



Towards a More Sustainable Manufacturing Environment: A First Proposal on SDG-Based Design Guidelines for Planning an Assembly Line

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Abstract. Manufacturing systems impact sustainable development among others through resource consumption and emissions, but also through working conditions and economic value creation. While planning and designing of production systems traditionally prioritizes economic efficiency, a more holistic approach incorporating environmental and social sustainability is needed. This research develops comprehensive design principles for more sustainable assembly lines based on their potential contribution to key Sustainable Development Goals. Sustainability criteria are systematically transferred into a framework that supports practical implementation in a general planning process. The resulting framework provides specific guidance for both high-level planning and detailed planning phases of assembly systems. The developed principles are a first attempt to enable companies to balance economic requirements with environmental resource conservation and social considerations.

Keywords: SDGs · sustainability · sustainable manufacturing · circular economy · sustainability criteria · assembly line · manufacturing process

1 The Importance of Sustainable Planning

The transformation towards a sustainable society and economy is a necessity. The vision of a sustainable global community is currently reflected in the UN's 'Agenda 2030' Sustainable Development Goals (SDGs). They establish a universally acknowledged framework of sustainability goals, endorsed by all UN member states [1]. The SDGs are comprised of 17 overarching goals, which are further subdivided into a total of 169 targets. Ensuring their relevance across all domains, the aforementioned objectives encompass a wide range of social, economic and ecological dimensions. Moreover, a total of 231 indicators have been delineated, providing a standardized metric for comparison between countries, regions and sectors. The majority of the SDGs' indicators are of a quantitative nature, with few being qualitative in nature (i.e. gender equality) [2, 3]. The Sustainable Development Goals, as a universally recognized framework with

global reach, should also function as a foundation for the consideration of sustainability issues. In particular, as the Sustainable Development Goals address the issue of industrial production directly through the twelfth goal ‘Sustainable consumption and production’, it is vital that engineering activities be given due consideration within this context [3].

To contribute to these goals, we aim to incorporate the consideration of sustainability criteria into the process of assembly line planning. In this work a planning process of a generic assembly line, and its methodology according to REFA is considered. Into this framework, additional a priori design principles and evaluation criteria are introduced, as a tool for proactive sustainable design; reducing later iterative efforts in optimization by application of purely retroactive methods. The result of this planning process should yield as sustainable as possible, in accordance with the SDG framework.

2 A Priori Concepts in Sustainable Manufacturing

In order to enhance the sustainability of an assembly line, the following research areas have been identified: ‘Sustainable Production’ and ‘Sustainable Manufacturing’. The following section will present the existing SDG-based approaches in these areas and then proceed to classify their relevance to the planning process.

Stark [4] defines the fields of action in sustainable manufacturing as ‘Manufacturing Technologies’, ‘Product Lifecycles’, ‘Value Creation Networks’ and ‘Global Manufacturing Impact’. ‘Manufacturing Technologies’ thereby directly addresses assembly lines [4]. Considering the planning process as a product development process, approaches from the ‘Product Life-cycle’ field of action are also relevant. The other two fields of action are of no further relevance and not considered further.

There are two remaining approaches to incorporating sustainability aspects into production: sustainability analysis and sustainability by synthesis. The analysis evaluates the sustainability of existing concepts a posteriori. The synthesis thus enables a priori thinking. In consideration of the objective of incorporating sustainability as early as possible in the planning process, the synthesis approaches based on SDGs are of interest and will be examined below.

Life Cycle Engineering (LCE) is a key approach in the field of sustainable product development. It encompasses a range of engineering methods that can be applied in relation to the Sustainable Development Goals (SDGs). In accordance with the principles of LCE, all engineering activities are required to be subject to the life cycle principle [5]. Consequently, cycles should be incorporated into the conceptualization phase of any developmental endeavour. In light of these concepts and the overarching goals of the SDGs, the EU is pursuing a transition towards a circular economy. This suggests a transition from a linear economic model, in which a linear flow of raw materials culminates directly in the disposal of products. It is imperative that the economic system, and consequently also production as part of this system, is transformed in such a manner that raw material cycles are established [6].

In the field of ‘Manufacturing Technologies’, the contribution potential of prevailing production processes and methodologies to the Sustainable Development Goals is, in certain instances, pointed out. For instance, the potential for resource savings in the utilization of additive manufacturing is accentuated, and the synergies between the

'Industry 5.0' concept and Sustainable Development Goal 9 are emphasized [7, 8]. In such cases, existing processes and concepts are only applicable to specific parts of the SDGs. However, methodologies are currently under development with the aim of integrating sustainability on a holistic basis. In the domain of factory planning, studies have been conducted to identify the interrelationships between factories and the SDGs [9]. Most notably, the 'Positivfabrik' is a comprehensive concept that was developed on the basis of all SDGs [10]. The study derives properties from the SDGs that characterize a sustainable factory. Consequently, the 'Positivfabrik' is a zero-emission facility, but only in respect to the building itself, its surrounding infrastructure and the organization - no immediately influential factors on the planning of production and assembly systems are considered [10].

A comprehensive review of the literature reveals a lack of adequate approaches. The prevailing focus of LCE-based concepts, such as the circular economy, on resource consumption is inadequate for achieving a balanced cooperation of social, economic and ecological factors [9]. The inadequacy of a priori concepts in manufacturing for addressing the entire SDGs is also evident in other areas. Moreover, there is an absence of assembly line specific concepts and no integration into a planning methodology. Nevertheless, the implementation of design principles would facilitate the process of sustainable transformation.

3 Sustainable Design Principles

In accordance with the condition that the SDGs be evaluated in a holistic manner, a set of criteria was formulated for an assembly line in a preceding work [11]. By focusing on key goals and analysing the relationships between influenceable attributes of an abstract assembly line and SDG-derived influence factors, a set of sustainability criteria was developed. These criteria cover the areas 'economic efficiency', 'Resources', 'Workplaces' and 'Providing sustainability relevant data'. They can be used in two ways: First, they can be used as a starting point for sustainability analysis. Second, they can be used for sustainable development through synthesis [11]. In this present work, the previously developed criteria are to be incorporated into a general planning process to be able to integrate sustainability a priori.

3.1 A Planning Process According to REFA

The planning methodology according to REFA divides the process into six stages: analysing the initial situation, detailing the planning task, high-level planning of the production system, detailed planning of the production system, implementing the system and operating the system [12]. In the first stage, the initial situation is analysed. The second step involves the application of analysis to the development of objectives and criteria, which are subsequently categorized and weighted. In stage three, the system is roughly designed and the first basic solution concepts are developed. From these variants, the favoured one is selected and detailed in stage four. Stage four, with detailed planning, specifies the individual subsystems from a technical and ergonomic point of view so that key figures such as personnel requirements can be derived. A schedule for

introducing the system is also drawn up. Stage five, system implementation, includes procurement, installation, and other measures such as employee training to realize the planned system. Stage six, system operation, comes at the end of the planning process [12]. This process is illustrated schematically in Fig. 1.

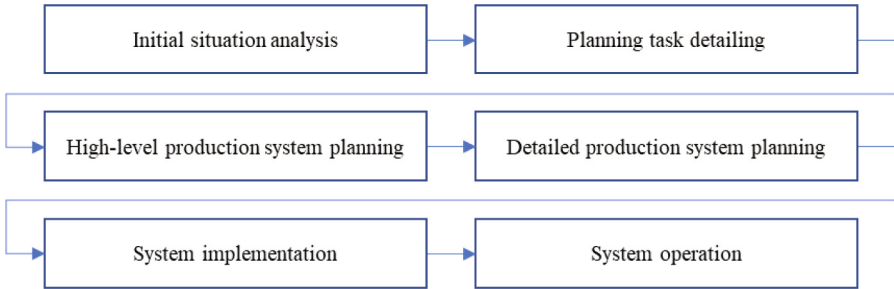


Fig. 1. Schematic planning process according to REFA [12]

In the context of the objective to develop the end product ‘assembly line’ sustainably, the question arises as to which part of the assembly line is influenced in which of the steps. In the initial stage, the existing situation is analysed without the formulation of decisions pertaining to the assembly line, thereby precluding the possibility of influencing sustainability. Conversely, in stage 2, the line is influenced by the objectives of the project that have been defined. At this point, the criteria that have been developed previously can be utilized. However, the actual design of the assembly line is undertaken in stages 3 and 4. The integration of sustainability considerations is imperative in this context, and as such, design principles are developed for these phases. It is evident that no substantial alterations can or should be made to the line following Phase 4. Consequently, these phases are deemed unimportant in terms of the sustainability of the end product.

3.2 Design Principles for High-Level Planning

In the REFA planning scheme, the high-level planning phase involves the generation and analysis of concepts through the integration of potential designs. This encompasses the identification of work processes, the preliminary design of the work system with respect to performance indicators, the estimation of stresses and hazards, the evaluation of working conditions, and the clarification of capacity requirements.

The configuration of work processes and the work system can be tailored during the phase of assembly planning, thereby exerting a degree of influence on the processes, the process chaining, and the requisite machinery and work equipment. However, the technical detailing is only incorporated into the detailed planning of the assembly system. At this time, the primary focus is on addressing the higher-level criteria. Moreover, it is only possible to make a recommendation for the majority of criteria if one is in possession of precise information regarding the work task and the product. Consequently, this section will solely address the design principles for a selection of the previous identified sustainability criteria and their subject areas. The issue of economic efficiency is already the

focus of extant planning methodologies and is therefore included, but not further detailed. The provision of sustainability relevant information can only be addressed in the technical detailing stage. The emphasis is placed on a selection of processes and machine principles that conserve resources, in addition to the sustainable conceptualization of workplaces. The relevant criteria from the subject areas are checked for addressability, supplemented with background information from concepts like circular economy and converted into recommendations for action. Finally, the derived recommendations are summarized and aggregated. This results in the following list of principals for an assembly line for the high-level planning phase (Table 1):

Table 1. Design principles for high-level planning

Subject area	Criteria
Economic efficiency	1. Consideration of the existing design principles
Resources	2. Low raw material quantity of the work systems
	3. Process selection according to
	3.1 Minimized raw material consumption
	3.2 Minimum energy requirement
	3.3 Minimum amount of waste
	3.4 Minimal waste heat
	3.5 Reversibility
	4. Select machine concepts according to,
4.1 Minimized raw material consumption	
4.2 Minimum energy requirement	
4.3 Minimum amount of waste	
4.4 Minimal waste heat	
Workplaces	5. Appropriate proportion of manual labour
	6. Automation preferably from
	6.1 Monotonous processes
	6.2 Complex tasks
	6.3 Physically demanding tasks
	7. Process and machine concept selection according to minimum hazard potential

3.3 Design Principles for Detailed Planning

In accordance with the REFA planning scheme, the favoured solution variant is detailed after the high-level planning. This includes the final definition of the work tasks, the specification of the work systems and the layout, as well as the design of the working environment in terms of lighting, air conditioning and noise protection. At this point, the selected processes and process chains are finalized, and the basic concepts of the work systems have also been selected.

Table 2. Design principles for detailed planning

Subject area	Criteria
Economic efficiency	1. Consideration of the existing design principles
	2. Precise dimensioning of the equipment
	3. Check for use of second-hand equipment
	4. Examination of the rationalization potential of facilities
	5. Minimizing the amount of
	5.1 Operating resources
	5.2 Auxiliaries means
	5.3 Waste
	5.4 Hazardous substances
Resources	6. Select substances according to their environmental impact
	7. Provide recuperation of energy and water
	8. Use of electric actuators
	9. Energy-efficient lighting design through
	9.1 Energy-efficient technology
	9.2 Minimum lighting equipment
	9.3 Adaptive lighting as required
	10. Consider greenhouse gas emissions
	10.1 in operation
	10.2 of the production of the equipment
	11. Provide assistance systems
	12. Ergonomic design according to current recommendations
Workplaces	13. Increase accessibility through
	13.1 Increasing physical accessibility
	13.2 Easy language and sign language
	14. Minimization of hazards through constructive means
	15. Select data to be recorded, at least
	15.1 Energy demand
	15.2 Resource consumption
Providing sustainability relevant data	15.3 Emissions
	16. Provide suitable sensors and observe the digital data infrastructure
	17. Provide information system with production-related sustainability data

High-level planning can influence some criteria such as the consumption of raw materials. However, the detailed planning enables a considerable influence on the final key figures through the technical design of the work systems. By deciding on the work systems, criteria such as energy requirements or raw material consumption can be influenced once again. It is also possible to address criteria relating to the provision of sustainability information or accessibility of workplaces during detailed planning. Influences on economic efficiency are not considered in more detail here, as current planning

projects are already based on financial considerations at this stage. Similar to the design principles for high-level planning, the criteria from the previous work are also taken as a basis here. They are again checked for addressability, enriched with background information and converted into recommendations for action, which in turn are summarized and aggregated to result in the following list of design principles (Table 2):

4 Discussion of Results

The design principles for the planning process that have been presented are based on the SDGs, and thus on a framework that has been recognized on a global scale. The integration of the SDGs into engineering tasks is supported, with these tasks being directly addressed in the target definition of the SDGs. Nevertheless, it should be emphasized that relatively generic guidelines have been drawn up due to the very generic initial situation and the consideration of an abstract assembly system. Depending on the application, additional factors must be taken into account and included accordingly in the sustainability considerations. In addition, a validation would have to be carried out in order to be able to assess the extent to which a more sustainable planning result emerges from the planning process.

5 Conclusion

The present study aims to address the discrepancy between the theoretical objectives of sustainability and their practical implementation within manufacturing systems. The developed principles represent a preliminary endeavour to empower companies to make informed decisions that balance economic requirements with environmental resource conservation and social workplace considerations. As an a priori approach, it is possible to consider the necessary sustainability aspects from the outset. However, planning the assembly line without taking into account other circumstances such as company policy is only a small part of the necessary transformation. In order to achieve the required sustainable production environment in the future, a broader scope of consideration is required in further engineering activities.

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