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Operationalisation Of Communication Structure Requirements In Factories In The Context Of Industry 4.0

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Abstract

In today's markets, customers are demanding increasingly individualised products at a consistent price and quality level. Within production, this development is associated with a decrease in batch sizes and an increase in variant-specific components. As a result, product and process complexity in factories are increasing. Given this fact, a high innovation capacity of manufacturing companies is more important than ever. This is decisively influenced by effective communication processes between employees and machines, which can be brought about by a suitable design of the communication structures in factories. In this context it should be noted that changes in the external environment of a factory can lead to a need for change in the internal factory structures and thus also in the communication structures. The third industrial revolution can be cited as an example of this. The accompanying automation not only changed the technology used in the factories, but also the organisational structure, which ultimately led to a need for change in the communication structures. If such needs for change are ignored or remain unrecognised, this can severely impair the innovative capacity and thus the success of manufacturing companies. Especially against the background of current trends, such as Industry 4.0, this appears to be of utmost relevance. Still a comprehensive and generally valid description of communication aspects in the context of Industry 4.0 is not yet fully available. The lack of specific understanding of communication in the context of Industry 4.0 leads to the inability to design effective communication concepts in factory systems. Therefore, existing systems remain exposed to undesired effects and leave desired effects underutilised. In order to close this research gap, a holistic model for the description, evaluation and the design of effective communication concepts in factories in the context of Industry 4.0 is in development within the frame of "Komm 4.0".

Keywords

Factory planning; Factory evaluation; Communication concept

1. Initial situation and problem definition

Today, the industrial sector is already in the fourth industrial revolution. The aim of Industry 4.0 is to meet the challenges of the scenarios described above by deploying so-called cyber-physical production systems that organise and control themselves independently in production and can thus react quickly to dynamic influences. This requires a continuous communication option from order entry to construction to production. Industry 4.0 supports this connectivity through the numerous communication possibilities of different employees, transport and operating resources and is thus increasingly becoming a part of factory planning [1]. This reveals an increasingly strong integration of information and material flows. A trend of increased integration of information and material flows is caused, which not only places new demands on production technology, but also on the communication structures of factories. However, these requirements for the

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communication structures resulting from Industry 4.0 have not yet been described uniformly or only in rudimentary form. This results in the problem that manufacturing companies are not yet able to systematically adapt their communication structures to the requirements of Industry 4.0 in order to efficiently realise innovation potentials in the future.

2. Objectives and structure of the paper

Considering the previously explained problems, the overall objective of this paper is the modelling of requirements for a communication-oriented evaluation of factories in the context of Industry 4.0. The modelled requirements are to be provided with an evaluation standard in a way that, for example, operators in manufacturing companies can be enabled to systematically and holistically describe and evaluate their communication structures in the context of Industry 4.0. Based on the results of the evaluation, suitable measures for action are to be derived that support the optimisation of communication structures.

To achieve the objective of this paper, an overview of the state of the art of existing communication-oriented design approaches is given in section 3 a need for action is identified. Subsequently, in section 4, the generic requirements from PARK ET AL. (2020) are addressed, further developed and provided with an evaluation logic [2]. The results from PARK ET AL. (2020) are adopted and the general communication requirements in the context of Industry 4.0 are further developed in section 4.1. In section 4.2, the requirements that, according to PARK ET AL. (2020), result from Industry 4.0 are developed further. After describing the requirements modelling, section 5 presents a catalogue of action measures that enables to fulfil the previously described requirements and optimises communication in the context of Industry 4.0. Finally, a conclusion on the results is presented in section 6 and an outlook for further research is highlighted.

3. State of knowledge and need for action

This paper focuses on those approaches that address communication in factories. For this purpose, approaches with objectives were chosen that consider communication to be a central function of change. Either communication is listed as a design criteria in the approaches or different communication characteristics are designed.

The results point out that there are already some approaches that deal specifically with communication. This includes BERGMANN (2008), who develops a communication-oriented target criterion. This is used in the course of material flow-based layout planning for arrangement optimisation. [3] The work of SCHÜTZE (2009) also focuses on communication processes. For this purpose, communication artefacts are identified, an existing method of business process modelling is adapted for the analysis of communication processes and finally the artefacts of communication are transformed into modelling elements [4]. The approach of NYHUIS (2010) focuses on factory processes. Here, internal communication at work process interfaces is examined from a process and spatial perspective [5,6]. A further contribution comes from FROITZHEIM (2015), who provides a method for manufacturing companies to record and evaluate their business processes in terms of communication in order to improve performance [7]. Based on the previous approaches, NYHUIS addresses the dynamics in communication in another project. A model and a methodology were developed with which dynamic communication structures in factories can be recorded and the design optimised with effective measures with regard to changes in the environment. [8] Although these approaches focus particularly on communication, they do not include the aspect of Industry 4.0.

Other approaches, such as SELINGER (2000), identify a research gap with regard to informal communication. Here, a digital tool is developed that supports informal communication and integrates it into formal structures and processes [9]. Another approach in this context of informal communication comes from REINEMA AND NYHUIS (2014) [10]. They develop a method for evaluating planning results with regard to the framework conditions of informal communication in factories. In ANDERL ET AL. (2016), small and medium-sized enterprises are to be adapted to the new requirements of Industry 4.0. The aim is to develop a learning factory based on analysed and applied new information and communication technologies that are coordinated with production technologies [11]. After a comprehensive study with analysis and evaluation of new technologies related to Industry 4.0, companies are presented with potential applications based on the learning factory, which are adapted to their factory. Here, the focus is again on Industry 4.0. There is no general consideration of the communication aspect. PARK ET AL. (2020) present an initial approach to describing, evaluating and designing communication concepts in factories. In this contribution, generic requirements for communication in the context of Industry 4.0 are presented, which should enable efficient and effective communication in factories. However, this is only a first approach. A detailed description of the requirements and possibilities to increase the degree of fulfilment are not described in detail.

The approaches presented deal, among other things, with informal communication in factories or focus on a strongly technology-oriented view of the topic of Industry 4.0. Here, the research gap described at the beginning becomes clear. General requirements for the communication structures that result from Industry 4.0 have not yet been described uniformly or only in rudimentary form in existing approaches. A promising approach is PARK ET AL. (2020), which, however, only describes generic requirements. This approach will be taken up and further specified in this paper.

4. Modelling evaluation scales for communication requirements

4.1 General communication requirements in the context of Industry 4.0

PARK ET AL. (2020) describe a generic communication concept in the context of Industry 4.0. The concept consists of requirements that have been modelled to evaluate communication structures in factories. The requirements are subdivided into general communication requirements and new requirements due to Industry 4.0. In this section, the general communication requirements are addressed and further developed. The aim is to provide these requirements with an evaluation scale so that they can be used to evaluate communication structures. The evaluation scales have been developed on the basis of a maturity model. Maturity models are particularly suitable for analyzing and evaluating the development status and for identifying improvement potential of an object to be assessed, which can have both qualitative and quantitative characteristics, which is why they are also used here. The scales were developed and verified with the help of a survey of three experts from the field of factory planning. These experts also have extensive experience in the scientific as well as the practical field of factory planning.

The first two requirements to be considered are called **communication type** and **communication means**. The communication type describes the directness of communication and can therefore be divided into face-to-face and media-bound communication [12]. Media-bound communication includes the use of a wide variety of physical media or aids [4]. The requirement of the communication means describes which media or aids can be used according to the respective communication type [5]. In face-to-face communication, only direct personal communication means can be used, whereas in media-bound communication, various written and electronic means such as whiteboard notes, memos, video conferences, mails, chat etc. can be used. This shows that the communication means is directly dependent on the communication type. With regard to these two communication requirements, the survey showed that despite the increasing relevance of media-bound, electronic communication, face-to-face communication is not losing importance. Non-electronic communication means, on the other hand, are losing importance. These results lead to two evaluation scales, which can be used to assess the communication type in the context of Industry 4.0. A distinction is made between communication in the day-to-day business or the implementation phase in the project and the preparation or completion phase in the project. The assessment of the communication type therefore depends on the respective activity. The scales are designed in such a way that a good form of communication is assigned a high score. Since written communication means are of rather little importance in the industrial environment, they will not be considered further in the following. An evaluation scale for communication means is therefore not required. Accordingly, a consideration of the communication type is completely sufficient.

Table 1: Evaluation scales - Communication type

Measure	Characteristics - communication type (day-to-day business and implementation phase in the project)
0	Face-to-face
1	Media-bound

Measure	Characteristics - communication type (preparatory and final phase in the project)
0	Media-bound
1	Face-to-face

The **communication direction** as a further communication requirement can essentially be differentiated into a horizontal, a vertical or a diagonal direction [13]. In horizontal communication processes, information is exchanged between the employees of one hierarchical level, whereby these do not necessarily have to belong to the same department [10]. In contrast, vertical communication processes take place between employees of different hierarchical levels, whereby the employees belong to the same department. If horizontal and vertical communication processes are combined, diagonal communication processes result. [13] With regard to the communication direction, the survey showed that interdepartmental cooperation is becoming increasingly important in the everyday work of manufacturing companies. Flat hierarchies were also referred to in this context against the current background of trend topics. The results of the survey lead to an evaluation standard that can be used to assess the communication direction in the context of Industry 4.0. The horizontal communication direction is the best conceivable form.

Table 2: Evaluation scales - Communication direction

Measure	Characteristics - Communication direction
0	Vertical i.e. communication takes place in one department but across several hierarchical levels
1	Diagonal i.e. communication takes place between different departments and different hierarchical levels
2	Horizontal i.e. communication takes place at one hierarchical level but between different departments

The communication requirement **communication quality** takes up the findings of the so-called "Media Richness Theory" by dividing communication processes into fast, complex, accurate or confidential communication. According to the characteristics mentioned, the communication means must be chosen correctly so that the communication process can run as effectively as possible. [14] Thus, a total of four assessment criteria can be used to evaluate the requirement of communication quality. The expert survey shows that great importance is attached to the parameters of speed and complexity in the context of future communication processes. However, a similar result emerges for the parameters confidentiality and accuracy. Accordingly, the focus of communication quality will be on all four parameters in the future. Since the survey results show that the individual parameters of communication quality will have almost the same importance in the future, it is all the more important that the right communication media are used according to the parameters. Therefore, the evaluation of this communication requirement in the context of Industry 4.0 is based on the use of media. It should be noted that the choice of the right communication medium depends on the respective parameter of the communication quality. Based on this, an evaluation scale is set up for each parameter. Each scale assigns the highest number to the medium that appears to be the most suitable with regard to the respective parameter

Table 3: Evaluation scales - Communication quality

Measure	Characteristics – Use of media (speed/convenience)
0	Face-to-face
1	Less rich media
2	Rich media

Measure	Characteristics – Use of media (complexity)
0	Less rich media
1	Rich media
2	Face-to-face

Measure	Characteristics – Use of media (accuracy)
0	Rich media
1	Face-to-face
2	Less rich media

Measure	Characteristics – Use of media (confidentiality)
0	Rich media
1	Less rich media
2	Face-to-face

Another requirement results from the **communication structure**. A distinction is made between five different types of structure [15], which result from the organisational aspects of communication. The communication structures are differentiated according to their degree of centralisation, i.e. the extent to which information is directed to a central point. The star/wheel structure has the highest degree of centralisation. In descending order of centralisation, the Y-structure, chain structure, circle structure and full structure follow. As the degree of centralisation of the communication structure decreases, the suitability for processing complex tasks increases. Therefore, the communication structure and the tasks must be coordinated with each other. In general, centralised structures are more suitable for solving simple, less complex tasks. On the other hand, decentralised structures should be preferred in the area of complex problems. [15] With regard to the communication structure, the survey revealed that the work content will tend to develop towards more complex tasks in the future. From this it can be concluded that decentralised communication structures are to be preferred in the future in order to cope with these work contents. Nevertheless, it cannot be ruled out that there will still be some rather "simple" work content in the future that can be handled more effectively with centralised communication structures than with decentralised structures. Therefore, it makes sense to set up two evaluation scales by which the communication structure can be evaluated in the context of Industry 4.0. The evaluation depends on the work content.

Table 4: Evaluation scales - Communication structure

Measure	Characteristics – Communication structure (complex tasks)
0	Central (rather few communication processes between a few people)
1	Decentralised (rather many communication processes between several persons)

Measure	Characteristics – Communication structure (simple tasks)
0	Decentralised (rather many communication processes between several persons)
1	Central (rather few communication processes between a few people)

The last general communication requirement that is extended with an evaluation measure in the context of Industry 4.0 is the **communication intensity**. This requirement describes the frequency of communication processes between several communication partners within a certain period of time. [5] A distinction is made between the characteristic values "low", "medium" and "high" [16]. For example, a high intensity means an exchange of information several times a week, whereas a low intensity means almost no exchange of information. The degree of communication intensity between the employees of a company can be, for example, an indication of the extent to which a company is able to generate new knowledge and thus innovations. Knowledge can only be generated if a company has a broad and uniform communication network in which as many employees as possible can communicate with each other as frequently as possible.

Only in this way the existing knowledge of the employees can be transferred to new fields of application and used there as new knowledge. [17] In this context, the survey revealed that the frequency as well as the diversity of information exchange is considered important. This leads to an evaluation scale that can be used to evaluate the intensity of communication in the context of Industry 4.0. Here, too, the scale is designed in such a way that a high score is assigned to a good form of expression.

Table 5: Evaluation scales - Communication intensity

Measure	Characteristics - Communication intensity
0	Low (almost no exchange of information)
1	Medium (information exchange once a week or less)
2	High (exchange of information several times a week)

The general communication requirements in the context of Industry 4.0 have thus been defined and fully modelled. In the following, as a further step, the new communication requirements that have arisen as a result of Industry 4.0 will be taken up from Park et al. 20 and modelled analogously.

4.2 New communication requirements as a result of Industry 4.0

In this section, new communication requirements resulting from Industry 4.0 are considered. These were already derived in Park et al. (2020) by looking at the communication interfaces in a factory. These requirements are now taken up here and modelled further so that they can be used to evaluate the communication structures of a factory. The possible communication interfaces of a factory result from the comparison of the core components of a factory, which can be taken from the following figure. For the purpose of completeness, the general requirements have also been included in this interface overview. It becomes clear here that these are predominantly requirements that exist at the "employee-organization" interface.

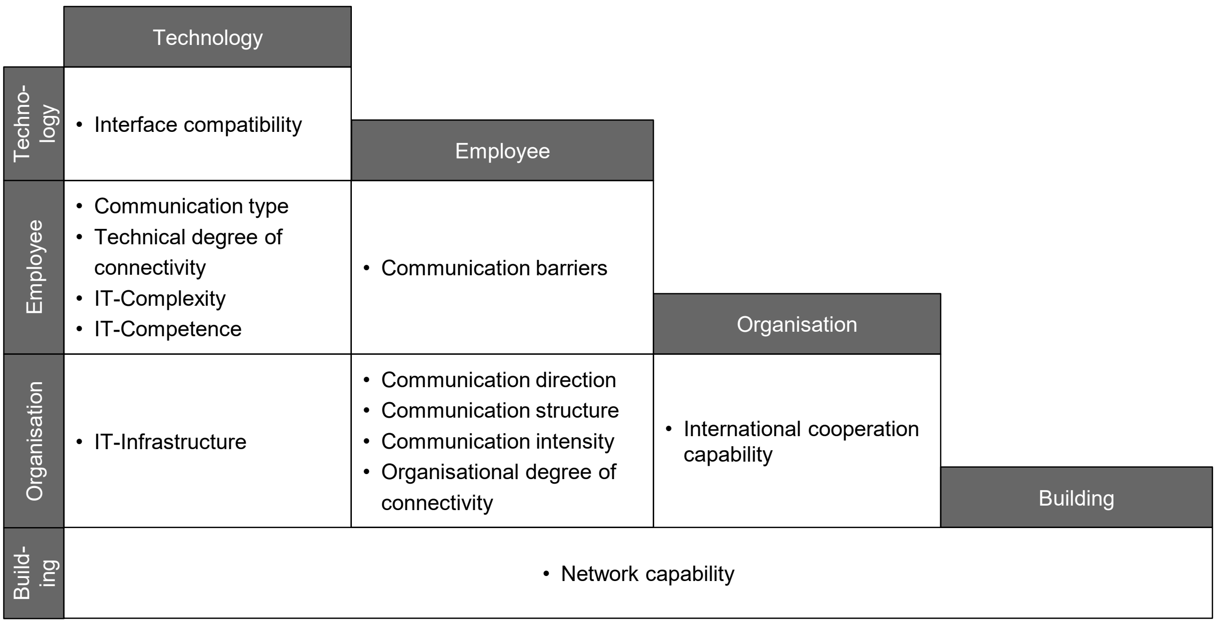

Figure 1: Communication requirements due to Industry 4.0 at the interfaces between the system components of a factory

Interface compatibility refers to the "technology-technology" interface within a factory. This communication requirement refers to the technical compatibility of different hardware and software components. Only when such system components are technically harmonised and can be operated together the integration of different technical systems is possible [18,19]. In the course of this integration, communication networks are created in which data and information can be exchanged unhindered due to interface compatibility [19]. Overall, interface compatibility in the context of Industry 4.0 can contribute to hierarchy-free and continuous communication between the technical systems used in real time. To characterise this parameter, it is necessary to examine the extent to which the exchange of data and information between different system elements is as unrestricted as possible, even at very high transmission rates. For example, it must be examined whether a real-time and error-free exchange of data and information is possible between the ERP system used and the CAD system, even with high data volumes. For this reason, a three-stage evaluation scale is introduced for the evaluation of the communication requirement interface compatibility.

Table 6: Evaluation scales - Interface compatibility

Measure	Characteristics – Interface compatibility
0	There is no exchange of data or information between the system elements under consideration.
1	There is a limited exchange of data and information between the system elements under consideration (time delays, partially faulty data/information reproduction at the receiver, very high transmission rates not possible, etc.).
2	A rather unrestricted exchange of data or information takes place between the system elements under consideration (near-real-time, no faulty reproduction at the receiver, high transmission rates possible).

The **technical degree of connectivity** results from the consideration of the "employee-technology" interface. This communication requirement describes the combination of information, which lead to knowledge, whereby the information is provided by IT systems at the workplace [20]. In the context of Industry 4.0, the technical degree of connectivity can contribute to an IT penetration of all factory processes. In order to make this degree of connectivity measurable, it is necessary to examine the extent to which both hardware and software components are used at the workplace and how strongly the information they provide contributes to value creation. Based on these explanations, it becomes clear that the evaluation of the degree of technical connectivity must be carried out by means of two evaluation standards. Ultimately, the forms of the degree of technical connectivity result from the combination of the two individual scales. The combination of the individual evaluation scale values lead to the evaluation scale of Technical degree of connectivity.

Table 7: Evaluation scales - Technical degree of connectivity

Measure	Characteristics - IT deployment
0	No use of IT systems
1	Rather low use of IT systems
3	Rather high use of IT systems

Measure	Characteristics – Contribution to value creation
0	Low contribution to value creation
1	High contribution to value creation

Measure	Characteristics - Technical degree of connectivity
0	No use of IT systems at all
1	Rather low use of IT systems, with the information received contributing little to value creation
2	Rather low use of IT systems, with the information received contributing strongly to value creation
3	Rather high use of IT systems, whereby the information received hardly contributes to value creation
4	Rather high use of IT systems, with the information received contributing strongly to value creation

The **IT complexity** also results from the consideration of the "employee-technology" interface. This requirement refers to human-machine communication and describes its degree of user-friendliness or manageability. In order for IT systems to be used successfully, the IT systems already in use must be accepted by employees as much as possible [21]. IT complexity can contribute greatly to acceptance and thus influence the IT penetration process. To characterise this communication requirement, it is necessary to examine the time required to access relevant information within IT. A high effort results, for example, from a less transparent and unclear presentation of information, which in turn is due to a too complex IT structure [21]. IT complexity is assessed using a three-stage scale.

Table 8: Evaluation scales - IT complexity

Measure	Characteristics – IT complexity
0	Accessing relevant information is always time-consuming
1	Accessing relevant information is only partly time-consuming
2	Accessing relevant information requires little time

Another communication requirement at the "employee-technology" interface is **IT competence**. This requirement refers to the ability to act correctly in an information technology environment. This ability results, for example, from how well the employees can handle the software programmes used. In order to characterise this communication requirement, it is necessary to examine what knowledge is available with regard to the IT systems used at the workplace. An indication of this may be the regular use of such systems. Three forms of IT competence are defined for the assessment.

Table 9: Evaluation scales - IT competence

Measure	Characteristics – IT competence
0	There is at most basic knowledge of the IT systems used in the workplace (sporadic use)
1	There is a good knowledge of the IT systems used in the workplace (regular use)
2	Very good knowledge of the IT systems used in the workplace is available (years of regular use)

Communication barriers can occur within a factory at the "employee-employee" interface. These barriers are present when a sender's message does not reach the recipient at all, or arrives incomplete or distorted. Especially in the context of Industry 4.0, such a situation must be avoided. In the course of this, IT penetration of all factory processes is taking place, resulting in CPPS, among other things. These systems are able to take over monotonous work processes, which in turn means a shift in work content for employees on the shop floor from executive to decisive, controlling and leading activities [22–25]. Employees of formerly separate areas of competence must increasingly interact or communicate with each other as a result of this shift in activity, whereby this cooperation should take place as quickly and as far as possible without difficulties [22,26,23]. However, at the interfaces of strongly differing areas of competence, different technical, linguistic or methodological skills often come together, which make interdisciplinary communication difficult or even impossible [27–29,20,30]. In order to characterise communication barriers, it is therefore necessary to examine the extent to which problems arise during interdisciplinary interactions. In order to assess this, three forms are defined.

Table 10: Evaluation scales - Communication barriers

Measure	Characteristics – Communication barriers
0	During communication, there are major communication problems that make cooperation enormously difficult or even impossible
1	During communication, there are rather minor communication problems that only slightly complicate cooperation
2	There are no communication problems during communication

At the "organisation-technology" interface, the communication requirement **IT infrastructure** arises. First of all, the term infrastructure generally refers to elements that are indispensable for the functioning of a system. In the context of Industry 4.0, the IT infrastructure includes the entirety of networks, hardware and software components within a factory as well as their ability to communicate with each other. The communication capability of systems describes the necessary structures that are indispensable for the communication of these systems. However, the communication capability of systems is not necessarily to be equated with active communication of these systems. For example, two technical systems are theoretically capable of communication because a connection already exists between them, but communication between the two systems is prevented by various software components. Only when almost all factory areas are equipped with IT systems and these have the ability to communicate with each other, the necessary conditions are created for an exchange of data and information across hierarchy levels without any media discontinuity [31,32]. For the evaluation of the IT infrastructure in the context of Industry 4.0, it is therefore necessary to examine the extent to which the individual processes within the respective factory area are permeated by IT systems and the extent to which these systems enable communication without media discontinuity and across levels. For example, it should be examined to what extent PDA systems are used and whether such systems are theoretically capable of forwarding data to the ERP system, for example. Based on these explanations, it becomes clear that two assessment criteria are necessary for the evaluation of the IT infrastructure.

Table 11: Evaluation scales - IT Infrastructure

Measure	Characteristics – IT deployment
0	No processes penetrated by IT systems
1	Rather few processes penetrated by IT systems
2	Almost all processes are permeated by IT systems

Measure	Characteristics – Communication capability
0	Limited communication between IT systems
1	Theoretically unrestricted communication between IT systems

Measure	Characteristics – IT infrastructure
0	No processes at all are penetrated by IT systems.
1	Rather few processes are penetrated by IT systems and only limited communication between IT systems is possible.
2	Rather few processes are penetrated by IT systems, but unrestricted communication is theoretically possible between the systems. Or: Almost all processes are penetrated by IT systems, but only limited communication is possible between the systems.
3	Almost all processes are permeated by IT systems and unrestricted communication is theoretically possible between the systems.

The **organisational degree of connectivity** results from the consideration of the "organisation-employee" interface. This communication requirement describes the combination of information, which leads to knowledge, whereby the information emerges from the interdisciplinary interaction between employees. At this point, the knowledge potentially relevant to the service creation process emerges through the networking of the information received. A necessary precondition for interdepartmental communication is the development away from isolated departmental/divisional thinking towards an open communication-friendly corporate culture [33,34]. In order to characterise the organisational degree of connectivity, it is therefore necessary to examine the extent to which the individual departments within a factory are connected with each other in terms of communication and to what extent the information gained through this networking contributes to the production of goods and services. Based on the preceding explanations, it becomes clear that two scales must be defined for the evaluation of this communication requirement. The combination of the individual evaluation scale values lead to the evaluation scale of organisational degree of connectivity.

Table 12: Evaluation scales - Organisational degree of connectivity

Measure	Characteristics – Communicative connectivity
0	No communicative connectivity
1	Low communicative connectivity (once a week contact or less often)
3	High communicative connectivity (contact several times a week)

Measure	Characteristics – Contribution to value creation
0	Low contribution to value creation
1	High contribution to value creation

Measure	Characteristics – Organisational degree of connectivity
0	There is almost no communicative connectivity between the departments under consideration (strong departmental thinking)
1	There is rather little communicative connectivity between the departments under consideration, with the information received hardly contributing to the value creation
2	There is little communicative connectivity between the departments under consideration, although the information received contributes strongly to the value creation
3	There is rather high communicative connectivity between the departments under consideration, whereby the information received hardly contributes to the value creation
4	There is high communicative connectivity between the departments under consideration, with the information received contributing strongly to the value creation

At the "organisation-organisation" interface, the requirement of **international cooperation capability** arises for communication. In the context of Industry 4.0, it is important that systems open up and international value creation networks can be established ad hoc, e.g. to meet individual customer requirements [35]. However, efficient international cooperation can be made much more difficult if the technology standards used only have a regional or national reference and are thus only compatible to a limited extent [36]. In addition, linguistic and technical differences can make cooperation difficult [33]. These differences address both the foreign language and the technical language problem. Consequently, it is necessary to examine to what extent the ability to cooperate internationally is impeded. A three-level ordinal scale is chosen for the assessment of the communication requirement under consideration.

Table 13: Evaluation scales - International cooperation capability

Measure	Characteristics – International cooperation capability
0	During international cooperation, major differences arise that enormously complicate or even stop the cooperation.
1	During international cooperation, there are rather few differences, which hardly complicate the cooperation.
2	During international cooperation, there are almost no differences.

The **network capability** is the last identified communication requirement and relates to the system component "building (and site)". This requirement arises at every interface combination within a factory and thus cannot be assigned to a unique interface pair. In this context, network capability means a horizontal as well as vertical networking of all processes involved in value creation within a factory as well as across several factories based on IT systems. For example, location-independent work organisation and resource availability can be realised through crowdworking or crowdproduction [35]. To characterise this requirement, it must be examined to what extent the existing IT landscape allows or supports network capability. On the one hand, the focus is on Wi-Fi availability in the individual factory areas, since both local and global networking in the context of Industry 4.0 takes place via the Internet [24]. On the other hand, the internet connection is important because, among other things, the possibility of transmitting high data rates depends on it, which is particularly relevant in relation to Big Data. Based on these explanations, it becomes clear that two scales must be defined for the evaluation of network capability. On the one hand, the forms of Wi-Fi availability must be determined and, on the other hand, the internet bandwidth must be operationalised. The combination of the individual evaluation scale values lead to the evaluation scale of network capability.

Table 14: Evaluation scales - Network capability

Measure	Characteristics – Wi-Fi availability
0	No Wi-Fi availability
1	Limited Wi-Fi availability
2	Unlimited Wi-Fi availability

Measure	Characteristics – Bandwidth
0	Low bandwidth
3	Medium bandwidth
6	High bandwidth

Measure	Characteristics – Network capability
0	Low bandwidth and no Wi-Fi availability
1	Low bandwidth and limited Wi-Fi availability
2	Low bandwidth and unlimited Wi-Fi availability
3	Medium bandwidth and no Wi-Fi availability
4	Medium bandwidth and limited Wi-Fi availability
5	Medium bandwidth and unlimited Wi-Fi availability
6	High bandwidth and no Wi-Fi availability
7	High bandwidth and limited Wi-Fi availability
8	High bandwidth and unlimited Wi-Fi availability

Overall, the communication requirements developed in this section and the findings from the previous section can be summarised in an Industry 4.0 communication concept. Based on Park et al. (2020), this concept contains all the components that are necessary for a holistic description and evaluation of communication within factories in the context of Industry 4.0. Against the background of the communication concept presented, the question now arises as to which measures must be introduced in order to successfully design communication in accordance with the associated communication requirements in the context of Industry 4.0. The following subchapter deals with this question.

5. Action measures to meet the communication requirements

In the previous sections, it was possible to model and further develop various requirements that industrial communication processes are confronted with in the context of Industry 4.0. In order to be able to fulfil these requirements after an evaluation of the communication, a catalogue of measures was developed. The measures can be used both department-specifically and across departments according to the respective communication requirement. Such a subdivision of the measures is necessary because the case can arise that several departments within a production company do not fulfil one and the same communication requirement in a similar way. In this case, it makes sense to introduce the same measures in the affected departments in order to ensure a uniform design of communication. An extensive literature research was carried out to identify the measures for action. All measures were then assigned to the Industry 4.0-side communication requirements according to their interface and sorted with regard to their department-specific or cross-departmental character.

Since the catalog of measures would exceed the scope of this paper, it is presented using an example. A more detailed insight into the measures will be presented in a subsequent publication. At this interface, for example, the communication obstacle of media breaks arises due to the lack of standard interfaces and heterogeneous IT landscapes. In the context of Industry 4.0, this obstacle is in complete contrast to the required interface compatibility, which describes a continuous and media-break-free exchange of data and information between the IT systems used. In order to meet this future communication requirement, it is therefore necessary to eliminate the media breaks between the technical systems within a factory. One potential department-specific action at this point is, for example, the introduction of new, compatible software in the department concerned. If there is an increase in media breaks between several departments, the definition of standards with regard to uniform software must be implemented as a cross-departmental measure. Further potential measures are included in the catalog of measures developed.

6. Conclusion and outlook

The objective was to develop a model with which the communication structures of factories can be evaluated in the context of Industry 4.0. This model should enable production companies to describe and evaluate their communication structures in the context of Industry 4.0 and to design them with the help of suitable measures. In doing so, the model should be as easy to use as possible, transparent as well as comprehensibly structured and associated with a reasonable amount of effort. In addition, it should guarantee a systematic and at the same reproducible evaluation. Overall, this was implemented in a first approach so that communication structures of factories in the context of Industry 4.0 can be described, evaluated and designed holistically as well as systematically. The comprehensive description model, which includes new Industry 4.0 requirements in addition to the already known communication requirements, ensures a holistic view and thus evaluation of the communication structures.

Nevertheless, further necessary and possible research needs were identified during the development of the method. Currently, the model is only a concept that is difficult to use in this form in an industrial environment. Although the focus on the description and evaluation of communication structures leads to a solid model, the design aspect must be considered more intensively in future research work. This includes, among other things, the implementation of the concept in an easy-to-use, software-based tool and the integration in a standardised process method. The process method must be holistic and include description, evaluation and design. Only such an implementation enables an efficient and effective use in the industrial environment.

Furthermore, the integration of such a procedure into the factory planning process as well as a consideration of different planning cases appears to be of great interest. Here, the model could be further developed so that not only communication structures of a factory are evaluated in the context of Industry 4.0, but also an evaluation of entire planning results is carried out from a communication-oriented perspective.

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Biography

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