Simulation-based planning of a logistics concept for modular production in the chemical industry

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Abstract. The increasing demand for fast and individual engineered chemical products is changing the production type from centralized large-scale production plants to the modularization of process plants. For this purpose, new logistics concepts have to be developed, which face the new logistical requirements due to the production changeover. In this research paper, a simulation model is presented. It reveals possible weaknesses of current used concepts by the integration of new plants into existing infrastructure and it also provides conclusions for new logistics concepts. Therefore, the structure of the simulation model is shown and it´s application possibilities are illustrated.

1 Introduction and motivation

The chemical industry is facing a growing demand for more flexible production due to increasing product differentiation, shorter product life cycles, and increasing market volatility. Therefore, new concepts for the modularization and transformation of production are the subject of current research. However, new logistics concepts are required when the production type changes from centralized large-scale production plants to networks of decentralized units. This includes the concern of the choice of the right location inside of the chemical parks or the design of the processes for the supply and disposal of the production units. There has not yet been any research on these uncertainties. Based on that logistical problem, this research paper presents a new approach to meet these challenges through a developed simulation model, which will help answer the questions concerning the logistical structure.

2 Literature review

Regarding the research topic, this chapter first introduces the general layout of a process plant followed by the representation of the used investigation method.

2.1 Modular Plants in the chemical industry

A physical modularization of process plants represents an approach to enable a continuous and decentralized production process. These are particularly suitable for multi-product and multi-purpose plants, where a reconfiguration between the individual production processes is common. According to the VDI directive for modular plants, a plant is composed of at least one PEA (Process Equipment Assembly), which again is composed of at least one FEA (Functional Equipment Assembly), and the corresponding parts [1]. The PEA executes an entire production step like distillation, whereas an FEA performs process engineering functions, such as stirring or heating. Accordingly, the FEA is composed of many different individual parts such as a pump or the sensor technology [1]. The combination of various PEA results in the modular plant, which allows adaptation to the different needs and the quick and efficient changing market requirements. Additionally, the time-consuming and complex process of planning new production plants is substantially shorted by this approach [2]. Another benefit of this technology is that as soon as the connection and coordination of multiple PEAs into a modular plant is standardized, they enable a smooth integration of these resulting in the plant to being ready to operate after setting the production parameters [2-3]. Furthermore, there is the opportunity to scale up the production outcome by numbering-up the modular plants [4]. In research, there are already different versions of plants like the F³-Factory (Flexible, Fast and Future), the EcoTrainer, or the Smart Factory [5-7].

Figure 1. F³ Factory [5]

However, these prototypes differ in their conceptual structure. While the idea of the F³-Factory and the EcoTrainer is the structured arrangement of units within a container (20'- or 40'-container (Figure 1)), the Smart Factory (Figure 2) doesn´t limit the layout of the different modules. Rather, this approach is intended to increase the diversity of the production process. Although, a plant-based on this approach can´t simply be set up on a field near a wind turbine, as in the case with the container-based design of a modular plant [5-7].

Figure 2. Smart Factory [7]

2.2 Simulation-based planning

Based on these possibilities, it is very important to research the logistical challenges of modular production. One aid to do this is the simulation of logistic activities. The simulation results enable knowledge for the future, which helps avoid costly planning mistakes and gain experiences around the material flow in the modular production. Furthermore, the degree of implementation of such modular plants is in the early stage, which results in a lack of experience in material handling. This missing expertise can be obtained with the help of simulation. Besides, the created model can be used as a prototypical application. Due to the mentioned reasons for using a simulation, the simulation tool, AnyLogic, is chosen. With the help of this software, it is possible to combine different simulation approaches for the various shown processes, like the continuous simulation for the fluid stock simulation or the agent-based approach for the modular simulation plant states. The model was verified and validated based on interviews and in workshops with experts from the chemical industry. For this purpose, simulation results were analyzed and the correctness of the simulation model is guaranteed. Figure 3 displays an exemplary analysis, where the production and the set-up times are shown over time. These determined results allow the examination of the correctness and of the length of the production processes and set-up times.

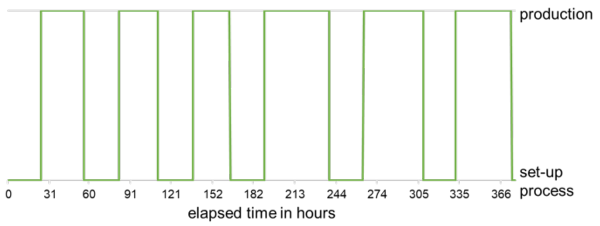

Figure 3. Schedule of the production and set-up processes

3 Simulation model

In the following chapter, the object of the consideration is shown followed by the representation of the objects of the model. Finally, the application possibilities of the simulation model are illustrated with the help of an exemplary evaluation.

3.1. Object of consideration

This simulation model is composed of a macroscopic and microscopic level. The macroscopic level contains a chemical park, in which a modular plant is placed. For this purpose, a satellite picture of an existing chemical park is used, in which the modular plant is located on a previously unused green field. Additionally, the paths, the storages for containers, and the logistics centre from the park are integrated into the model to guarantee the detailed replica of the provision of raw materials (Figure 4). At the microscopic level, the processes around the modular plant are examined more closely. As a result, the logistic activities around the modular plant are reproduced in detail, wherefore the logistical areas have depicted around the plant. These areas vary from the provision of raw materials for production to the short time storage areas for the different types of containers.

Figure 4. Screenshot of the graphical user interface

3.2 Structure of the model

In the following section, the displayed objects of the model and the fields of application of the simulation model are explained in more detail.

3.2.1 Objects of the model

This simulation model consists of eight different agents, which in turn represent components for the simulation of the production and the associated logistical processes. An exemplary named agent, "Good", represents the load carriers with the help of the population of this agent. It can represent either container with the material, with waste, with the final product, or just an empty container. Besides these, the other agents of the model are:

- Forklift,
- Truck,
- Intralogistics Order,
- Load zone,
- Modular Plant,
- Production Order,
- Good,
- Main.

3.2.2 Application of the simulation model

Different objects of consideration can be analyzed in the current stage of the development of the model. One of these contains the question if a modular plant can be integrated into the chemical park and into the already existing logistic conditions. Therefore, the model can be used to investigate whether the supply of the plant with raw materials and empty containers and the pick-up of the products, wastes, and empty containers are possible in addition to the already existing tasks of the service provider. Another object of investigation can be the determination of the time when a new container with raw material has to deliver to the modular plant. Furthermore, the simulation results can also deploy to conclude the required number of employees. Also, the model can investigate the efficient layout of a modular plant. For this, the individual areas around the plant are analyzed, whereby the distance covered by the agents of the transport units is recorded. In Figure 5 an exemplary evaluation of such an examination is illustrated. This shows two different scenarios, which differ in the spatial arrangement of the logistical areas. On closer examination, it can be seen that in the case of scenario 1 the distances covered by the transport units is less than in scenario 2. Due to this and even further objects of investigation, such as the time of the load and empty trips, the layout of the scenario 1 represents more efficient.

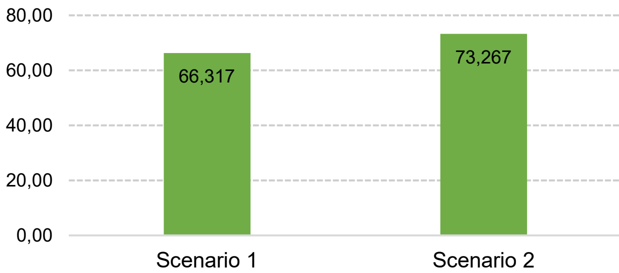

Figure 5. Traveled distance by transport units in km depending on the different scenarios

In addition to the possibilities described above, many other approaches can be investigated with the help of this simulation model.

4 Conclusion

Based on the previous investigation results, this model represents an approach to investigate the logistical tasks in connection with the continuous production on a modular plant. Initial test results have shown that such a simulation model can help to estimate the required effort for the integration of a new modular plant into an existing structure or whether it can be integrated into an existing environment at all. Moreover, it will help to investigate the conceptual structure of the different modular plants, which additionally provides informations about the required resources and thus an essential help for the process and resource planning. Lastly, during the verification and validation of the model, it has shown that the behavior of the illustrated system is reproduced with sufficient accuracy and it has reflected the processes to be displayed.

Acknowledgment

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References

1. VDI-Richtlinie 2776. Verfahrenstechnische Anlagen: Modulare Anlagen – Grundlagen und Planung modularer Anlagen, pp. 4-6, (2020)
2. Temporärer ProcessNet-Arbeitskreis "Modulare Anlagen": Modulare Anlagen: Flexible chemische Produktion durch Modularisierung und Standardisierung - Status quo und zukünftige Trends, DECHEMA e. V. (2017)
3. A. Klose, S. Merkelbach, A. Menschner, S. Hensel, S. Heinze, L. Bittorf et al.: Orchestration Requirements for Modular Process Plants in Chemical and Pharmaceutical Industries. In: *Chem. Eng. Technol. 42 (11),* pp. 2282–2291. (2019)
4. S. Kaczmarek, C. Mosblech, S. Lier, M. Hompel: Modularisierung und automatische Anordnungsplanung der Intralogistik für modulare Containeranlagen in der Prozessindustrie. In: *Chem. Ing. Tech., Weinheim:* Wiley-VCH Verlag, pp. 1246-1257 (2015)
5. Bayer Technology: Fast, flexible, modular production technology provides platform for future European growth. Available online at: *cordis.europa.eu/project/id/228867/reporting/de.* (Last Access: 30.10.2020)
6. Evonik Industries AG: Fertilizing with wind. Available online at: *ecotrainer.evonik.com/*. (Last Access: 30.10.2020)
7. Merck KGaA: Die Fabrik wird smart. Available online at: *merckgroup.com/de/the-future-transformation/smart_factory.html.* (Last Access: 30.10.2020)