From traditional to transformable production logistics – measures for successful transformation

Pia Vollmuth[1][0000-0002-1123-0683], Lasse Bethäuser[2], Felix Brungs[2] and Johannes Fottner[1][0000-0001-6392-0371]

[1] Technical University of Munich, Chair of Materials Handling, Material Flow, Logistics, Boltzmannstraße 15, 85748 Garching
[2] MAN Truck & Bus SE, Dachauer Strasse 667, 80995 Munich
pia.vollmuth@tum.de

Abstract. The dynamic and rapidly evolving business environment poses numerous complexities for production logistics. The increasing frequency of product and model changes, coupled with the growing variability of components, underscores the urgency for adaptive measures to address reducing product life cycles and advancing customer demands. Technological advancements have enhanced logistical productivity, but it is important to comprehensively tackle these challenges. To overcome these limitations, the concept of "transformability" is explored as a central cornerstone of the solution.
A design framework is proposed to increase the transformability. This paper systematically captures and models the production logistics system to achieve the goal. Key change enablers are identified and aligned with the production logistics system to develop specific change enablers for each production logistics area. These serve as the foundation for formulating transformation measures that can be incorporated into logistics planning. The results guide companies for successful implementation and long-term competitiveness by offering potential users a wide range of possibilities to increase their transformability within planning activities. This work contributes to raising awareness of the importance of transformable production logistics and offers practical recommendations for action. By embracing this approach, companies can proactively and effectively respond to dynamic fluctuations in the production environment, ensuring long-term competitiveness and sustainability.

Keywords: Adaptability, Commercial Vehicle Industry, Production Logistics, Transformability, Versatility.

1 Turbulence and complexity as challenges of production logistics

The supply chain of many companies is exposed to a changing environment. Production logistics, which forms part of corporate logistics, is affected by increasing turbulence, complexity and dynamics. The increasing frequency of product and model changes and the rising variance of components describe the effects of ever-shorter lifecycles and the growing customer individualisation demand [1, 2]. Although technological advances in transportation and production technologies increase the productivity of the logistics system, they can only solve the challenges selectively. Instead, structural, long-term adjustments to production logistics are needed to meet these challenges [3].

Especially in complex systems with many interfaces and dependencies, it is likely that requirements will change over time [4]. For this purpose, dynamic influencing factors, discontinuities and possible adaptation scenarios must be considered early in planning [5–7]. This situation makes it necessary to identify degrees of freedom for change and initiate suitable measures.

Traditional, static planning of production logistics is reaching its limits. Upcoming dynamics in day-to-day business are rarely anticipated due to limited capacities. Reactive adaptation of logistics concepts with accompanying delay has been the transformational response to these problems. However, protracted and delayed adaptation can lead to losing competitive advantage. In addition, many adjustments are based on empirical knowledge and take place at irregular intervals.

Transformability is seen as a critical solution-building block to meet these challenges. Transformability enables companies to react structurally to uncertain changes and quickly adapt to new requirements [8]. In production logistics, however, the difficulty lies in making this transformation effective. Through proactive and long-term planning, preparatory measures can be managed appropriately, resources can be focused, and companies can be put on a sustainable path with the definition of coherent production and logistics concepts [9]. Adaptive and dynamic planning can successfully meet the challenges of turbulent influences.

Transformability has not been given much importance in planning production and logistics processes. On the one hand, this is because, in practice, other objectives, such as cost savings and efficiency, are in the foreground. On the other hand, there needs to be more knowledge about the possibilities for promoting transformability.

This article presents an approach for increasing the transformability of production logistics. A design framework is developed to support companies in identifying the required courses of action for change-capable production. The design framework considers various aspects such as processes, technology, space, organisation and employee competencies to comprehensively examine measures for change.

The results of this study offer companies guidance for the successful transformation of their production logistics. By using the design framework presented, companies can improve their transformability and thus better respond to the constantly changing requirements in production logistics. The successful implementation of change-capable production logistics helps secure companies' competitiveness and sustainability in the long term.

2 Transformability in science and practice in production logistics

Production logistics as a subsystem of corporate logistics encompasses all logistical processes within the plant, including the operational flow of materials and goods as well as the accompanying flow of information. This is to be distinguished from the preceding and subsequent phases of procurement and distribution logistics, which handle all logistical processes outside the plant [10, 11]. The tasks of production logistics include the guarantee, optimisation and execution of transport to and between the operating resources and workplaces as well as the handling of goods. For this purpose, the material and information flow in production is planned, controlled and monitored. The overriding goal of production logistics is the timely and cost-effective provision of materials. [12]

The scientific definitions of **transformability** in the literature are diverse. Transformability can be described as the ability of a system to adapt reactively or proactively to structural changes to dynamic internal or external influencing factors (so-called change drivers) that are difficult to plan [13, 14]. In this context, transformation can encompass the dimensions of organisational, technological, or spatial change [15, 16]. Transformational capability is also closely related to the concept of flexibility but must be distinguished from it. Flexible systems can adapt reactively to changing indicators within specific given dimensions and scopes of action (so-called flexibility corridors). However, as soon as proactive and more extensive structural adjustments and thus a shift or scaling of the bandwidth or location of the flexibility corridors are necessary, transformable systems without explicit limits and with largely solution-neutral preconceived degrees of freedom are needed. [16–19]

Change enablers are central to a system's ability to transform itself. They describe the inherent property of the system that can be activated in a given change period and bring about the desired change [20]. In most of the literature, the five primary change enablers defined by Wiendahl et al. are used (see **Fig. 1**) [16]. Accordingly, the components of a production system are particularly capable of change if they have diverse properties and can be used in different combinations and locations [21]. Since these primary change enablers have a thoroughly abstract character, these five primary enablers are subdivided and concretised into up to two sublevels [22–24].

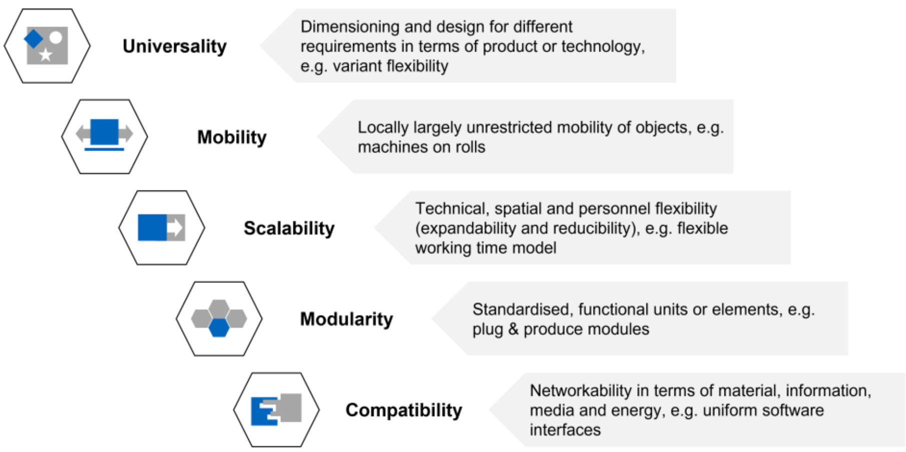

Fig. 1. Primary change enabler [16]

2.1 Existing design approaches to the transformability in production logistics

To plan and ensure a smooth transformation, production resources and their potential to change, as well as suitable options for action, must be analysed and selected. Since planning and executing change capability is often knowledge-dependent, time-consuming, and error-prone, it is essential to emphasise the significance of a systematic design framework for the change process. The following abstract aims to give a brief overview of five existing approaches in research. The developed design framework is based on these components respectively individual building blocks of the publications presented:

- *Cisek et al.* propose a concept for designing transformable production systems that can adapt to market conditions by identifying minimum requirements for production resources. They define the concept of transformability as the foundation for designing such systems and develop a receptor model to capture influences from the business environment, enabling adjustments to the production system. The production system is divided into three levels: resource, process, and organisational level. To ensure adaptability, essential functions are identified, prioritised, and used to derive resource requirements. [25]
- *Pachow-Frauenhofer* develops a model for planning transformable assembly systems by dividing the system into four specific element categories (Processes, Resources, Organization, and People). Specific change enablers are identified and related to change dimensions to enhance the system's transformability. The focus is on deriving practical design features for each element category. [24]
- *Heger* presents a method for assessing the transformability of factory objects by analysing their inherent potential for enabling change. The factory system is divided into three superordinate fields: Technology, Space, and Organization, with 24 specific factory objects. The method identifies specific potential characteristics and suggests a rating system to assess the transformability of each object. [23]
- *Steffens* transfers the concept of transformability to industrial logistics using a context-based model. Seventy specific transformability measures are defined to enhance transformability for tactical and operational logistics processes. [26]
- *Erlach et al.* categorise and define changeability in production, including flexibility, transformability, and agility. They provide solutions to transformability, identifying corresponding enablers in the requirement areas: number of pieces, product variance, technology characteristic and location. [27]

2.2 Research gap and need for action

To describe in which context a research gap was identified, the transformation control loop (see **Fig. 2**.) is used. The control loop illustrates the processes and decisions to implement transformation in a system.

As already described, the production system is subject to constant influences in the form of change drivers. Examining and evaluating the current state of transformation in the system can determine whether there is a specific need for change.

If neither flexibility nor transformability potential is available, transformation measures to increase the transformability are needed [28] (blue marking). The developed design framework serves as a mean for systematically developing transformability measures.

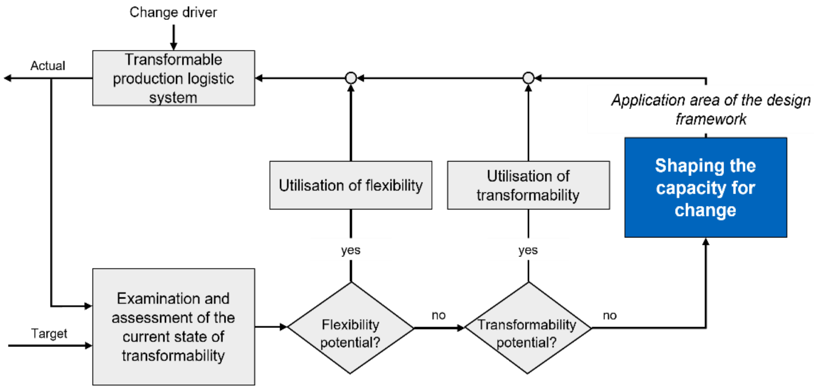

Fig. 2. Transformability control loop [2, 29]

Despite the diversity of existing projects and research results, existing solution approaches must be expanded because they are either very abstract and theoretical at the factory planning level or tailored to specific implementation scenarios. Due to the increased turbulence in the supply chain environment, the production logistics involved is changing from a stable developing towards a disruptive and revolutionary one [30, 27, 31]. The existing planning system in practice is no longer sufficient for these higher requirements. Overall, there need to be more systematic approaches for identifying transformation potentials and deriving concrete transformation measures for the production logistics system.

3 Design framework for transformation measures

A design framework was developed to fill the research gap of a systematic design for transformability measures in production logistics. The design framework is designed in a matrix structure, illustrated in **Fig. 3**. The proposed matrix structure is used to combine the two aspects of production logistics and changeability and to emphasise their intersections [24]. The vertical axle comprises the systematisation of production logistics (orange marking). For this purpose, relevant design fields of the production logistics system are identified, to which more detailed element categories are then assigned (see Chapter 3.1). In the horizontal axle (blue marking), the five primary change enablers are presented and divided into more concrete enablers. In total, three levels are formed based on the five primary change enablers (see Chapter 3.2).

The two axles (design fields and change enabler) are combined to develop a production logistics-specific change enabler hierarchy in the field of commercial vehicle production (see Chapter 3.3). The assignment of design principles and transformation measures in the design framework thus follows the systematics of production logistics (orange) and change enablers (blue) (see Chapter 3.4). The transformation measures can therefore be assigned to specific design fields, element categories, and the specific change enabler.

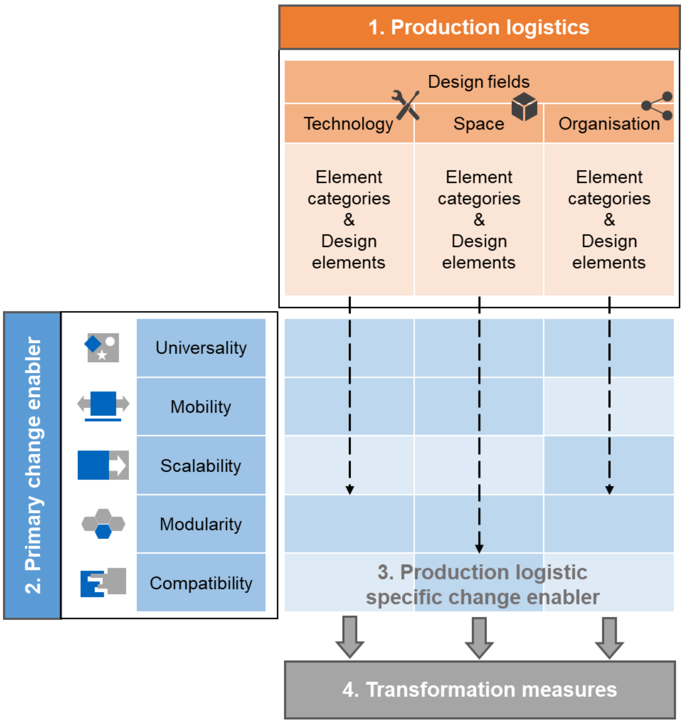

Fig. 3. Approach to the creation of the design framework

3.1 System model of production logistics: design fields

Production logistics can be seen as a delimited subsystem of the production system in which tasks and functions are fulfilled to supply the production with the necessary components. Production logistics as a part of the production system represents a highly complex system in itself [15]. To master this complexity, a systematic approach is essential. As described in Chapter 2.1, there are several approaches to cluster production logistics. According to the structural and hierarchical concept of the system theory [32], the production logistics system can be divided into three design fields: technology, space and organisation for production logistics [23, 33]. The design fields are given two more sub-hierarchy levels, referred to as element categories and design elements [34] and shown in **Fig. 4**.

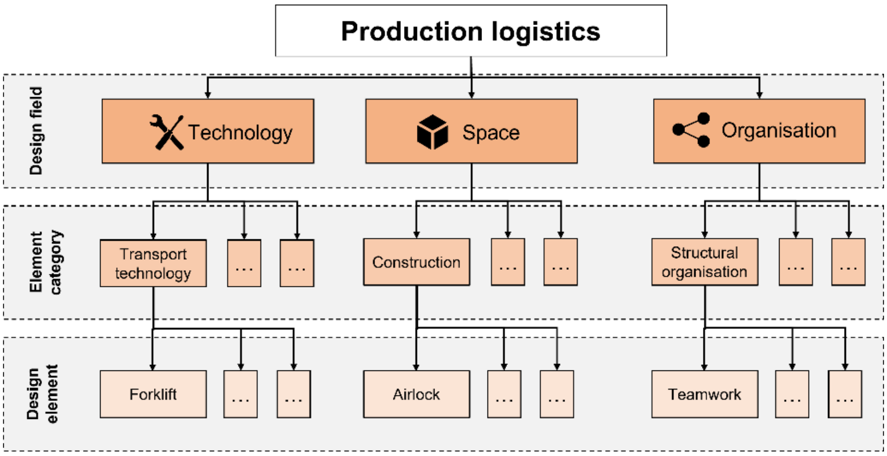

Fig. 4. Hierarchy structure of production logistics, own illustration based on [34].

3.2 Structure of a change enabler hierarchy

Since the five primary change enablers mentioned in Chapter 2 have a thoroughly abstract character, several authors divide these so-called primary change enablers into up to two sublevels [22, 24, 35]. The secondary change enablers, and the tertiary enablers below them, referred to in the following as change features, detail the respective higher-level change enablers but do not add any fundamentally new aspect [24]. The term "change features" is defined as a combination of the terms "change potential features" by Heger and "design features" by Pachow-Frauenhofer as a more precise, change-promoting property of a design element through which the primary change enablers are made visible and designable [23, 24]. For example, interconnectivity can be defined as a secondary change enabler of compatibility. In this context, interconnectivity concretises the compatibility concept according to the above definition. A potential change feature for this could be diverse interface configuration. They represent the feature by which a design element ultimately becomes networkable and thus compatible.

3.3 Identification of production logistics-specific change enabler

Since previous considerations have focused on the factory planning level, a production-logistics-specific assessment of the transformation enablers is required.

For this purpose, it is examined to what extent the change enabler can influence the properties of the design fields of the production logistics system. This evaluation was carried out in particular in the sector environment of the commercial vehicle industry and is therefore sector-dependent.

103 production logistics-specific change enablers were identified with an extensive literature review and expert knowledge in the field of commercial vehicle industry. Of these, 54 are assigned to the design field technology, 29 to space and 20 to organisation, as shown in **Fig. 5**.

Primary change enabler	Secondary change enabler	Change feature	Technology: Transport technology	Technology: Storage technology	Technology: Ressources	Space: Construction	Space: Layout	Organisation: Organisation structure	Organisation: Process organisation	Organisation: Staff
Universality	Diversity	Automatability	x	x		x				
		Organizational diversity						x	x	x
		Location variability	x	x	x	x	x			
		Technical Versatility	x	x	x	x	x			
	Neutrality	Generality	x	x	x	x	x	x	x	x
Mobility	Mobility	Automation	x	x		x				
		Compactness	x	x	x	x	x			
		Transportability		x	x	x				
	Mountability and dismantling	Fixed location	x	x	x	x				
	Social mobility	Mental mobility								x
Scalability	Expandability and reducibility	Capacity variation	x	x	x	x		x	x	
		Reconfigurability	x	x	x	x	x	x	x	
		Robust sizing	x	x	x	x	x			
Modularity	Segmentation	Autonomy	x	x	x	x	x	x	x	
		Functional delimitation	x	x	x	x	x	x	x	
	Standardisation	Combinability	x	x	x	x	x	x	x	
Compatibility	Simplicity	Usability	x	x	x	x				
		Robustness	x	x	x	x				
		Supply requirements	x	x	x	x				
	Networking capability	Connection flexibility	x	x	x	x				
		Ability to integrate and disintegrate	x	x	x	x	x	x	x	x

Design field

x = *Identification of a specific change enabler in commercial vehicle industry*

Fig. 5. Specific change enabler in the field of production logistics

3.4 Transformation measures and design principles

Adaptable solution approaches for increasing the transformability of production logistics are defined based on the developed structure from the design fields and specific change enablers. For this purpose, general, application-neutral design principles are defined on the one hand, which should be considered as underlying framework conditions during a transformation process, and more concrete transformation measures for production logistics are compiled on the other hand. Design principles and transformation measures in the design framework thus follow the systematics of production logistics and the change enabler and are assigned to the corresponding matrix fields. In total, 103 design principles and 146 transformation measures were identified.

The following examples of concrete transformability measures assigned to the change enablers for the element category transport technology are given. Increasing transport technology's transformability requires considering applications, especially in the field of Industry 4.0. Due to their usually high degree of automation, these technologies, like AGVs, are particularly suitable for meeting the challenges arising from the increased complexity and dynamics of the corporate environment. However, specific vital points must be observed when using AGVs to develop the full potential for change. This is because a high degree of automation does not always go hand in hand with a higher transformability of the transport system [23] due to the increased "complexity in terms of planning and design, initial setup and adaptation" [36]. On the one hand, AGVs should therefore be highly user-friendly and be able to be commissioned and maintained by the user himself, as well as adapted to changes in logistics processes. On the other hand, the capabilities of AGVs should be "especially [in] the area of environment perception and corresponding autonomous behaviour adaptation" [36]. This can be achieved by integrating the autonomous capabilities of the AGV. Intelligent algorithms can, for example, independently compensate for missing configuration data during commissioning and thus replace cost-intensive, external expert know-how. Furthermore, AGVs can independently locate and control changing targets with the help of the algorithm, which was previously only possible through time-consuming programming by an expert.

Another transformability measures concerns autonomy and function delimitation. It refers to the mutable design of the conveyor technology. In principle, the conveyor technology should be designed modularly, i.e., the respective modular units should be able to function autonomously, and their functions should be delineated. In detail, this means that one module contains, for example, the drive with motor, control system and the driven axes for movement, and another part represents the pick-up unit for the goods to be conveyed. It should be possible to link the two modules via standardised interfaces. The functional separation enables either further functional units to be added module by module or even the existing module to be replaced entirely in the event of a potential change in the requirements of the material to be conveyed on the pick-up element (e.g. higher weight, higher fire protection requirements, etc.).

4 Application area of production logistics

The design framework has been applied in a case study from practice. This was used to critically reflect on the mode of action and the functions of the design framework. The exemplary use case involves planning a mixed production of e-mobility and conventional commercial vehicles.

The use case is characterised by an uncertain development of the future unit number and their distribution. Hence there are expected advantages through high flexibility regarding quantity and variant mix. Low margins and the high cost of new assembly lines characterise the commercial vehicle industry. A conversion design for new products with high variance is integrated into a mixed assembly. If the model mix or derivatives of the vehicle types change, the entire assembly and associated logistics processes must be adapted to the new product requirements. This entails a complex planning process and high additional costs [37].

Transportation technology is selected as an example to demonstrate the application of the design framework. The choice of the appropriate means of transport for a new component on the factory floor depends on various influences and framework conditions of the brownfield environment. The options for evaluation and selection are forklifts, AGVs and tugger trains. Aspects such as sufficiently dimensioned hall entrances, integration into existing routes, cost-effectiveness, system integration and avoidance of delays due to bottlenecks must all be considered.

With a focus on exemplary AGV-specific transformation measures, an optical system is proposed over a rail-based system for controlling AGVs. This has the advantage that the routes of the vehicles controlled by lasers or reflectors can be changed quickly and with little effort if necessary. In the case of laser-guided AGVs, all that is required is an adjustment of the control software program, whereas, in the case of reflector-controlled AGVs, the corresponding reflector markers must be physically repositioned along the route. It can be seen that both variants are significantly more adaptable than a rail system.

Another measure concerns the procurement and scheduling of the vehicle systems. In the case of uncertain planning parameters about demand, parts availability or energy costs, as is the case in the commercial vehicle industry, it is advisable to conclude special framework agreements with providers of AGV systems for the flexible addition and removal of AGV units. Depending on requirements, the type and number of AGVs in the system can be varied without having to purchase the respective units in their entirety. This ensures a high expandability of the AGV fleet, which will help manage the ramp-up of the battery-powered truck model.

The findings are particularly relevant for manufacturers in the commercial vehicle industry to achieve higher transformability in production logistics. In addition, this work can be used as a nudge and basis for the transformation capability of production logistics in other sectors, for example, the automotive industry.

5 Summary and Further Research

This paper contributes to the broad research field of transformability and extends it, especially concerning production logistics in the commercial vehicle industry.

The framework presented shows design principles and transformation measures in production logistics in a structured form. In this way, the concept supports the increase of the transformability of internal logistics processes to maintain the efficiency of production logistics in a dynamic environment.

As a further need for research, an extension to include application-specific value ranges to the single measures was identified as the possibility of evaluating and comparing transformation measures. This would ensure the comparability of different transformation measures and, if necessary, with the aid of suitable evaluation models, enable well-founded, multi-criteria decision support about the selection of measures.

In the design framework presented, the transformation measures were also considered individually. Further research requires a more in-depth analysis and consideration of the interactions between the set goals, individual measures and design elements.

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