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Efficient Intralogistics Planning Based On An Innovative Intralogistics Tool Using The Example Of A Flexible Battery Cell Factory

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Abstract

In the course of increasingly volatile markets, globalization as well as shorter product life cycles, factories and thus also the logistics system as a central component of a factory have to be designed in a more flexible way. Battery cell production faces a special challenge in this aspect. Due to the trend towards a sustainable and environmentally friendly energy supply and mobility, the demand is expected to increase significantly. New battery cell factories have to manage rising product volumes and simultaneously react versatile regarding new research findings. Thus, the market for battery cells, the product itself, and the corresponding manufacturing processes are constantly changing. New materials, manufacturing methods, variations of cell formats as well as the possibility of scalability and the associated changes in the requirements for the factory must be taken into account as early as possible in the planning stage. The logistics system as one of the core elements of a factory is always affected by changes in the product, manufacturing processes or input materials. If, for instance, other materials are used, the storage and transport of these goods with different dimensions, weight or even environmental requirements must still be guaranteed.

In order to consider the required flexibility already in the planning process, simulation can provide a decisive benefit. It enables the planner to analyse the production and iteratively adapt logistics planning. Since there are many possibilities and combinations, especially in the design of warehouse and transport systems, a reduction of these should take place at an early stage. However, the preselection of suitable logistics systems that provide the necessary flexibility is currently often based on empirical knowledge and extensive market research. Therefore, this paper presents an efficient, holistic approach to logistics planning and an intralogistics tool in detail, which is based on established data. As a result, an optimal logistics system can be defined through an iterative optimization of the flexibility corridor, taking into account the factory goals.

Keywords

Intralogistics; Flexibility; Battery Cell Factories; Simulation; Factory Planning

1. Introduction

In the course of the energy transition, all industries face new challenges in order to achieve the Paris climate targets. The automotive industry plays a major role to reach the targets. About 22% of the GhG emissions come from the mobility sector [1]. Electromobility is not just a trend anymore. The transformation from combustion engines to electric cars is forcing car manufacturers to act quickly. According to the IEA's Global EV Outlook 2021, there were around 10 million electric cars worldwide at the end of 2020, representing a

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growth rate of 41% in 2020 [2]. Under current conditions and assumptions, there will be approximately 145 million electric vehicles (excluding two/three-wheelers) on the roads worldwide by 2030, requiring a battery cell capacity of 1.6 TWh [2]. However, in order to be able to meet the climate targets despite changed framework conditions, around 230 million vehicles will have to be on the roads in 2030, resulting in a demand for battery cell capacity of 3.2 TWh. For comparison, the potential production capacity for battery cells worldwide in 2020 was 300 GWh [2].

Thus, the need for new battery cell factories will increase. Today, battery cells are already used in electric cars, but their development is not yet well advanced and variants that are more efficient are constantly being presented. Lots of research is being conducted into new, alternative materials, variations of cell formats as well as innovative manufacturing processes [3,4]. In addition, the demand for the available product variants is also changing. New battery cell factories must face these challenges.

One possibility is to design the factory highly flexible in terms of production volume, materials, product varaints and manufacturing processes. This flexibility should already be taken into account in the factory-planning phase [5]. In addition to the production system, the intralogistics system must be designed flexible. For example, the means of transport must be able to cover the transport capacity even if the production volume increases and must be suitable for transporting alternative materials [6,7].

Since the logistics system as part of the entire factory is very complex, planning requires methods and tools to manage this complexity. To support the intralogistics planning, simulations can be built up, which help to better understand the complexity of the logistics system and thus optimize and validate the planning [8]. The present work introduces a concept, how the required flexibility can be considered in simulation-based intralogistics planning, whereby simulation-relevant parameters are transferred over a developed tool into the simulation. The self-developed tool named Intratel is to be used to make a preliminary decision for possible storage and transport systems according to the required flexibility in battery cell production, so that the simulation is only build up with systems that provides the required flexibility and faster recommendations for action are possible.

Therefore, in chapter two the term flexibility in connection with factory planning is presented. Additionally, intralogistics or intralogistics planning while using a simulation in the context of factory planning is defined. Chapter 3 explains the concept with its individual components. Finally, in chapter 4, a short summary and conclusion is given.

2. Fundamentals

2.1 Flexibility as a target variable in the factory

Flexibility can be considered as a property of a system. It gives the system the ability to react to uncertainties and dynamics on the basis of specified action spaces, according to defined options for action. If a system is flexible, it can react and adapt to known but varying requirements [9–12]. In this context, a flexibility corridor defines the action space in which a system can adapt to changes in the environment for all possible future scenarios [10].

In the present work, flexibility shall exclusively refer to the meaning within a factory. One way to classify flexibility in the context of a factory is to divide it into three levels of consideration. According to Sethi and Sethi [13], component flexibilities, system flexibilities and aggregated flexibilities are differentiated. Subsequently, eleven types of flexibility are assigned to these levels. Relevant types for the present work are, product mix flexibility, which means the simplicity of introducing new products, program flexibility which describes stability of the system to produce different variants, quantity flexibility, which describes the ability to remain economical at different utilization levels and material flow flexibility, which describes the ability to produce different work pieces efficiently on any paths through the system [13]. The concrete effects that these types of flexibility can have in the context of battery cell production are presented in chapter 3.1.

Since much of the planning process depends on the defined flexibility or flexibility corridors, these should be integrated in an early phase of factory or logistics planning. Factory planning is based on different goals for the factory, which are derived from the company's strategy and general conditions. These goals are already worked out and defined at the beginning of a factory planning project. According to the guideline VDI 5200, flexibility is also mentioned here as a possible factory goal [14]. A company must be competitive and generate profit. For logistics, this results in performance, cost and quality targets. Examples of performance targets are the correct execution of orders or meeting the delivery times. Quality targets, on the other hand, are, for instance, the ability to deliver or the flexibility of the willingness to perform in the event of changes in requirements. For cost targets, the avoidance/reduction of inventories, the optimal use of infrastructure, the maximum utilization of load carriers or an efficient use of resources can be mentioned [15,16].

Flexibility as a factory goal is also important, but may conflict with the other goals. For example, high program flexibility adversely affects quality targets. In addition, ensuring a defined level of flexibility usually leads to higher production costs. It is important to include all target dimensions, flexibility as well as performance, costs and quality, in planning process. In order to be able to achieve an optimal planning result, the goals must also be prioritized depending on the application [17]. Furthermore, it is essential to define a suitable flexibility corridor for each type of flexibility, which is in line with the other factory targets according to the prioritization.

2.2 Intralogistics and Intralogistics planning

The intralogistics system can be divided into individual subsystems such as machine, warehouse, picking, supply, buffer, handling and transport system [15]. In the present work, the focus is on the planning of a flexible transport and warehouse system for battery cell production. If logistics planning is considered as a subarea of factory planning, it must be integrated into the factory planning process. Figure 1 shows the seven phases of factory planning according to the VDI guideline 5200.

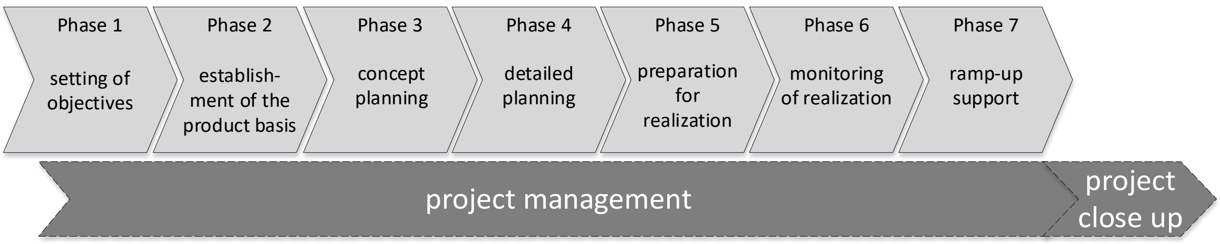

Figure 1: Factory planning phases according to the VDI guideline 5200

Logistics planning can be included in the conceptual and detailed planning phases, whereby prerequisites and boundary conditions for the subsequent planning phases are already defined in Phase 1 and Phase 2. According to the VDI guideline 5200, the concept phase (Phase 3) already results in a determination of the type and quantity of operating equipment and personnel resources, a dimensioning of logistics equipment, and the development of a material flow concept. In the subsequent detailed planning (Phase 4), the logistics concept is supplemented by process descriptions, whereby an assignment of products and resources to the respective processes becomes necessary [14].

The complex connection between factory planning (1) according to the VDI 5200 guideline and the logistics planning process (2) is detailed in Figure 2.

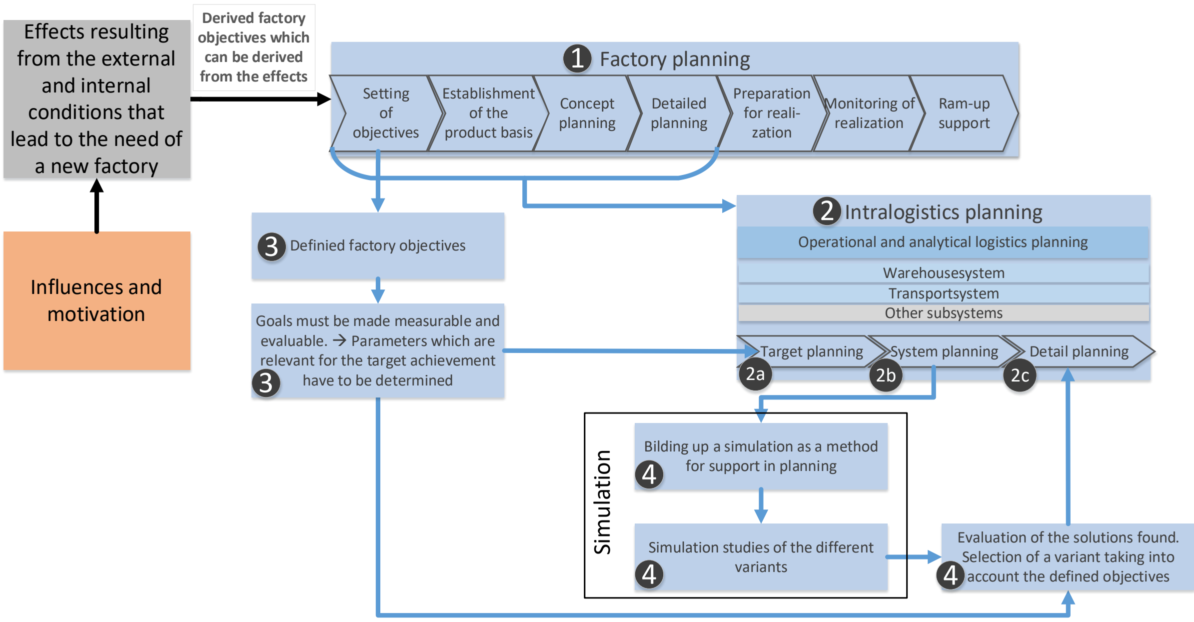

Figure 2: Factory and Intralogistics planning

The intralogistics planning can be divided into the phases target planning (2a), system planning (2b), and detailed planning (2c). Based on defined factory objectives (3), which were defined in the first phase of the factory planning process and need to made measurable and evaluable, all boundary conditions, the most important planning assumptions as well as performance requirements for the following phases are documented and, if necessary, analyzed in the target planning (2a). Thus target planning has a strong interaction with Phase 1 and Phase 2 of the overall factory planning process (1). In the next phase, the system planning phase (2b), possible solutions are developed, which also corresponds to the conceptual phase in the factory planning. In this context, suitable resources must be selected from a large number of possibilities. These are linked as performance points to logistics chains, organized and dimensioned so that specified performance targets can be met with specified restrictions as cost-optimally as possible. For the selection of a solution variant, methods such as a feasibility study or a performance comparison can be carried out. The feasibility study focuses on the technical feasibility, the fulfillment of the performance requirements, the compliance with the general conditions, restrictions and requirements and the feasibility within specified time. The performance comparison involves a crosscheck of marginal performance, capacity reserves, and flexibility of the selected solutions. In the case of flexibility, for example, it is considered whether the system is still suitable in the event of a change in the order structure or a change in logistics units or throughput and inventory fluctuations. In the profitability comparison, solutions are to be compared with each other with regard to their operating costs at maximum performance. Finally a utility value analysis is carried out, in which all remaining solutions are further compared with each other on the basis of defined criteria. In the subsequent detailed planning phase (2c), the selected solution is elaborated and getting prepared for approval. For this purpose, further specialist planners are consulted [15].

In system planning (2b) in particular, an optimum for the logistics system must be found on the basis of the different technical requirements and boundary conditions as well as the various factory targets. In principle, for this purpose many different methods and tools are available. However, analytical methods quickly reach their limits in a complex and dynamic system like a factory. In order to cope with the dynamic environment within the intralogistics planning, a simulation (4) can offer a considerable benefit. Often the interaction of boundary conditions and goals as well as dynamic behavior during future operation can be better understood if this is represented in a simulation model and different simulation scenarios can be executed. Multiple stochastic and dynamic interactions make it difficult to predict how a system will behave. Possible bottlenecks or potentials can be identified more quickly by means of a simulation and the logistics system can be planned and iteratively optimized accordingly [16]. The use of a simulation as a planning method and the current status of how intralogistics planning as part of the factory planning is done nowadays is shown in Figure 2. After the simulation is set up in the system planning phase (2b) and different variants are simulated (4), results must be evaluated. For this purpose, those parameters must be determined which are relevant for the achievement of the factory goals (3). After the evaluation, the selected variant enters the detailed planning (2c). However, the flexibility of the logistics system depicted in the simulation is already determined by the previous selection of technologies. An adjustment or optimization of the flexibility corridor, taking into account other factory goals, is therefore always associated with the manual search for suitable logistics technologies for the corresponding flexibility corridor before the simulation is set up. This complex process currently prevents the efficient mapping of different simulation scenarios with different flexibility coordinates and makes it difficult to achieve an optimum between all factory goals.

Simulation-based logistics planning is already known in the literature [18–20]. In the present work, a simulation is used as well. However, this simulation is coupled with a self-developed intralogistics TOOL (Intratel). The use of this tool makes it possible to select storage and transport systems early in the planning process that are suitable for the application and offer the necessary flexibility. Such a concept was not found in the literature so far to the best knowledge of the authors.

3. Efficient Intralogistics Planning For Flexible Battery Cell Factories Based On An Innovative Intralogistics Tool

This paper presents a concept to make the planning of a flexible logistics system more efficient. The construction of a battery cell factory is taken as a use case, since the requirement for flexibility is very important in future as described in section 1. Based on the conventional approach in logistics planning, the objectives for the logistics system in a flexible battery cell factory are derived (cf. Figure 3).

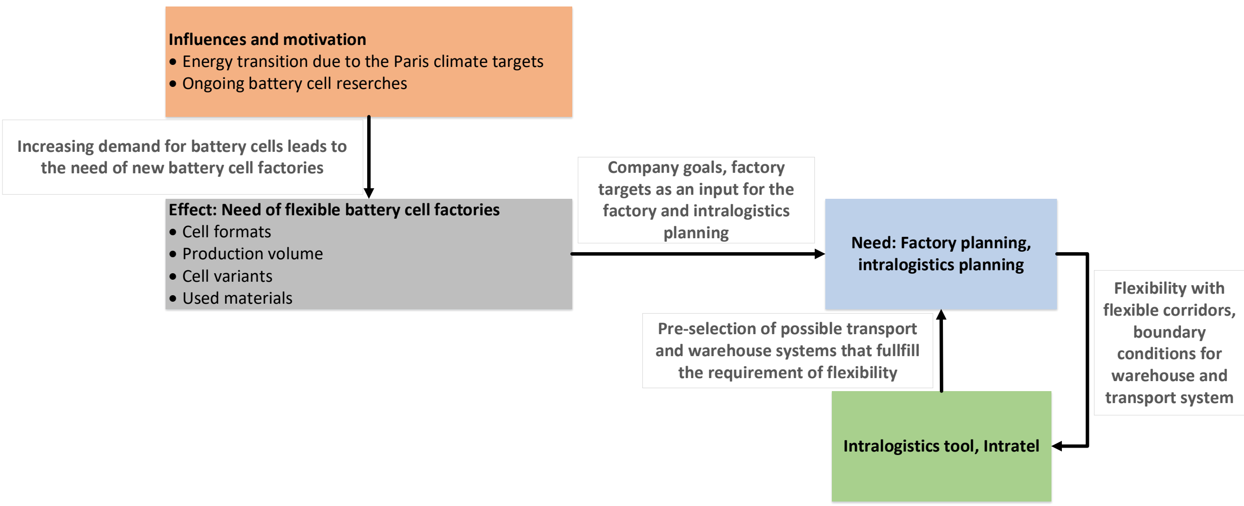

Figure 3: Concept for the intralogistics planning combined with the developed tool Intratel

In order to integrate the derived requirements in the intralogistics planning and to ensure an efficient planning process, the simulation model for the battery cell production is linked to a developed intralogistics tool, named Intratel. The goal is to get a pre-selection of possible storage and transport systems that meet the goal of flexibility by using the intralogistics tool in a first step.

This automatically leads to the fact that only systems are simulated, which can fulfill the goal of flexibility and can replace most of the components of a feasibility analysis as an evaluation method, while ensuring a holistic optimization of the logistic system. In the following, the overall concept with its individual components is presented. It includes the connection between the external influences (orange box), the flexibility requirements for a finished battery cell factory (grey box), the connected factory and intralogistics planning (blue box) and the developed intralogistics tool (green box).

3.1 Flexibility targets and relevant requirements

In addition to the typical factory goals, such as quality, performance and costs, battery cell factories must have a high degree of flexibility in the future (cf. chapter 1). The need for flexibility has various implications in the context of the logistics system of a battery cell production. In particular, the logistics systems must be able to cover the product mix flexibility, material flow flexibility, quantity flexibility and program flexibility.

Product mix flexibility

The introduction of new products should be considered in advance. In the case of a battery cell factory, this can be either a completely new cell format, such as round, pouch or prismatic cells or even solid state battery cells. Here, for example, the dimensions and weights of the finished products differ greatly. Also the input materials differ in some points. For round cells, for example, cans and lids are required, which have to be washed before they enter the clean and dry room of production. In the case of pouch cells, on the other hand, the case may first be deep-drawn during production and is supplied as a foil before. For each new product to be produced, it is necessary to estimate in which form and in which containers the input materials can arrive, so that suitable systems can be planned for both transport and storage. Another example for the extension of the product range could be electrode coils for which the storage and transport system would have to be designed, if they are part of the flexibility corridor.

Program flexibility

Alternative materials may be required for new variants, which may be supplied in other containers or on other loading equipment. An example of this is the solvent used in slurry production (first process step in battery cell production). Currently, NMP is often used for the cathode. This solvent is considered a hazardous material and is subject to special requirements for storage, handling and use. Alternative solvents are already being discussed. Storage and transport options should also be considered. If the factory also produces semi-finished products in the form of electrode coils, different variants can be produced here in terms of dimensions and weights. The storage and transport system used must be capable for these variants.

Quantity flexibility

If the factory is to be flexible in terms of quantity, the output quantity should be variable within the defined flexibility corridor. For example, the factory may be required to be able to produce between 1 GWh and 3 GWh per year. On the one hand, this requires more materials, which have to be stored, and on the other hand, the throughput has to be increased. Both have an impact on the transport system as well as the storage system. If material is stored or transported in larger quantities, for example, the use of tanks and silos for storage and transport via pipelines may be worthwhile. Alternatively, for smaller quantities, pallet storage can be used. The electrolyte and the active material can be mentioned here as example materials.

Material flow flexibility

In the context of battery cell production, the process steps slitting, calendering and vacuum drying can be interchanged within electrode production. Vacuum drying can also be an intermediate step in the assembly process. It may therefore be necessary to return the products to the vacuum dryers. Another requirement may be that, despite a separation into anode production line and cathode production line, both electrodes should be able to be produced on both lines. If required, the transport system used should be able to fulfill this flexibility within the material flow.

3.2 Intralogistics tool Intratel

The idea of the developed tool is to filter out from the multitude of warehouse and transport systems those that are suitable for the define flexibility corridor at hand before the simulation. Figure 4 shows the usage of the developed tool Intratel. To use the tool boundary conditions in particular to materials, semi-finished products, products and the production program must already exist.

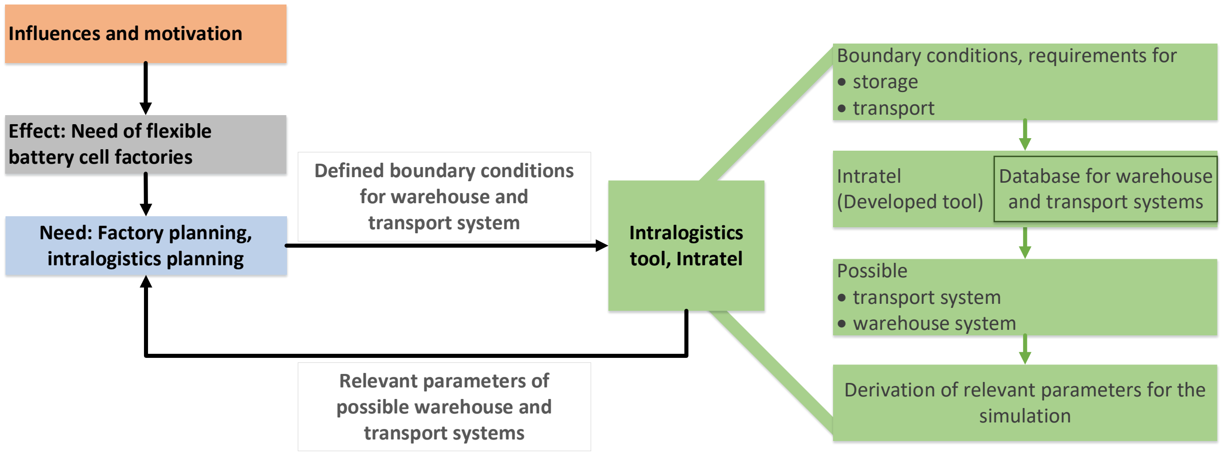

Figure 4: Intralocistics tool Intratel

The tool itself consists of a database, which has integrated all transport and warehouse systems with their properties and a user-friendly dashboard. Currently, the tool considers the selection of storage and transport systems separately. In the developed database, all fundamentally different transport and storage systems were summarized and classified. Also an initial division was made into continuous conveyors and discontinuous conveyors. In the next step, subcategories were formed within these categories, like belt conveyors or trackless floor conveyors. The final transport systems are then divided into these subcategories, such as apron conveyors, narrow aisle stackers or trackless AGVs. In the database for the warehouse systems are for example block storage, row storage, high rack storage for pallets, cantilever storage or carousels as options for warehouses. Furthermore, those characteristics were compiled, which can be relevant for the later selection. The properties were divided into two categories. These are especially important for the application. Mandatory attributes must be specified in order for the tool to make suggestions. An example of a mandatory attribute is the specification of whether bulk goods, general cargo or liquids are transported. Optional attributes can still be entered if they are already known in order to further reduce the number of possible systems. Currently, the tool works with 7 mandatory attributes and 16 optional attributes. The optional attributes include, for example, whether the quantity flexibility must be high. If there are too many requirements, some of them may be in competition with each other, which can lead to the fact that no suitable system is found.

The user himself sees only a dashboard on which he is guided through the attributes. For each attribute there are already predefined selection options. At the end, the user is shown those systems that are compatible with the requirements. Finally the parameters that affect the further factory targets, have to be integrated into the simulation model. In this application, the focus is on the corresponding parameters regarding capacities, personnel requirements, and the speeds of the individual systems.

3.3 Intralogistics planning based on a simulation and the tool Intratel

The developed concept shown in this paper uses a simulation as a method during the system planning phase for the intralogistics planning. The use of a simulation is not a mandatory method for planning. However, as shown in chapter 2.2, the dynamic and complex environment as well as the multitude of stochastic and dynamic interactions can be depicted more truthfully by a simulation and better statements can be made or the planning can be optimized. In the simulation model, the pre-selected warehouse and transport systems are now simulated and evaluated. If it was not possible to find systems that match on one hand with the required flexibility and on the other hand with all the other factory targets it could be that the flexible corridors have to be adapted and the pre-selection has to be done again. Afterwards one system for the warehouse and one for the transport system should be selected. This systems are then the input for the detailed planning phase of the intralogistics planning.

The simulation model was built with the software Tecnomatix Plant Simulation from Siemens. Modeling was done in 2D as well as in 3D. First, a network structure was developed for easier adaptability. Areas to be logically separated from each other were set up in individual networks. In cooperation with the manufacturing and production planning team, the networks for production were created. In addition to the production systems, all logistics areas such as provisioning, buffers, waste areas and workstations were integrated and properties such as capacity were assigned to these components on the basis of static calculations. An input table has been created so that all parameters can be changed and adapted for later simulation runs. This makes it easier to carry out planning and simulation scenarios. The planner can use this Excel table, which is linked to the simulation, to change the values before each run without having to go into the individual building blocks of the model. When starting the simulation, the current values of the table are applied. In addition, a warehouse concept including incoming and outgoing goods was developed in parallel, which was then mapped in a network. Delivery processes were integrated into methods and different delivery scenarios can be analyzed. No particular storage system has yet been selected. The first dimensioning regarding capacity was worked out on the basis of the production program and sales planning. Other important networks in the battery cell use case are locks, since these should not become a bottleneck in later production. Figure 5 shows a section of the simulation. In this model, production scenarios can already be run through and the effects on the utilization of the logistics elements used can be analyzed.

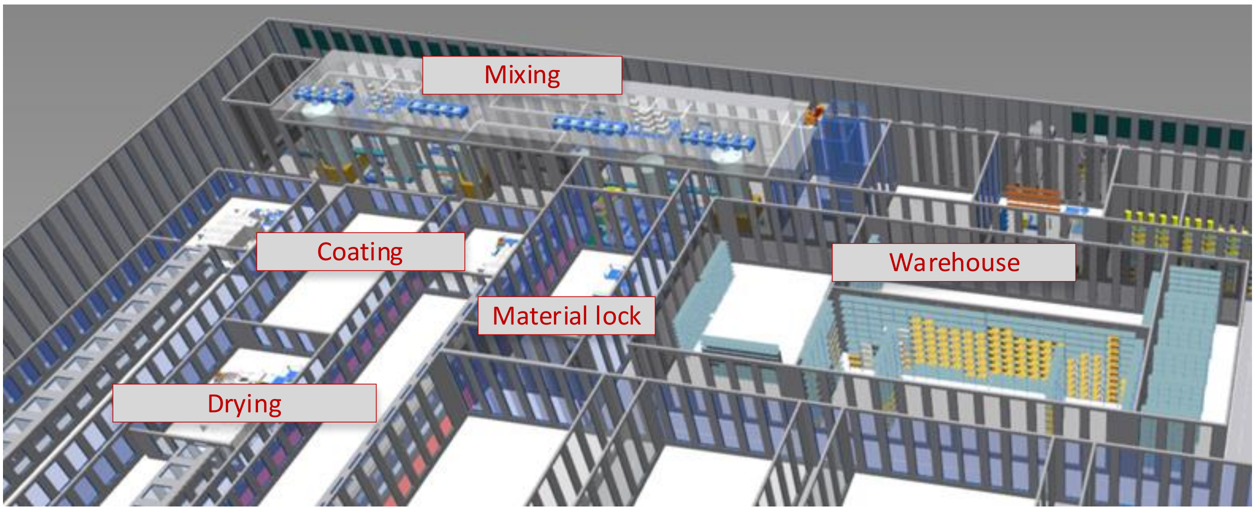

Figure 5: Section of the battery cell factory material flow simulation

In the present use case, flexibility was required in the context of product variants as well as a change of production volume. By using the tool Intratel, a pre-selection of possible transport and storage systems that can meet the flexibility requirements was made. As soon as the tool identifies suitable systems for the given application, those parameters are also determined which have an influence on the achievement of the factory goals. In the case of transport systems, for instance, the speed of the system. These parameters are in turn given as input to the simulation model.

4. Summary and conclusion

Intralogistics planning as part of factory planning requires structured and targeted implementation in every application. In the construction of a battery cell factory, planning is subject to many boundary conditions. New findings on production technologies, product variants and new materials are constantly generated and at the same time, factories must be scalable. The production and logistics system must be adaptable. Flexibility as a factory goal must therefore be integrated into the planning process. In order to support the planning process methodically and to be able to map the complexity, a simulation can be built up as in the developed concept. Within simulation studies it should be analyzed how far the factory goals can be reached with the plans. The developed tool Intratel can be used in advanced to get a pre-selection of possible warehouse and transport systems that can meet the flexibility requirements. Using the tool narrows down the warehouse and transport systems at an early stage of the planning. Here, the number of possible systems are suggested to the user on the basis of various input parameters as well as the flexible requirements.

In the next step, the concept shown must be verified in a concrete use case. The concrete application and subsequent evaluation should follow the developed concept. For this purpose, the interfaces between the simulation model, the tool and the corresponding evaluations must be worked out and implemented. In addition, the Intratel tool is to be further expanded to include additional subsystems for logistics planning.

5. Acknowledgements

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Biography

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