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INDICATING THE CRITICALITY OF CHANGES DURING THE PRODUCT LIFE CYCLE

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ABSTRACT
As technical changes account for a significant part of the efforts like cost and time in product development and result from failures, which mainly appear after the Start of Production (SOP), change management need to consider further life cycle phases to indicate the criticality of changes. With Original Equipment Manufacturers (OEM) concentrating on their core competences, suppliers are increasingly involved in the change process, which is challenging the established models for the evaluation of changes. This paper presents a model for indicating the criticality of changes, which is based on a product life cycle model and a change process including the change transmission by cause-effect relations. On that basis, a literature-based discussion of indicators leads to the deduction of two alternative indicators. The combination of those indicators finally enables the indication of the criticality of a change during the product life cycle through the affected life cycle phases and the organisational interfaces, which are the basis of the developed indication model.

Keywords: technical change, cycle, life cycle, indication model, organisational interfaces

1 RELEVANCE OF CHANGES IN LATE LIFE CYCLE PHASES

1.1 Motivation
Change Management of innovative companies in the field of costumer and capital goods is of high competitive importance, as changes absorb up to 50% of the product development capacity [1][2]. According to CONRAT the cause of changes is either related to a failure (53%) or result of an alteration within external aspects (47%) [2]. The latter is characterized by a very limited latitude in terms of the underlying reasons like new markets [2][3], customer requirements [4], the frequency of emerging new technologies [3][2] and legislations [2]. As a result, this paper focuses on the failure related changes, which includes up to 20% of the sales of a product for their elimination [5]. Those changes are even intensified by a shorter product development process, an increasing innovation pace and the deployment of simultaneous engineering [6]. With PFEIFFER and SCHMITT reporting that the majority of those failures are generated before the Start of Production (SOP) and are mainly eliminated after the SOP (Figure 1) [7], it is difficult to overestimate the relevance of considering further phases of the product life cycle than just the product development process for the indication of the criticality of changes.

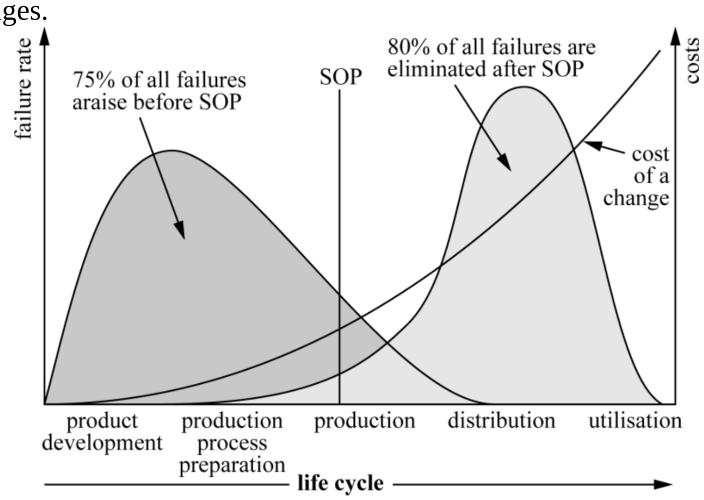

Figure 1. Failure generation, elimination and change costs at the life cycle (According to

[7][8])

Moreover, the expansion of the life cycle requires external factors to be considered. The in-house production depth of Original Equipment Manufacturers (OEM) is partially less than 30% [9], due to their concentration on core competences [10][11][12]. As a result, a considerable part of the product is provided by suppliers, which consequently are involved in the change process [13]. The discrepancy between the failure generation at the product development process and the failure elimination at production and usage indicates that the criticality of changes solely based on the product development process [14][15][16][17][18][19] neglect an important aspect of changes. Failures, which are eliminated later at the product life cycle, are not considered. Although, the resulting changes at the usage phase accounts for up to 25% of all changes and are very intense in terms of the effort of resources [1][2][8] (Figure 1). Beside the focus on the product development process the existing approaches for the indication of the criticality of changes present a wide field of potential dimensions for the evaluation. Thereby, the major challenge is the acquisition of the required information during the life cycle, which is a key constraint of existing approaches. In order to enable change management to indicate the criticality of changes, we create the basis of the evaluation by identifying the relevant aspects of those changes, which leads to an indication model of the criticality as an answer of the central research question of this paper:

How could the criticality of changes during the product life cycle be indicated?

This paper concentrates on the indication of the criticality of changes based on the product life cycle. To set the terminological basis, paragraph 1.2 is providing the background of research. Based on the relevant life cycle phases (2.1) and the change process (2.2), paragraph 2.3 is presenting indicators of models in literature. After the discussion of relevant dimensions, paragraph 3.1 and 3.2 develop two dimensions, which are combined to an indication model (3.3).

1.2 Background of Research

The life cycle of complex products is characterized and influenced by a number of company-internal and external cycles. These cycles are the object of investigation of the Collaborative Research Centre (SFB 768) – ‘Managing cycles in innovation processes – Integrated development of product-service-systems based on technical products’. The long-term goal of the cycle management is the planning and controlling of influenceable cycles and interdependencies. Moreover, the influence on the innovation process in terms of the dimensions time, quality and costs are investigated, as well [20]. Thereby, cycles are a reoccurring pattern (temporal and structural), which is classified by phases. As a result, a cycle is always connected with repetition, phases, duration, triggers and effects. Moreover, cycles could include retroactive effects, interlockings, interdependencies (within cycles and between cycles), hierarchies and further influencing aspects [21][22].

Triggers are the reason of the repetition of a reoccurring pattern and result of a deviation of the current and the intended status of an object. Moreover, the triggers are part of a chaining of factors, which are processed prior to the reoccurring pattern. The deviation and the other factors are independent and describe an effect chain [20]. In order to resolve this chain, the deviation needs to be eliminated, which requires a change. As the change is either resulting of a inaccurate current status of the object or a changed intended status of the object, they are closely linked to cycles. As a result, changes are just a specific occurrence of cycles.

The current research in the field of managing cycles is focusing on identifying triggers, objects and effects of cycles both within as well as outside of development processes [22]. The indication of the criticality of changes requires – according to the relevance of the consideration of further phases at the product life cycle – a focus on changes after the SOP. Based on the product life cycle model (Figure 2), which is motivated by the product planning process [23], the whole product life cycle needs to be considered for the indication of the criticality of changes in the first instance.

2 MEASURING THE CRITICALITY OF ITERATIONS WITHIN THE LIFE CYCLE

2.1 Relevant life cycle phases

Based on the product life cycle reference model of the SFB 768 [23], ASSMANN breaks down the relevant phases for the change process as shown in Figure 2 [24]. Thereby, the '*product planning'* is excluded, as well as the *'product disposal'*. Moreover, the phases '*Maintenance*' and '*Modernisation lifecycle*' aren't mentioned in context of changes [24]. As a result, five top level life cycle phases with relevance for the changes are remaining, which lead to a total number of nineteen sub-phases based on the initial life cycle model.

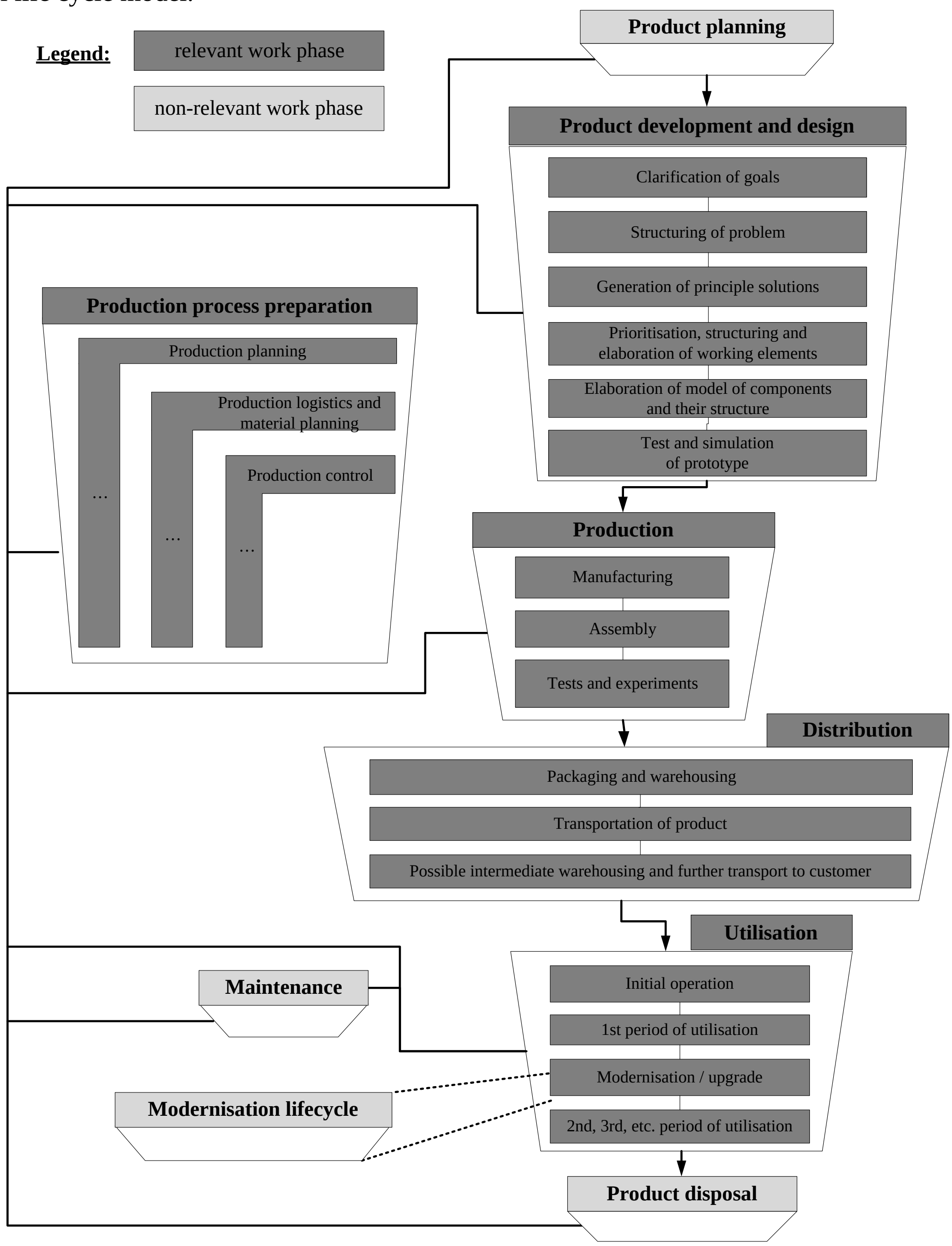

Figure 2. Adjusted product life cycle model [23]

The first phase, '*product development and design'* details the product idea within six sub-phases [25][26][27], while the *'production process preparation'* with three sub-phases is running in parallel [28][29][30]. The next phase is the '*production*', which is based on three sub-phases, due to the fact, that its characteristics are highly dependent, whether the product is part of mass production, mass customisation, small batch series, pilot run or single product production [2][29][31]. The following ‘*distribution*’ phase mainly describes the packaging, warehousing, and transportation of a product through three sub-phases [32]. The last relevant life cycle phase is the ‘*utilisation*’, which represents the different periods of the usage of a product [33].

As the five top level life cycle phases have a different duration ([34] referring to the ramp-up and change management of the DaimlerChrysler AG), the including sub-phases have a different time-based extend. Moreover, the average effort of a change varies by the time of the implementation of a change [2]. As a result, the imbalance between many less resource consuming sub-phases at the beginning of the life cycle and few more resource consuming sub-phases at the end of the life cycle is compensated on an abstract level.

2.2 Change Process

In order to set a terminological basis for the utilisation of the change process, Table 1 provides a definition of the relevant terms change, trigger, cause and effect of a change. The consistency of those terms is indispensable for the relations at the change process.

Table 1. Definitions of relevant terms

Term	Definition
change	Agreed definition of a new condition instead of a previous condition and the belonging transformation [1].
trigger	Deviation of the intended and the current status of an object, which represents a specific result of the product development process. The trigger releases the change process, because either the current status of the object is inaccurate or the intended status changed as result of varying requirements [2].
cause	Causal background of the deviation between intended and current status. The reason for the cause is either a failure at the product development process or an alteration at the general conditions [2].
effect	Result of a change [20]

Based on the definition (Table 1) the change process is basis for the indication of the criticality of changes, because it is demonstrating the process of a change, which is caused by a reason, released through a trigger and implemented through a decision and the corresponding operative activities. As a result, the change process illustrates the resulting cause-effect relations of a change.

DIN 199 Part 4 is oriented at the operative execution of changes based on the operational periphery [1][35]. The different steps mentioned in this norm like ‘*write a change request*’, ‘*check change request*’, ‘*write a change order*’, ‘*change drawings and part lists*’ or ‘*change service: distribute changed drawings and part lists*’ are closely linked to the creation of specific documents, as this process was originally designed for the administration of drawings and part lists [1][35]. As a result, this model isn’t supporting the illustration of cause-effect relations.

Another model for the change process is distributed by CONRAT, which is illustrating the interdependencies between ‘*cause*’, ‘*trigger*’, ‘*decision*’ and ‘*implementation*’ of a change [2]. Moreover, it is mentioning the ‘*reaction time*’, which is indicating the time between cause and trigger of a change. This period leads to the shift between the generation and elimination of failures, as changes by definition are the correction of failures [1][14][15]. As the last step in a change process is the indication of effects caused by a change, this model needs to be expanded.

In order to demonstrate the relevant aspects of a change Figure 3 is illustrating the change process based on the models distributed by CONRAT and DIN 199 [2][35].

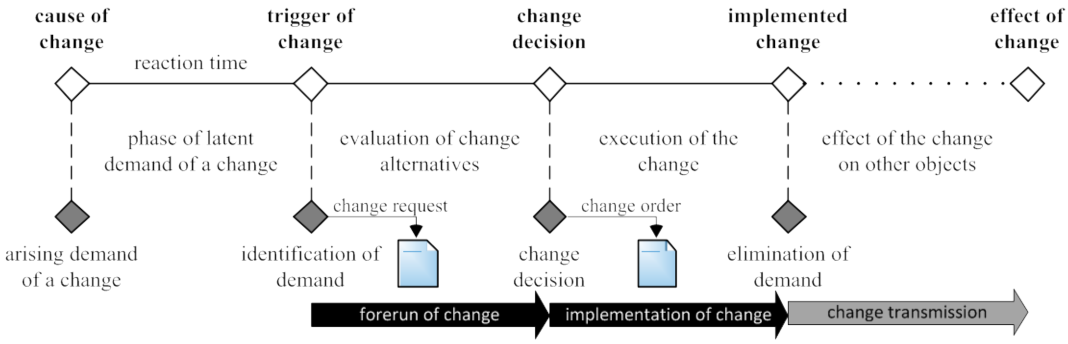

Figure 3.Extended change process (According to [2][35])

The '*cause of a change'* symbolise the arising demand, which remains latent as long as *'the trigger of a change'* reveals this demand. As a result, a change request is generated, which is the beginning of the forerun of a change. During this phase alternative change options are evaluated and finally approved at the '*change decision*', which leads to a change order [35]. With this document the next phase in the change process starts and the execution of the change order is processed as long as the demand of a change is eliminated through the '*implemented change*'. The last phase is the change transmission, which covers the aspect, that changes can be cause and trigger for following changes in terms of cause-effect relations [36]. This '*effect of a change'* is considering the influence of a change on other objects and leads to a significant failure rate at OEMs and suppliers [13][37].

2.3 Dimensions of changes in literature

This section focuses on the change decision, which is based on the evaluation of changes against specific dimensions. Those dimensions are intended to indicate the criticality of changes on the one hand and to be collected within the product life cycle without large effort on the other hand. Referring to the investigated aspects of the Collaborative Research Centre (SFB 768) indicating dimensions are time, quality and costs [20]. In addition to that, SAYNISCH proposes two other dimensions, with the system complexity and the innovativeness level [38].

One indicating dimension is represented by costs as the rule-of-ten for the product development process [14][15][39]. This dimension is a major goal of change management, although the acquisition of the required information is elaborate due to the fact that change costs emerge in different areas [1]. Based on the change process of DIN 199 [35], LINDEMANN and REICHWALD derives four major cost drivers for inter-case change costs [1]. These cost drivers represent processing costs for the forerun and the implementation of a change and the corresponding follow-up costs for both [1]. Beside cost drivers and their interdependencies an accurate estimate has to consider cause-effect relations of changes, which include the supply chain [13][37], as a considerable part of the product is provided by suppliers [9]. Another dimension to indicate the criticality of changes is time, which is referring to the required period to correct the failure (cycle time of a change order) [1]. In this context GEMMERICH is reporting, that the majority of changes are taking up to thirteen weeks for their accomplishment [40]. However, this absolute number is not representing a valid basis for the indication of the criticality of changes due to the fact that the duration of the life cycle varies a lot between different products. As a result, the change duration of thirteen weeks won't be as critical for products with a long life cycle (aircrafts) as for products with a short life cycle (e.g. mobile phones) [41]. Therewith, the absolute change duration is no reliable indicator for the criticality of changes as long as the duration is not set into proportion to the overall duration of the product life cycle. However, the time for the correction of failure is only based on a rough estimate at the change decision, so that this dimension is more applicable for a retrospective investigation. Moreover, this dimension is underlying the same difficulties as the evaluation of the costs in terms of an accurate estimate of interdependencies between the different activities, as a result of cause-effect relations.

The last dimension according to the investigated aspects of the Collaborative Research Centre is quality [20]. As changes are by definition the correction of failures, it seems to be less constructive to indicate the criticality of changes by this dimension [1][14][15]. However, quality represents the level of correction of the failure in terms of a symptom control versus an elimination of the root cause in this context [1]. Therefore, this dimension rather creates an order between different alternative change options, than an indication of the overall criticality of different changes.

Beside those dimensions SAYNISCH is proposing a model, which deduces the extent, influence and frequency of a change based on the system complexity and the innovativeness level [38]. Those dimensions rather represent an indicator for the overall effort of changes than the indication of the criticality of single changes during the life cycle. Moreover, the evaluation of the system complexity and the innovativeness level of a product are based on a rough estimate due to the fact, that the alteration resulting from a single change is only to be identified on a specific level of accuracy through a reflexion. Moreover, the resulting graph is only established for the product development process and not for further life cycle phases.

2.4 Discussion of relevant dimensions

As a result, the presented dimensions are either used for a retrospective evaluation of changes or an appraisal of the overall effort of changes on an abstract level. The presented dimensions do not match the idea to indicate the criticality of changes based on information, which are accessible during the life cycle. Moreover, those dimensions don't enable an appraisal of resulting consequences for organizational units or the residual process, as their focus is on their separated dimensions [1]. This constriction hinders the capturing of indirect cost effects like sunk costs or coordination and information costs, which need to be considered according to LINDEMANN and REICHWALD [1]. As a result, those dimensions are not the first choice for the indication model (paragraph 3.3), although they bring up valuable evidence for the importance of time, cost, coordinating and informational efforts. Moreover, the evaluation of those dimensions during the life cycle is based on rough estimates, which makes it difficult to overestimate the relevance of developing alternative indicators. Based on the life cycle model, time in context of changes could be represented by life cycle phases of a change referring to paragraph 2.1. As coordinating and informational efforts lead to costs [1], two dimensions could be addressed at the same time through the consideration of the organisational interfaces. Those interfaces are an indicator of the required efforts to keep up the flow of information, which comes along with changes. As a result, the aggregated indicators affected life cycle phases and organisational interfaces, create the basis for the following development of the indication model.

3 INDICATION MODEL OF CRITICALITY OF CHANGES

3.1 Dimension: life cycle phase

One indicating dimension of the criticality of changes is the affected life cycle phases, which are an alternative representation of time due to the assumption, that the imbalance between many less resource consuming sub-phases at the beginning of the life cycle and few more resource consuming sub-phases at the end of the life cycle is compensated on an abstract level (paragraph 2.1). Thereby, the time-reference is not focused on the duration of the implementation of a change, but on the number of affected life cycle phases, which consider the varying average effort of a change over the time of implementation at the life cycle [2]. As a result, the basis of the first dimension is the 19 relevant sub-phases of the product life cycle (paragraph 2.1). With an increasing period of time, indicated through the affected life cycle phases, between the cause and the implementation of a change, the criticality raises due to the fact that more life cycle phases need to be redone [1]. Thereby, the criticality is closely interlinked with the number of affected sub-phases. As the absolute number provides no valid basis due to the fact that the number of sub-phases might vary according to the business model of a company, the number of affected sub-phases needs to be correlated with the total number of sub-phases of the corresponding product life cycle to build a valid basis. Figure 4 is demonstrating the calculation of the criticality based on the top level life cycle phases and their underlying sub-phases.

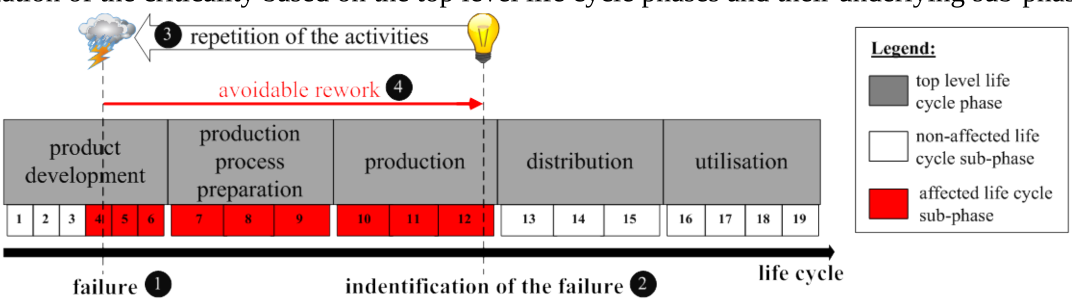

Figure 4. Changes in the life cycle model

3.2 Dimension: Organisational Interfaces

Beside the affected life cycle phases, the organisational interfaces are another indicating dimension of the criticality of changes. Based on the change process, different areas in the life cycle are affected by changes, which include the supply chain according to SCHMITT [13]. The time period between the cause, trigger, implementation and the effect of a change, results in a need of coordination and flow of information. The organisational area which sets the cause is not necessarily the same area, where the effects of an implemented change are going to appear. As a result, the flow of information needs to bypass different organisational interfaces. The coordination, queue time, annotation and transport time at those interfaces lead to coordination and information costs [42], which are even intensified by the increasing number of interfaces due to the division of labour [24][31]. In this context, BOZNAK and PFLICHT are reporting significant costs, which result from the processing of the information in case of a change [43][44]. As suppliers provide a considerable part of the product, their interfaces within the supply chain need to be considered beside the organisational interfaces within the company [13], to cover aspects like the change transmission as result of cause-effect relations of changes [13][37]. Based on this, Figure 5 demonstrates a user-defined change process with the flow of information at the interfaces between different departments as a result of a change. Moreover, the relation between the repetition of activities and the avoidable rework between the failure generation and the failure identification, with consideration of the supply chain is revealed.

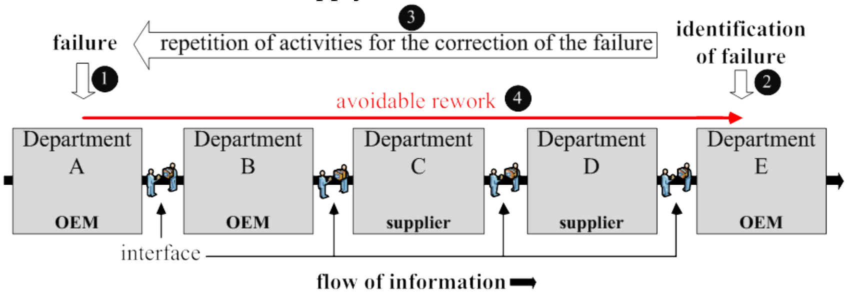

Figure 5. Effects of changes on the information flow (According to [1])

The deviation of labour causes a higher number of organisational interfaces and leads to a higher level of criticality. As Simultaneous Engineering is proposing an integration of activities in contrast to the deviation of labour [45][46][47], the reduction of avoidable efforts of a change, according to BULLINGER and WASSERLOOS [48], is supported by this indicator. Higher integrated organisational areas have fewer interfaces and are therefore less critical in case of a change.

3.3 Indication Model

The indication model is based on the described dimensions (life cycle phases and organisational interfaces), which are combined to a two-dimensional model for an overview (Figure 6). While the dimension of the life cycle phase is interlinked to time and the dimension of organisational interfaces are related to informational efforts and the resulting costs, the relevant factors for the evaluation of changes, as a specific occurrence of cycles, are covered by this model. The classification of the criticality of a change based on the two dimensions refers to three different specific levels (critical, semi-critical and non-critical), which require a detailed definition.

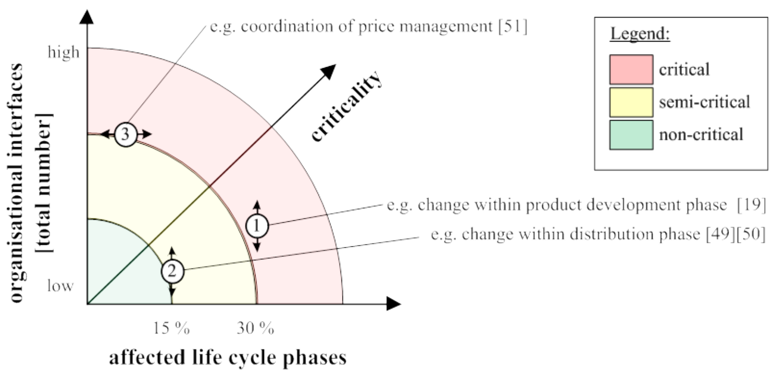

Figure 6. Indication model for the criticality of changes

An indication of the criticality of a change as a dimension of a life cycle phase is referring to a specific percentage of affected sub-phases to relevant sub-phases. Critical changes in terms of time are mainly reported at the product development phase, which is composed of six sub-phases [19]. Thereby, critical changes are already reached for a percentage of six affected sub-phases to 19 relevant sub-phases of the adjusted product life cycle model (Figure 2). As a result, changes are already critical at a minimum of 30% − independently of the affected organisational interfaces. The borderline between the remaining semi-critical and non-critical changes is based on the consideration that semi-critical changes can appear within the other top level life cycle phases, which have an average of three sub-phases. For example the detection of a new distribution channel affect the three sub-phases of the distribution [49][50]. Therewith, semi-critical changes are located between 15% - 30% and non-critical changes have less than 15%, which is dependent of the number of organisational interfaces.
In contrast, the criticality in terms of the organisational interfaces refers to informational efforts and the resulting costs. Thereby, the flow of information between different organisational areas is a key aspect, which is already leading to a significant effort in terms of the coordination between a small number of interfaces [31]. The classification of changes is more qualitative at that dimension due to the fact that literature is only providing qualitative figures based on case studies [31], which focus on the overall effort of the coordination ([31] referring to a study of the management consulting firm Arthur D. Little about the efforts on the information flow at interfaces of different departments). This dimension uses a qualitative scale, which range from a low to a high number of organisational interfaces. In order to give evidence of the range of this qualitative scale, the flow of information between two organisational areas within a company already reaches a considerable level of criticality according to the operative price [51]. Although, the resultant position in the portfolio is dependent of the affected life cycle phases. Based on the classification within both dimensions, the criticality of a change is indicated at the portfolio, through its position according to the three levels (critical, semi-critical and non-critical), which are represented by the coloured hemicycles in Figure 6.

4 CONCLUSION AND OUTLOOK

In this paper an indication model of the criticality of changes is presented. Based on the initial product life cycle model, the phases with relevance for changes were deduced and the change process was enhanced in order to cover the change transmission as result of effect-cause relations, which even affect corresponding suppliers. As existing models are mostly focused on the evaluation of the criticality through time and cost, they are based on estimates. Indirect cost effects like sunk costs or coordination and information costs were not considered. In contrast to that, the consideration of these costs is an advantage of the developed model compared to the existing models. Thereby, the relevant factors time, coordination and cost were described by two alternative indicators, which are represented by the affected life cycle phases and the organisational interfaces. While the former is related to time, the latter covers efforts for the coordination and the resulting costs. As a result, both indicators include the relevant factors for the evaluation of a change and are not elaborate to collect during the life cycle, which is a major constraint of existing models. The illustration of the criticality in a two-dimensional model finally enabled the classification of changes according to their level of criticality.
In a first step of future work, the life cycle phases of the initial product life cycle model are detailed to processes by conducting case studies in industrial applications. This increases the level of accuracy in the dimension of time. Another focus of further work is the detailed analysis of the effects at organisational interfaces regarding the flow of information to deduce a specific value for the criticality of a change in terms of efforts for the coordination and the resulting costs. Finally, the classification of the changes will be refined with the focus of balancing the two indicators in order to gather the operative loss of changes [1].

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