 4.0 concept with basic problem – stabilised manufacturing and supporting processes. Through this phenomenon of stabilisation, they will achieve positive digital management of both processes and continuously throughput. There is required structural stability of horizontal (business) and vertical (digitized) manufacturing processes, supported through digitalised technologies of INDUSTRY 4.0 concept. Results presented in this paper based on the research results and survey realised in more industrial companies. Following will described basic model for structural process stabilisation in manufacturing environment.

1. Introduction

In recent years, we are speaking a lot about Internet of Things and about Industry 4.0 concept. All initiatives in this fields are concerned on the right process parameters compatibility. By implementation of both concepts we are confronted with core requirement: to have stabile processes in manufacturing and by manufacturing supporting enterprise processes. Many scientific papers describe the future state, but we need to find right way, how to prepare our industrial enterprises for input (implementation stage) of Industry 4.0 – we are speaking at this place often about revolution in managing, thinking and living in the frameworks of our traditional business models. Daily in our practice we can monitor the important change: computers will no longer be a tool, but in each industrial enterprise they will be "a digital management". And if we will initialize this state in the framework of Industry 4.0, we need to have aligned designated internal and external enterprise processes. Future target is a vision of adequate digital functionality.

Companies can be successful in any industry, but only if they use their intellectual capital to find sources of competitive advantage. Process innovation in production and administration processes must be reflected in human performance systems, processes and completely production technology. Implementation of Industry 4.0 concept strong depends from the right understanding of people, integrated in this new change processes in 4^{th} industrial revolution.

Main goal of presented paper is to present core parameters of process innovation methodology, which enables to achieve real results in relative short time. Core output of presented methodology is a complexly way of mutual connection of people knowledge and skills, effective connection of man-man production conception integrated with e-processes and administration systems in enterprise. Results demonstrate, that SMEs have limited awareness of the risks associated with underinvesting in process innovation system.

2. Theoretical background of process stabilisation model

Process is important (Grieves, 2011), but it really doesn't describe the really interesting thing that people do, engage in practices, that is the real driver in creating, building, supporting and disposing of products. A successful product (Brissaud, Tichkiewitch, Zwolinski, 2006) must be balanced: marketing, technology, and user experience all play critical roles, but one cannot dominate the others. There is a big difference between infrastructure products, which we call non-substitutable goods, and traditional products, substitutable goods. With traditional goods, a company can survive with a stable, but non-dominant market share. With infrastructure goods, there can be just one.

Different factors are important at different stages in the development of a technology. In the early days, technology dominates. Who cares if it is easy to use? All that matters are better, faster, cheaper, more powerful technology. In the middle stages, marketing dominates. And in the end, mature stages – where the technology is a commodity. User experience can dominate, user experience and marketing. The customers want convenience and value for their money. They want ease of use, emotional appeal. The customer is not well served. As companies (Ernst & Young, 2012) find themselves in the behavioral change business, they would do well to leverage behavioral economics, a discipline that is rich with actionable insights on the biases that guide our behavior and on the levers – from the immediate feedback of social networks to the rewards of games – that actually work. Process innovation can dramatically improve business performance. Its goals are ambitious – companies embarking on process innovation often seek tenfold improvement in cost, time, or quality.

Estimates show that firms enter the market experiencing high productivity growth, and that above-average growth rates tend to last, although progressively weakened, for many years. The estimates also point out that productivity growth of surviving firms converges to different values according to activities and, on average, to almost 1.5% annually. Process innovations at some point then lead to some extra productivity growth, which tends to persist, although somewhat attenuated, for a number of years. If the introduction of process innovations then stops, however, innovation appears to be associated with an end to all productivity growth in the following years (Huergo, Jaumandreu, 2004).

Industry 4.0 concept can be characterized through the following words: big data, networking, digitalization, automation, Wi-Fi connection, cloud computing. A lot of effort will be invested in the restoring of old data to the latest IT standards. Special layers are used to transfer the experience of all employees into comprehensive IT systems. A lot of money will be invested in development of exclusive software solutions that help us in industrial enterprises look forward to the digital future.
In recent times, traditional manufacturing is upgrading and adopting Industry 4.0, which supports computerization of manufacturing by round-the-clock connection and communication of engineering objects (Shafiq, Sanin, Szczerbicki, Toro, 2016). Decisional DNA-based knowledge representation of manufacturing objects, processes, and system is achieved by virtual engineering objects, virtual engineering processes, and virtual engineering factories. Decisional DNA features as tools for effective Industry 4.0 implementation can facilitate in real time critical, creative, and effective decision making.

Manufacturing IT and Industry 4.0 is the Fourth Industrial Revolution with a potential of 12 bn Euros in Germany's chemicals industry (Gentner, 2016). But Switzerland is currently the best prepared of all countries in Europe. Many of the ideas are still very vague. As projects in Manufacturing IT and Industry 4.0 are different from the classical technical projects other strategies, for example agile project management, are necessary to secure success.

The fourth Industrial standard is based on advanced automation and robotics, sensor based computer technology, interconnected by wireless communication, and supported by big data solutions (Sandengen, Estensen, Rodseth, Schjolberg, 2016). Effective management and human cooperation i.e. teamwork and all processes will be increasingly important in the future. There will be important new form of industrial standard in relation to overall equipment effectiveness (OEE), predictive maintenance and total performance related to all equipment in the industrial factory processes. Not a few highly automated machines, but the system as a whole. OEE is a well-known standardized tool for performance measurement throughout the industry. In order to utilize data systems as ERP (Enterprise Resource Planning) and PLM (Engineering Systems), they must be integrated with business systems. Management normally acts on the bases of facts and financial performance. In most companies increase profit is the overall goal. Future management systems aim for a fully integrated and automated data flow based on advanced sensor technology. Increased use of digital systems enables quicker and better decisions.

Industry 4.0 describes the organisation of production processes based on technology and devices autonomously communicating with each other along the value chain: a model of the ‘smart’ factory of the future where computer-driven systems monitor physical processes, create a virtual copy of the physical world and make decentralised decisions based on self-organisation mechanisms. The concept takes account of the increased digitalisation of manufacturing industries where physical objects are seamlessly integrated into the information network, allowing for decentralised production and real-time adaptation in the future (European Parliament: Directorate-General for Internal Policies. Policy Department Economic and Scientific Policy).

Inter-connectivity and adaptivity in production are forming a strong foundation for Industry 4.0. The term adaptivity is synonymous with a new form of flexibility and adaptability of production processes and process chains which are self-adapting and optimizing. In its research and development projects, the Fraunhofer IPT addresses the challenges associated with planning both individual steps and the entire production process, in a virtual environment and in a simulation-assisted process then implements these in the corresponding machines, equipment and software systems (Fraunhofer IPA Stuttgart).

With regard to indi- vidual Industry 4.0 processes and technologies, however, it appears that across the board, regardless of company size and branch, little use is made of the evaluation of large data streams to optimise processes or for downstream services. Accordingly, little use is made also of higher level cloud services that are useful for that purpose, in contrast to SMEs elsewhere in Europe (Schroder, 2017).

To capture emerging opportunities and keep pace with the rapidly advancing technological frontier, industrial players need to act in three dimensions:

- Reach the next horizon of operational effectiveness
- Adapt business models to capture shifting value pools and
- Build foundations for the organization’s digital transformation by developing digital capabilities, enabling collaboration in the ecosystem, managing data as a valuable asset, and coming to grips with cybersecurity.

In the realistic, hands-on production environments of our digital model factories, we will accompany on digital journey – across all stages, from interactive training in a digital diagnostic, through to an evaluation of your digital solutions, through to the process of building organization’s digital capabilities (McKinsey Company).

3. Research study oriented on the process structure stabilisation in industrial enterprises

In according to the realization of research study we identify following research goals, concentrated on the fact, that production system oriented on the implementation on Industry 4.0 concept must fulfill following parameters:

- Information processes supporting manufacturing and production process planning – integrated information systems should create virtual reality managed by digital technologies in real time and place
- Communication processes in digitalized form – machines, technologies, processes, information and material flows should connect effective virtual information world with real technological world

- Operational management oriented on stabile flexible production – optimal performance of production system in according to the problem solving and decision making with right integration of human
- Production management based on relevant defined operational production processes – integrated value chain oriented on the standardized decision making and autonomous operability of production components
- Data security of used digitalized manufacturing technologies
- A high degree of reliability and stability of realized production processes without integration barriers
- Production systems IT maintenance

In according to the proposal of process stabilization model we identify following testing hypothesis – defined research questions:

a) **Industry 4.0 concept is based on stabile process managed structures and bring the expected cumulative benefits from digitization in the form of lower costs and increased revenues.**
Our survey was realized in 120 industrial companies in Czech and Slovak Republic (40% automotive, 30% mechanical, 20% external supply for automotive, 10% other industry). A lot of industrial enterprises is today confronted with directly requirement – to integrate three core areas:

- Enterprise organization structure
- Process / Product technological structures
- Digitized processes, supported all manufacturing integrated processes
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Results achieved by individual interviews in selected industrial companies in Czech and Slovak Republic showed, that a lot of managers have not clear vision about the optimal combination of mentioned three core areas, the managers are oriented daily and strategically primarily on the achievement of defined company goals connected with effective productivity and performance preparedness for flexible production. They have small opinion, but this isn't enough for complexly problem solution in according to the implementation of INDUSTRY 4.0 concept. Medium companies made some steps according to digitization of machines and selected technologies, but it absent the right connection with enterprise information systems.

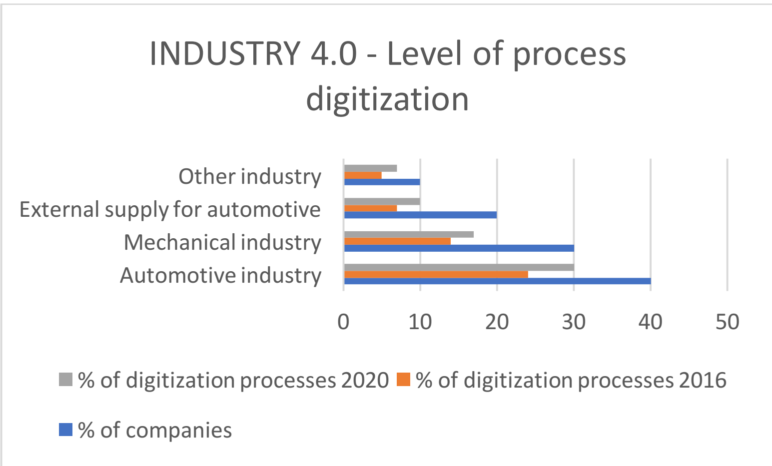

Fig. 1: Industry 4.0 – Level of process digitization – comparison 2016 and 2020 (source: Chromjaková, Bobák, Hrušecká)

Results verified mentioned hypothesis and showed, that positive cost regulation and revenues management lies in in optimal combination of advanced connectivity (14%), better "internet of things" services (26%), computer integrated processes (35%), cloud computing and advanced automation (15%) and user-friendly process standardization (15%). Right combination of all mentioned parameters secures and bring the potential of lower cost and increased revenues.

b) Industrial company has clear identified the core processes supported the organization – process – digitized structures as a basis for implementation of Industry 4.0 concept.

Verification of given hypothesis has brought a clear signal to the issue of identification of key business processes. The hypothesis was not confirmed, because all companies have identified key processes mostly in relation to the production process (horizontal core processes), but not in according to the implementation of Industry 4.0 concept as supporting managerial company process (vertical processes).

In according to the identification of core processes we mentioned by our survey the fact, that a lot of people in industrial companies have a problem with right understanding of the "process" definition. Traditional we are oriented on the production processes, supporting processes or we distinguish between managerial or operational processes. In the environment of Industry 4.0 concept we should make radical change in our thinking, because we are speaking about digital company – digital culture – digital processes. According to this fact we speak about new type of "process content" according to the digital enterprise environment. From our survey we achieved secondary the following knowledge: most industrial companies have respect before traditional enterprise culture, standards infrastructure, intellectual property protection by workplace, personnel leadership and coaching. This is in direct correlation with traditional model of personnel security or personnel integrated management and decision making processes. By this processes was the responsibility and delegated competencies by human, now in the Industry 4.0 concept there is necessary to transfer all important operational business competencies, responsibilities connected with production processes planning, scheduling and organization to the computer technologies and digital processes. Big accent will be given by process stabilization model proposal to the integration of professionals from IT departments. All these people should achieve clear opinion about future required process statement.

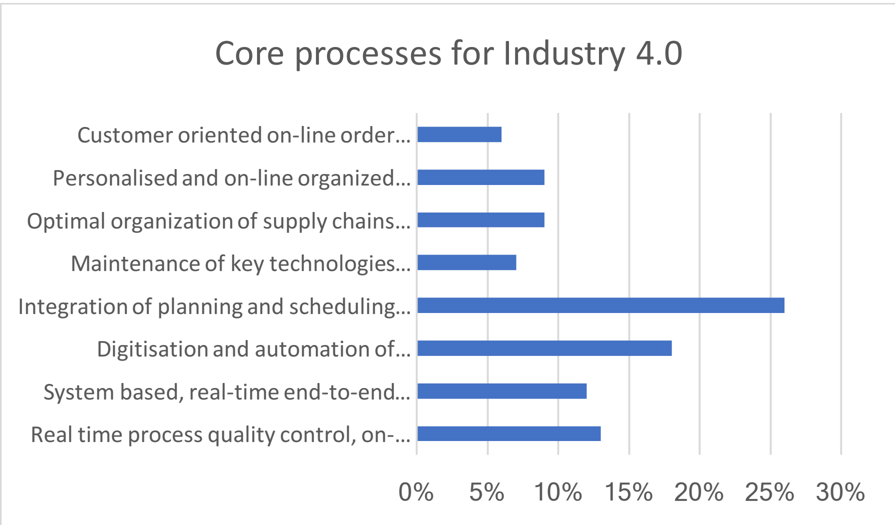

Fig. 2: Identification of core processes for Industry 4.0 implementation – process standardization and stabilization (source: Chromjaková, Bobák, Hrušecká)

c) **Industrial company has a clear vision about process steps, their mutual combination and optimal functionality, they know exactly the core process stabilization pillars before the implementation of Industry 4.0 concept.**

A lot of companies have clear vision about content of Industry 4.0 concept, they are waiting on positive experiences from other companies, that absolved first stages of implementation process. The realized questionnaire showed the accuracy of given hypothesis with an important signal to give to the companies more knowledge and skills from successful industrial companies having experiences with first implementation steps.

Where is in enterprise competent to identify the vision and define process steps of Industry 4.0 by concept implementation? This was our principally question during realization of our research in industrial enterprises. Basic impulse for this question was the fact, that we know responsible person as a director in each enterprise for the production department (evtl. production process), but we don't know the director for implementation of supporting business processes – for example – for implementation of new IT projects. In more companies we found during our survey product responsible person for implementation of IT project (78%), in better case for implementation of Industry 4.0 concept (14%). From point of process stabilization this is a crucial moment, because nobody from product managers can't be responsible in industrial enterprises for combination of horizontal and vertical integrated processes. Firstly, as we can see, we should identify right person, which will be responsible complexly for the process of Industry 4.0 concept preparation and implementation.

If we speak about process stabilization pillars, we are oriented on right mutual combination of three key pillars:

- Main production processes (stories, workflow, workplace organization, quality, TPM,etc.)
- Supporting administrative processes (production planning, logistics, economics, etc.)
- Production organization and management processes (human management, customers, etc.)

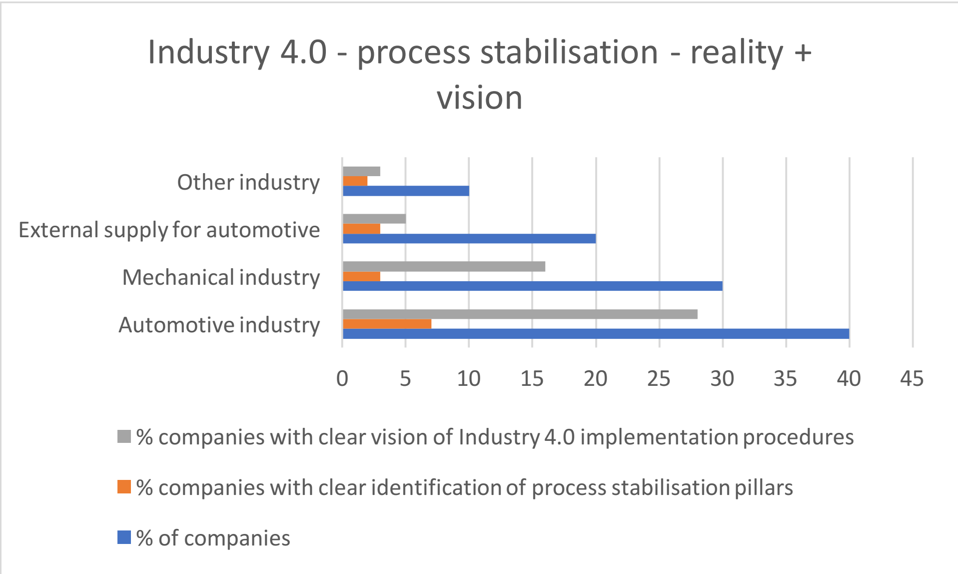

Fig. 3: Industry 4.0 – reality + vision – comparison between number of industrial companies (source: Chromjaková, Bobák, Hrušecká)

d) **Production process stability of INDUSTRY 4.0 concept enables flexible and optimal implementation of mentioned concept in manufacturing processes**

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Research results identify by monitoring of production process stability as core value following metrics of process stability, used in analyzed companies:

- Production amount realized per one scheduled production cycle (74% companies)
- Productive throughput time per one scheduled production cycle without disruptions (65% companies)
- Stability of work/job standards per planned and realized totally customer order (54%)
- Number of flexible tasks identified through the just realized process (57%)

4. Proposal of process stabilization model

Definition: Process stabilization model build a background for preparation, implementation, testing and improvement of complexly integrated vertical and horizontal enterprises processes, connected with installation of digitized business processes.

The objective of the process stabilization model is to propose a mechanism by which a clear structure of processes realized by implementation of Industry 4.0 model is made, a strategic aims and objectives are identified, activities are sequenced and prioritized and the resources required are identified. It is designed in according to the right management and coordination of all realized processes from the planning procedures to the realization procedures.

By model development we take into account the following fundamental principles:

- Knowledge of principles of system oriented digitalized model of processes and process elements based on Industry 4.0
- Clear vision in according to the digitized operations, data delivery safety, data complexity, digital standards, norms and certificates
- Standardization of maintenance system for computerized and digitalized processes and operations through MES and MRP
- Skills with a human and his activity in the digitized processes by workplace

Important part of each model definition there is the first diagnosis of the production system, identification of core parameters connecting with stabilization, standardization of production processes, operations, workplaces, machine technologies, information and material flows, layouts, human. Right availability all process components build background of next process stabilization from the Industry 4.0 concept point of view.

From the Industrial Engineering point there is important to implement the same methods of management and process improvement: methods, which we used for management and process improvement in production processes should be the same for management and implementation of computered or digitized technologies. That means, firstly we should take into account parameters as system oriented thinking, simultaneous process management and organization, process owner, workplace identification and other important facts, that are crucial for the right functionality of proposed technologies or systems integrated into production processes with strong connection on digital technologies.

In according to the stability we identify important knowledge: each stabilized process or process pillar is confronted in real practice with the phenomena of allowable values for each defined index or relevant process parameter. Process stabilization model can be used than as a tool for process new definition or as a preventive tool for process management, in most cases we can use it for daily operative process management, when some unforeseen process conflicts occur.

Structure of process stabilization model was defined by research team as follows:

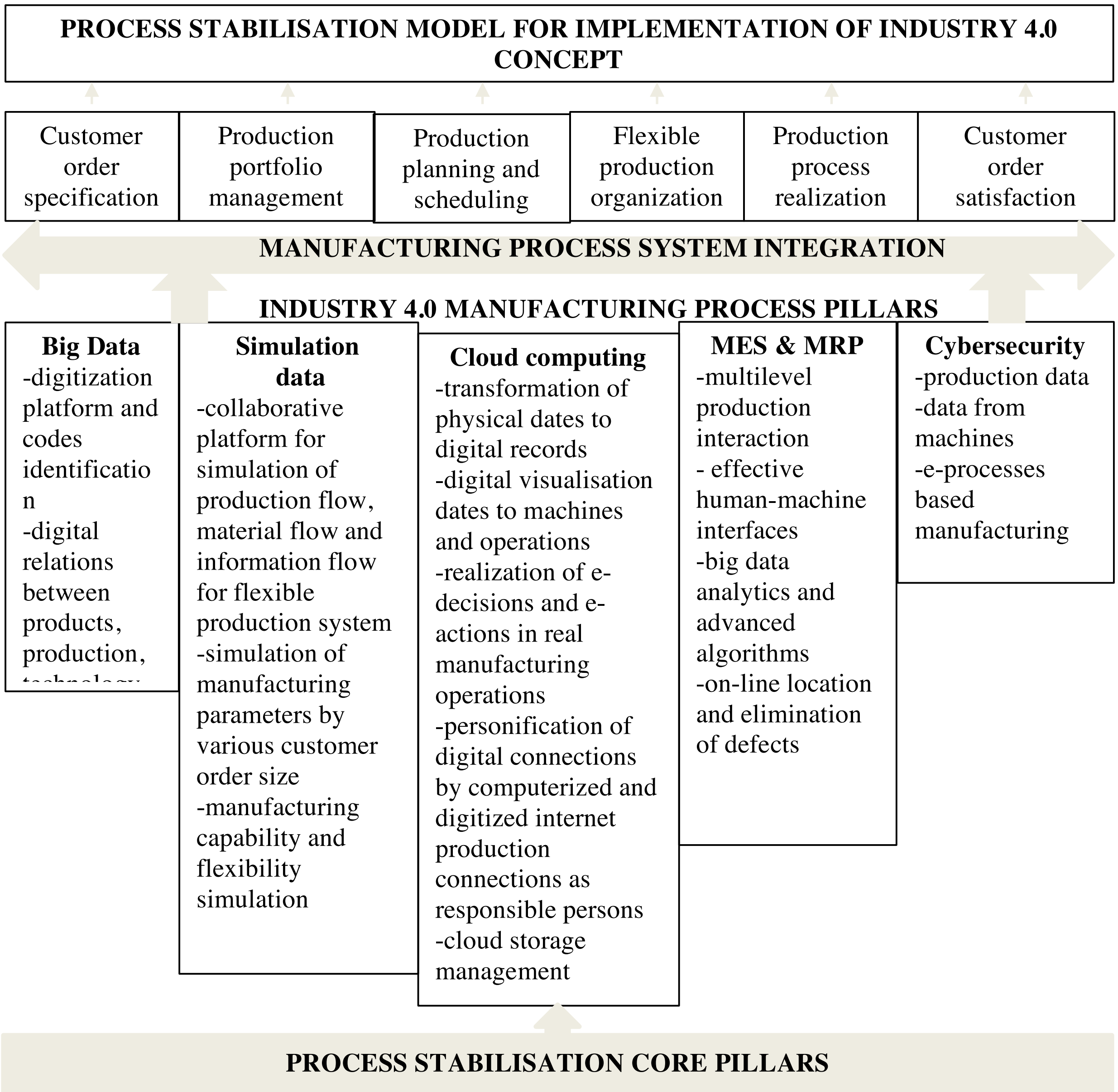

Fig. 4: Process stabilization model structure for Industry 4.0 concept implementation in industrial company (source: Chromjaková, Bobák, Hrušecká)

Process stabilization model proposal targets are concerned on following criterions:

- Coordination of production plan in according to the flexible production processes with available production capacities in production and supporting manufacturing processes
- On-line task prioritization and optimal sequencing between digitized processes and manufacturing workplaces ("just in sequence optimization")
- Physical objects are referenced, scheduled and managed by an ID
- Co-operative production planning in triangle "customer – producer – supplier" realized by web developed interactive digitized environment and data storehouse

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- Optimization of production planning and scheduling through utilization of big data storehouses and cloud computing technologies in according to the customer order satisfaction in real time
- Optimization of supplier connections, transport and logistics costs
- Improvement of customer relationships and customer intelligence through the programmed on-line connection before production process
- Storage and inventories are regulated by different ID types for each component and by product component number through optimal virtual dynamic behavior knowledge
- Effective data maintenance, data security and responsibility for timeliness of data
- Assigned human responsibility for each component integrated in process model in according to the management and organization of each component

Process stabilization model should bring in the practice positive effects in the area of customer order specification, production planning and organization. We can develop our internal calculation model of benefits achieved after implementation of first stages of Industry 4.0 as follows:
Process stabilization model should bring in the practice positive effects in the area of customer order specification, production planning and organization. We can develop our internal calculation model of benefits achieved after implementation of first stages of Industry 4.0 as follows:

Industry 4.0 system real availability:
ISA = PD – ST - PSM [minute]
(PD - planned time of availability, ST – service time, PSM – preventive service maintenance)

Throughput time of e-process operation
TePO = IITS + DeOP + WTSR + IINO [minute]
(IIS – instruction input time in the system, DeOP – duration of e-operation, WTSR – waiting time on system reaction, IINO – instruction input time for next e-process operation)

Average reaction time on the system incident
ARTSI – TSU – ID - IE [minute]
(TUS – Time of system unavailability, ID – incident diagnosis, IE – incident elimination)

Index of data completeness availability for process realization in Industry 4.0 system
DCA = SRDO / RDI
(SRDO – Number of successful realized digitized operations given into systems as requirements, RDI – Returned no realized digitized operations)

Complex model of process stabilisation for implementation of Industry 4.0 concept:

$$\text{Max ISA} = 0{,}2\,COS + 0{,}1\,PPM + 0{,}2\,PPS + 0{,}3\,FPO + 0{,}1PPR + 0{,}1\,COS$$

$$BD_{COS} + BD_{PPM} + BD_{PPS} + BD_{FPO} + BD_{PPR} + BD_{COS} = 1{,}0 \text{ (Big Data Condition)}$$

$$SD_{COS} + SD_{PPM} + SD_{PPS} + SD_{FPO} + SD_{PPR} + SD_{COS} = 1{,}0 \text{ (Simulation Data Condition)}$$

$$CC_{COS} + CC_{PPM} + CC_{PPS} + CC_{FPO} + CC_{PPR} + CC_{COS} = 1{,}0 \text{ (Cloud Computing Condition)}$$

$$MM_{COS} + MM_{PPM} + MM_{PPS} + MM_{FPO} + MM_{PPR} + MM_{COS} = 1{,}0 \text{ (MES\&MRP Condition)}$$

$$CS_{COS} + CS_{PPM} + CS_{PPS} + CS_{FPO} + CS_{PPR} + CS_{COS} = 1{,}0 \text{ (Cybersecurity Condition)}$$

(COS – Customer Order Specification, PPM – Production Portfolio Management, PPS – Production Planning and Scheduling, FPO – Flexible Production Organization, PPR – Production Process Realization, COS – Customer Order Satisfaction)

Index values given in maximisation function: 0,2 COS + 0,1 PPM + 0,2 PPS + 0,3 FPO + 0,1PPR + 0,1 COS build size of value added contribution to the whole complexly Industry 4.0 chain. These values were derived from the proposal, implementation, observation and testing of interval limit values by simulation project in the framework of RO Research Project, realized by Industrial Engineering and Information System Department by Tomas Bata University under title: "Parameters modelling for effective production and administrative processes in industrial companies based on Industry 4.0 concept". This project is realised from 2016 and till 2017 by Tomas Bata University in Zlin.

Identification of all core process components integrated in Industry 4.0 concept
Availability of all required functionalities of computerized and digitized technologies
Number of intelligent drive units integrated in the Industry 4.0 concept
Defined technical functionality, virtual functionality, communication capability and model process structure
Communication ability verification by each Industry 4.0 system component
Standardization of e-connections, standardization of input and output process parameters
Number of objects managed through digitized technology in one e-chain (ID-chain) and by one ID-administrator
Number of process conflicts in pre-implementation stage of Industry 4.0 concept (technical conflicts, technological conflicts, interface conflicts, data cybersecurity)
Number of total digitized processes in production
Number total digitized machines integrated in Industry 4.0 chain
Defined human responsibility for each process component integrated in the Industry 4.0 chain
Real time of system communication by realization of production process through Industry 4.0 system
React time on delivery of system components availability for realization of production process after input of customer order into system (specification and commitment of customer order)
Testing and validation of digitized processes in according to the flexible planning and organization of production process
Ability to re-plan the production process virtually by given instructions through ID competencies for flexible production organization
Availability of all relevant data and on-line data corrections availability in integrated process components
React time on process defect in system between process component owner (ID) and digitized workplace in production (identified by ID)
Grade of standardization of interfaces and abilities of units for and digitized regulation of flexible production system
Stability and security of defined standards, technological and technical rules, mutual process e-communication and e-management
Number of digital certificates for authentication of realized operations
Number of identities with login data for maintenance and management of operational Industry 4.0 system
Definition of system responsibilities for human – guaranty of system timeliness and usability
Number of virtual instances for recovery functions and security incidents elimination in Industry 4.0 system

5. Conclusion

Industry 4.0 concept enables radical improve the productivity and efficiency of complexly production value chains, enable to focus on the creative and strategic oriented business activities. Positive effects we can see by workers – this concept enable to organize flexible work in production processes and contributes to higher satisfaction of employees at all enterprises levels through the better work-life balance.

In our model proposal were integrated the verified research goals:

- Industry 4.0 concept is based on stabile process managed structures and bring the expected cumulative benefits from digitization in the form of lower costs and increased revenues.
- Industrial company has clear identified the core processes supported the organization – process – digitized structures as a basis for implementation of Industry 4.0 concept.
- Industrial company has a clear vision about process steps, their mutual combination and optimal functionality, they know exactly the core process stabilization pillars before the implementation of Industry 4.0 concept.
- Production process stability of INDUSTRY 4.0 concept enables flexible and optimal implementation of mentioned concept in manufacturing processes

Generated potential savings for companies are radical, special in according to the investment and return of investment in the IT technologies, customer relationships, production process planning and scheduling and flexible production outputs effects. An important role play here the phenomena of "collaborative factory" enables to realize the jobs and process operations in virtual reality with use of mobile workplaces. Each master, supervisor, team leader or shop floor employee can use in their work the assistance of multimodal, user-friendly interfaces through the complexly oriented computerized and digitized technologies, used in Industry 4.0. Industry 4.0 concept integrates the three key lines: internet of things, internet of services and internet of people – networks objects, people and systems. Optimal combination of strategic pillars will combine in the industrial company best principles from smart factory, business and social platforms. This combination guarantee right functionality of production process initialization, planning and scheduling and production process realization with according to the effective and real-time necessary data exchange, safety and reliability.

Our future work will be concentrated on the initialization of flexible digital process parameters, connected with the continuous implementation of INDUSTRY 4.0 concept.

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