Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 98 (2021) 464–469

www.elsevier.com/locate/procedia

28th CIRP Conference on Life Cycle Engineering

Coordinated Planning in Closed-loop Supply Chains and its Implications on the Production and Recycling of Lithium-ion Batteries

Christian Scheller[a,d*], Steffen Blömeke[b,d], Mathias Nippraschk[c], Kerstin Schmidt[a,d], Mark Mennenga[b,d], Thomas S. Spengler[a,d], Christoph Herrmann[b,d], Daniel Goldmann[c]

[a]Institute of Automotive Management and Industrial Production (AIP), Chair of Production and Logistics, Technische Universität Braunschweig, Germany
[b]Institute of Machine Tools and Production Technology (IWF), Chair of Sustainable Manufacturing and Life Cycle Engineering, Technische Universität Braunschweig, Germany
[c]Institute of Mineral and Waste Processing, Waste Disposal and Geomechanics (IFAD), Clausthal University of Technology, Germany
[d]Battery LabFactory Braunschweig (BLB), Technische Universität Braunschweig, Germany

* Corresponding author. Tel.: +49-531-391-2204; fax: +49-531-391-2203. *E-mail address:* christian.scheller@tu-braunschweig.de

Abstract

The need for sustainable mobility requires measures to reduce the impacts along the product life cycle. One mitigation option is the closed-loop use of products, components and materials, with resulting increased interactions and interdependencies between production and recycling. Research focusses generally on individual planning tasks and levels and does not consider production and recycling simultaneously. Therefore, we develop a coordinated planning approach for closed-loop supply chains which considers interdependencies in the form of directives, feedback, and coordination between the forward and reverse supply chain. Concluding, the approach is discussed in the context of lithium-ion batteries.

Keywords: production and recycling planning; circular economy; digitalization; lithium-ion batteries

1. Introduction and motivation

In order to achieve the objectives of the Paris Climate Agreement and limit global warming to 1.5 degrees Celsius compared to pre-industrial levels, CO_2-emissions must be reduced. The electrification of transport is a major lever for this reduction, as it can be operated CO_2-neutral. In 2019 electric vehicles (EVs) have already avoided 53 Mt carbon dioxide equivalents (CO_2-eq) compared to vehicles with internal combustion engines. According to the International Energy Agency, the use of EVs can avoid up to 440 Mt CO_2-eq in 2030 (assuming rapid decarbonization of power generation) [1]. Besides the positive aspects of EVs, the use of the lithium-ion batteries in EVs and, therefore, the increasing demand for battery raw materials is problematic. The International Energy Agency assumes a 36% annual increase in EV stock which leads to 245 million EVs in 2030. As a result, the raw materials required for traction batteries in 2030 will be among others 360 kt cobalt, 370 kt lithium, and 1850 kt class 1 nickel where the first two are considered as critical raw materials for the EU's raw materials supply [2]. However, the mining of these raw materials leads to significant social and environmental impacts. For example, the mining of cobalt in Congo is associated with child labor and the mining of lithium in Chile leads to increasing dryness, which makes access to water supply difficult for the inhabitants. In order to lift the maximum potential of electromobility, economic, environmental, and social impacts need to be reduced.

To reduce these impacts of EVs, a circular economy is necessary since it supports the reduction of the high impacts resulting from primary materials and offers the opportunity to reduce the impacts from landfill. In circular economies companies of the forward supply chain (e.g., original

10.1016/j.procir.2021.01.135

equipment manufacturer (OEM)) are linked to companies of the reverse supply chain (e.g., recycler) and to groups that can be assigned to political, social and ecological demands such as governments, non-governmental organization, or the environment. As part of the circular economy, a closed-loop supply chain integrates the actors of the forward and reverse supply chain. In such closed-loop supply chains interdependencies between the forward and reverse supply chain increase significantly since recyclers become suppliers for the manufacturers. Hence, these interdependencies need to be considered during the planning on all planning levels.

Additionally, the results of all three planning levels influence each other. According to the hierarchical planning, upstream planning tasks set the basis for the downstream tasks [3]. The downstream tasks identify problems and give feedback on the achieved goals. An isolated examination of the strategic, tactical, and operational planning without directives and feedback between the different planning levels leads to non-optimal decisions. Similar problems occur when coordination between the forward and reverse supply chain is missing since recyclers serve as supplier for the manufacturers and, therefore, have a direct influence on the quantity and quality of the supplies. If not taken into account, both cases lead to negative effects for the entire closed-loop supply chain. To achieve efficient cooperation, a coordinated planning approach across all planning levels and the entire supply chain is required.

Hence, this paper aims to discuss the individual planning tasks at the strategic, tactical, and operational level in closed-loop supply chains and to present a coordinated approach to fully take into account the inherent interdependencies in the planning of the forward and reverse supply chain.

Therefore, the remainder of this article is structured as follows: in chapter 2 we present the planning foundations of the forward and reverse supply chain under consideration of the strategic, tactical, and operational planning level. Furthermore, an overview of existing planning approaches is provided. Based on this, chapter 3 derives the requirements for a coordinated planning approach for closed-loop supply chains and consequently presents this approach. Afterwards, chapter 4 discusses this coordinated planning approach in the planning of closed-loop supply chains for lithium-ion batteries.

2. Existing planning approaches for the forward and reverse supply chain

In research, approaches for individual planning tasks exist, i.e., network planning or production planning and control, which focus on a single or few life cycle phases, planning levels or planning objects. The majority of existing planning approaches focus on the forward supply chain and little focus on the reverse supply chain or even cover a generic planning. Subsequent, existing planning approaches are analyzed and (sub)divided by their planning level.

Strategic planning

Strategic planning is the highest of the three planning levels which is responsible for the long-term system design and control and thus provides the basis for all decisions on the tactical and operational level. Typical strategic planning tasks such as the network design are summed up in Table 1 according to Egger and Winterheller [4]. Typically, strategic planning is divided into two parts: the analysis of the previous mission, values, vision and goals, and the analysis of the internal and external environment of the organization together with the planning how to reach the target.

Due to the long-term planning horizon, a main challenge is the uncertain information basis, which leads to high risk when deciding on a strategy. To counteract these imponderables, there are a variety of models and approaches that reduce the risk and uncertainty of strategic planning. The selection of planning approaches presented in Table 1 focuses on the cost and resource-efficient strategic production and network planning of the forward or reverse supply chain by different modelling approaches and decision support tools. For instance, Dér et al. [5] present an approach that integrates environmental impact targets in strategic production planning, however an implementation of the end-of-life sector and planning tasks on tactical and operational planning level, i.e. process characteristics and sequencing are missing.

Tactical planning

Tactical planning is intended to achieve the goals set at the strategic level with typical planning tasks summed up in Table 1. The upper and middle management of a company focuses on the mid-term horizon and defines e.g. production capacity, layout, technology and resource planning [3,6], which require different information.

The listed publications focus on methods and tools, i.e., mathematical optimization and simulation-based planning, to support individual tactical planning tasks. As an example Cerdas et al. [7] analyze the disassembly planning and automatization potential for lithium-ion batteries. Nevertheless, the consideration of the forward supply chain, as well as the strategical and operational level, are missing. Furthermore, the sourcing volume is not taken into account.

A second example is the approach of Hoyer et al. [8], who present an optimization model for the technology and capacity planning for lithium-ion battery recycling. The focus of the model is on the economic selection of recycling technologies and capacities to be deployed in the recycling network over time. Even if a consideration of the forward supply chain is taken into account ecological issues as well as the consideration of further operational planning tasks or capacity synchronization with the forward supply chain are missing.

The examples clarify that the listed approaches neglect the integration of strategic and operation planning and focus on either the forward or reverse supply chain, but not both.

Operational planning

The operational planning concentrates on the optimization of the value-added processes using the resources previously created on the tactical planning level [4]. Typical planning tasks such as the resource scheduling are listed in Table 1.

For the production planning and control, different methods exist that are often supported by modelling, simulation and

Table 1: Targets, objectives, and characteristics of strategic, tactical, and operational planning [4]

		Strategic level	Tactical level	Operational level
General Information	Characteristics	▪ Decision on corporate management level ▪ Long-term planning (> 5 years) ▪ Qualitative orientation ▪ High uncertainty and risk through lack of information ▪ High level of abstraction	▪ Decision on upper and middle management level ▪ Mid-term planning (3-5 years) ▪ Concretization of the content of strategic planning ▪ Stronger quantitative orientation ▪ Partial uncertainty and risk through lack of information ▪ Partial possible adaption	▪ Decision on middle and lower management level ▪ Short-term planning (< 1 year) ▪ Quantitative orientation ▪ Translating tactical planning into concrete implementation plans ▪ Minor possible adaptation
	Planning objective and tasks	▪ Defining objectives and policies ▪ Rough cut market forecast ▪ Network design ▪ Actor selection (i.e. supplier)	▪ Product targets, asset and capital structure targets ▪ Program and layout planning ▪ Capacity and resource planning ▪ Technology planning ▪ Order coordination	▪ Performance targets ▪ Production planning and control ▪ Production sequencing ▪ Resource lot-sizing and scheduling ▪ Resource management and control ▪ Warehouse management
Forward supply	Approaches	[5,12,13]	[7,14–17]	[18,19]
	Challenges	▪ Regulations for take-back of used products ▪ Uncertain market development ▪ Rising resource prices	▪ Supply shortages	▪ Procurement duration ▪ Outsourcing of take-back and recycling operations
Reverse and closed-loop	Approaches	[12,20]	[7,8,21–23]	[9,24–26]
	Challenges	▪ Uncertain market development ▪ Uncertain political and legal boundary conditions	▪ Sourcing in quantity, quality and distribution ▪ Uncertain future recyclate characteristics ▪ Product technology leaps between production and reverse flows ▪ Delay of reverse flow raise	▪ Complex production control ▪ Uncertain product quality and lot-sizing ▪ Complex stock management ▪ Additional product and process testing processes ▪ Additional process cleaning and retooling

optimization approaches. The mentioned publications focus on short-term planning and control tasks of mostly individual processes of the forward or reverse supply chain. The focus in the reverse supply chain is e.g., on the optimal depth of disassembly since the disassembly is the initial process for many end-of-life options. Alfaro-Algaba and Ramirez [9] present a techno-economic and environmental disassembly planning for battery remanufacturing, however strategical and tactical planning tasks such as the battery sourcing and the influence of the assembly technic of the forward supply chain on the disassembly expense are neglected.

Individual planning approaches focus on single planning levels and tasks and do not integrate the forward and reverse supply chain. Moreover, the approaches do not consider the interdependencies between the different planning levels and tasks, however they can be significant. A perspective on one task does not represent the complex reality of closed-loop supply chains and its support for the overall planning is limited.

General planning approaches

Beyond individual planning approaches, general approaches which integrate the mentioned planning levels and tasks exist.

The Aachen production planning and control (PPC) model aims to describe PPC from different perspectives (task, process, function, and goal view). Therefore, the model focuses on the reorganization of PPC as well as the development, selection, and implementation of planning and control concepts and systems [10].

The Hannoverian Supply Chain Model, based on the Aachen production planning and control, is a reference model which compactly illustrates the interdependencies between the tasks of production planning and control and logistic actuating variables, control variables, and objectives [11]. Both models are coordinated approaches of the forward supply chain; however, integration of the reverse supply chain is missing.

The Supply Chain Planning Matrix presents the tasks of supply chain planning structurally and to classifies needed modules of a supply chain planning software and the advanced planning and scheduling. It considers strategical, tactical, and operational planning levels which are connect according to hierarchical planning. Furthermore, it consists of the following modules, among others: strategic network planning, material requirement planning, production planning and production scheduling [3,27]. Like the Aachen PPC, an implementation of the reverse supply chain in the model is missing.

One hierarchical planning approach that is the first conceptual framework for the planning of the reverse supply chain is the Reverse Supply Chain Planning Matrix. It is a classification scheme, which categorizes planning problems, identifies relevant variables and shows their interrelation in recovery operations [28]. However, the Reverse Supply Chain Planning Matrix focuses only on the reverse supply chain and does not integrate the forward supply chain.

Discussion of existing approaches

Summarized the presented approaches show, that individual and general planning approaches exist. However, the focus of coordinated planning approaches is either on the forward or reverse supply chain and a connection is missing. Furthermore, approaches for individual planning tasks do not integrate all planning levels in a sufficient and coordinated extent in the context of the closed-loop supply chains.

The planning of closed-loop supply chains requires quantifiable input flows e.g., for network, capacity, and program planning, which are uncertain and can fluctuate considerably at the forward and reverse supply chain. However, the different planning levels and the forward and reverse flows influence each other significantly and need to be planned coordinated. This approach is missing and is the focus of the following presented coordinated planning approach.

3. Approach for the coordinated planning in closed-loop supply chains

This new coordinated approach focuses on the illustration of the correlations between the forward and reverse supply chain. Therefore, it supports related actors of the production and recovery of products. For the forward supply chain, these actors include raw material suppliers, refineries, tier-x suppliers, and OEMs. For the reverse supply chain, these comprise collectors, disassembly companies, recyclers, and remanufacturers. These actors have in common that they own the product or component and, therefore, have significant power to control the material flows. Besides these directly involved actors, further actors can profit from the framework by understanding the interdependencies in such closed-loop supply chains. These include inter alia logistic providers, politics, and academics.

Based on the interests of potential actors, we identified three main requirements for the framework. First, the planning tasks need to be identified which are necessary and crucial for a sophisticated planning of product-owning companies in closed-loop supply chains. Second, the planning tasks differ regarding the time horizon. Therefore, planning tasks need to be structured into strategic, tactical, and operational planning or long-, mid-, and short-term planning. This enables the clear definition of the temporal distribution of the planning tasks and their interdependencies. Such coordination between the planning tasks is described as vertical coordination. The described vertical coordination follows the hierarchical planning [3]. Third, the interdependencies between the forward and reverse supply chain should be identified, described, and analyzed. For the forward supply chain, especially the selection of partners for the takeback and recovery of their products as well as the sourcing of secondary material are in focus. For the reverse supply chain, the selection of sourcing channels for spent products and the definition of specific sales channels for secondary materials and components are crucial. This can be described as horizontal coordination. We define our novel coordinated planning approach based on the described requirements as shown in Figure 1.

According to the hierarchical planning, each planning task is influenced by the superior planning task in form of their planning results as a directive, e.g., production targets. Furthermore, each planning task gives feedback to the superior planning task which contains problems and the achieved level of the set target, e.g., achieved production rate. This idea is already integrated into the Supply Chain Planning Matrix. However, the framework gives a significant extension to the current planning approaches which is the connection between forward and reverse supply chain.

On the strategic level, the development of cooperation, the coordination of the network structure, and the compatibility of the production and recycling technologies are critical. Long-term cooperation enables both supply chains to lift significant potentials. For the forward supply chain, take-back and recycling requirements are often applied by law. However, manufacturers usually are not involved in the recycling. Therefore, cooperation with the reverse supply chain allows them to manage the legal requirements and focus on their core business. Additionally, such cooperation can reduce supply risks of scarce materials and reduce the carbon footprint of their

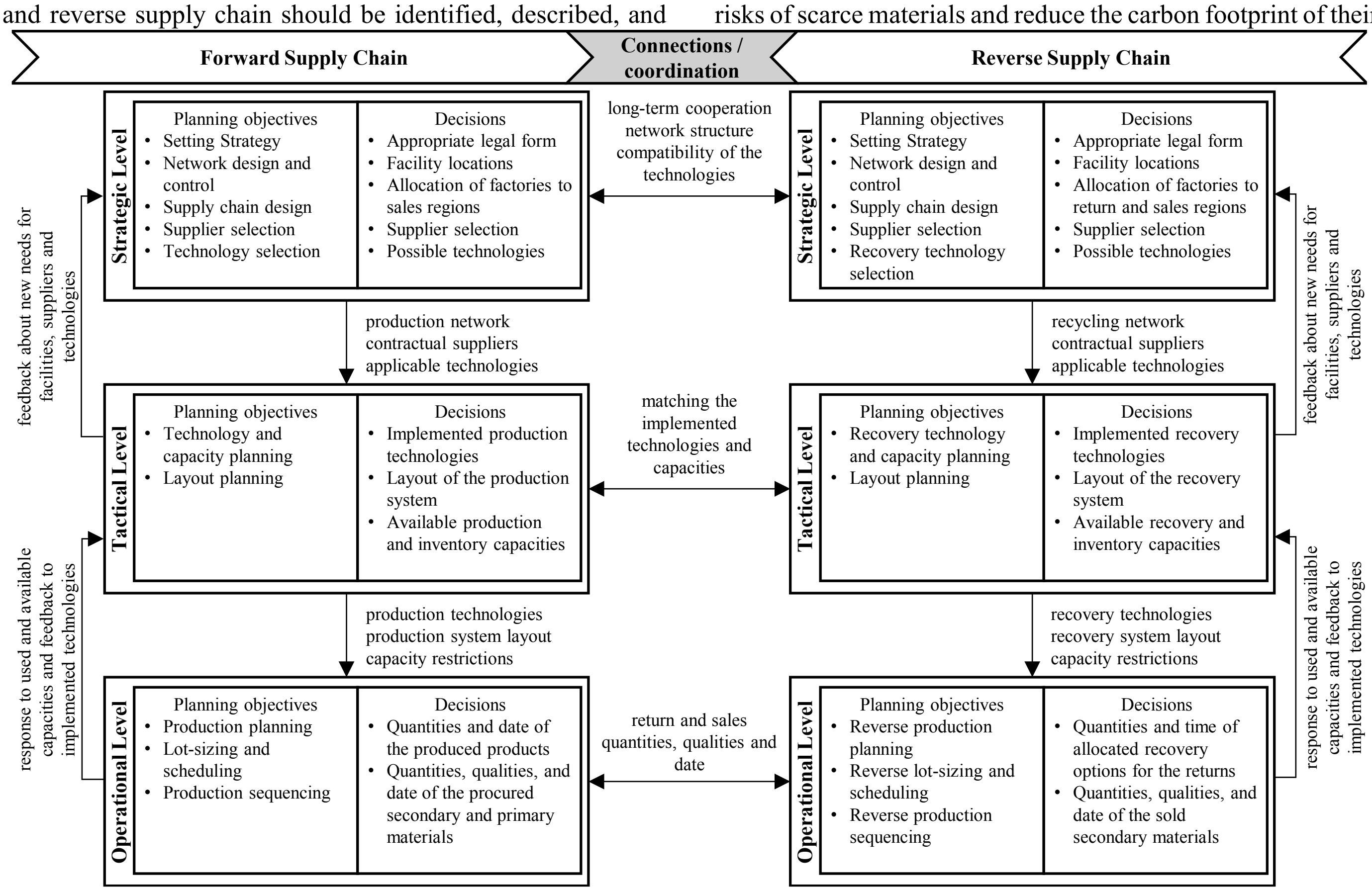

Figure 1: Coordinated planning approach for closed-loop supply chains

products [29]. For the reverse supply chain, long-term cooperation enables a more certain amount of spent products, a certain demand for secondary products, and often the gain of critical information such as the product design from the manufacturer. However, for a successful long-term cooperation two aspects must be met. First, the network structure of the forward and reverse supply chain needs to be coordinated to achieve the maximum benefit. For example, transportation cost can be reduced significantly if the location of the recycling plant is near the location of the production plant. Second, the production and recovery technologies must be compatible.

On the tactical level, the technologies and capacities need to be coordinated. Since technologies are only preselected on the strategic level, the specific technology, e.g., in form of a specific machine, is planned and implemented on tactical level. Therefore, achieving compatible technologies is critical. Furthermore, the implemented capacities of each resource are planned on this level. Hence, coordination of the amount of expected returns and exchange of secondary material is needed on this level to implement the optimal capacity.

On the operational level, the coordination of exchange materials is needed. In this context, quantity, quality, and time of the exchange are in focus. Furthermore, if no price is set, e.g., on tactical or strategic level, it must be coordinated as well.

4. Discussion of the coordinated planning approach in the context of lithium-ion batteries

Currently, many car manufacturers and battery recyclers start long-term cooperation and a coordinated planning approach is needed to enable a well-founded cooperation. Therefore, our coordinated planning approach is discussed in the context of lithium-ion batteries and the key challenges in such cooperation of the different planning levels are described.

On the strategic planning level, these cooperation are implemented due to different reasons. For the car manufacturer, legal requirements, such as the DIRECTIVE 2006/66/EC, necessitate them to take back and recycle their sold batteries at the end-of-life. Some car manufacturer, such as Nissan or Volkswagen [30,31], tackle this challenge by implementing their own recycling facilities. However, most manufacturers outsource the take back and recycling operations because this is not their core business. Furthermore, the spent batteries are spread across Europe and the entire world and it is not feasible for car manufacturers to build recycling facilities worldwide. Therefore, every car manufacturer needs to interact with companies of the reverse supply chain to tackle the challenge of spent batteries. Additionally, the cooperation with recyclers of batteries enables a new sourcing channel for scarce materials, such as cobalt, lithium, and nickel. For the recyclers, cooperation enables them to increase the amount of gathered spent batteries and at the same time to reduce the uncertainty regarding the amounts of spent batteries. Furthermore, a part of such cooperation often is the trade of the recovered secondary materials to the car manufacturer. Therefore, a certain customer for their products is gained. Last, within a cooperation, critical information, such as the cell chemistry, are more likely to be transferred to the recycler, which enables them to achieve higher qualities of the recovered materials.

However, the cooperation needs to fit into the networks of the partners and the production and recycling technologies should suit each other. Since spent batteries are spread widely, the location of the recycler and the location of the spent batteries is critical. Therefore, it can be necessary for a car manufacturer to cooperate with more than one recycler. This would also reduce supply risk for secondary materials due to a diversification of the suppliers. Furthermore, recycling and production technologies need to be compatible. Current recycling processes for lithium-ion batteries contain a hydrometallurgical process to regain cobalt, nickel, and further materials. However, the actual composition of the recycled materials varies. For example, lithium can be regained as lithium carbonate or lithium hydroxide. However, the production process usually necessitates for a specific composition and quality. Furthermore, recycling processes vary regarding recoverable materials. For example, by using a pyrometallurgical preparation it is more difficult to regain lithium than in a mechanical preparation. These circumstances need to be considered in the strategic planning between the forward and reverse supply chain.

On the tactical planning level, the implemented technologies and capacities need to be coordinated. Since technologies are usually only preselected on strategic level, e.g., using a mechanical preparation instead of a pyrometallurgical, the specific machine and, therefore, the actual specifications of the recovered and used materials are highly influenced. Furthermore, the actual amount of spent batteries is more certain at this planning level. Therefore, car manufacturer and recycler need to coordinate the amount of spent batteries to be able to implement the optimal recycling capacity and to be able to ensure a specific amount of secondary material.

On the operational planning level, the described coordination of the amount of returned spent batteries and traded secondary materials is further detailed. However, in this planning stage, no capacities can be built up. Therefore, the aim of the coordination is to achieve suiting and feasible production and recycling plans. Uncoordinated planning between forward and reverse supply chain leads to inefficiencies and in the worst case to unfeasible production and recovery plans [24].

5. Conclusion and recommendations

The coordinated planning approach describes the complex planning in closed-loop supply chains and the occurring interdependencies. Therefore, planning tasks on the strategic, tactical, and operational level are identified and clustered. These planning tasks are further structured into forward and reverse supply chain specific tasks. However, the key advantage of the approach is the description of existing interdependencies in the form of directives, feedback, and coordination between the forward and reverse supply chain. Especially the coordination between forward and reverse supply chain is in focus since it is critical for economic and environmental sustainability and long-term competitiveness.

The structured description of the planning tasks and their interdependencies enables managers to understand the complex causes during the design and planning of closed-loop supply chains. When integrating the findings of the coordinated planning approach in their planning companies of the forward supply chain can become more sustainable by increasing the use of secondary materials and at the same time reducing supply risks of scarce materials. For the reverse supply chain, understanding the interdependencies and the importance of a coordinated approach can lead to decreasing uncertainties and, therefore, increasing profitability of their operations.

In this regard, further research is needed especially in two research field. First, using the digitization is a promising opportunity to achieve cooperation and coordination between the forward and reverse supply chain. However, it is widely neglected in the existing planning approaches. Such a digitized circular economy can be described as an advanced circular economy. First approaches of such an advanced circular economy can be found in [32]. Second, only a few planning approaches focus on the specific requirements of the circular economy of lithium-ion batteries. These consist of significant supply risks, legal requirements, and high uncertainties for the reverse supply chain. Therefore, further research is needed in order to achieve sustainable closed-loop supply chains.

Acknowledgements

This paper evolved of the research project “Recycling 4.0” which is funded by the European Regional Development Fund (EFRE | ZW 6-85017297; ZW 6-85018080) and managed by the Project Management Agency NBank.

References

[1] IEA, 2020, Global EV Outlook 2020.
[2] European Commission, 2020, Study on the EU’s List of Critical Raw Materials – Final Report.
[3] Stadtler, H., Kilger, C., and Meyr, H., eds., 2015, Supply Chain Management and Advanced Planning, Springer Berlin Heidelberg, Berlin, Heidelberg.
[4] Egger, A., and Winterheller, M., 2007, Kurzfristige Unternehmensplanung.
[5] Dér, A., Gabrisch, C., Kaluza, A., Cerdas, F., Thiede, S., and Herrmann, C., 2019, “Integrating Environmental Impact Targets in Early Phases of Production Planning for Lightweight Structures,” Procedia CIRP, 80, pp. 168–173.
[6] Günther, H.-O., and Tempelmeier, H., 2020, Supply Chain Analytics, Books on Demand, Norderstedt.
[7] Cerdas, F., Gerbers, R., Andrew, S., Schmitt, J., Dietrich, F., Thiede, S., Dröder, K., and Herrmann, C., 2018, “Disassembly Planning and Assessment of Automation Potentials for Lithium-Ion Batteries,” pp. 83–97.
[8] Hoyer, C., Kieckhäfer, K., and Spengler, T. S., 2015, “Technology and Capacity Planning for the Recycling of Lithium-Ion Electric Vehicle Batteries in Germany,” J. Bus. Econ., 85(5), pp. 505–544.
[9] Alfaro-Algaba, M., and Ramirez, F. J., 2020, “Techno-Economic and Environmental Disassembly Planning of Lithium-Ion Electric Vehicle Battery Packs for Remanufacturing,” Resour. Conserv. Recycl., 154, p. 104461.
[10] Schotten, M., 1998, Produktionsplanung Und -Steuerung, Springer Berlin Heidelberg, Berlin, Heidelberg.
[11] Schmidt, M., and Schäfers, P., 2017, “The Hanoverian Supply Chain Model: Modelling the Impact of Production Planning and Control on a Supply Chain’s Logistic Objectives,” Prod. Eng., 11(4–5), pp. 487–493.
[12] Bocken, N. M. P., de Pauw, I., Bakker, C., and van der Grinten, B., 2016, “Product Design and Business Model Strategies for a Circular Economy,” J. Ind. Prod. Eng., 33(5), pp. 308–320.
[13] Herrmann, C., Spengler, T. S., Mennenga, M., Wachter, K., and Kieckhäfer, K., 2012, “The Transition to Alternative Powertrains: Concept for the Life-Cycle-Oriented Symbiosis of Technology, Product and Product Portfolio Planning,” Volume 5: 6th International Conference on Micro- and Nanosystems; 17th Design for Manufacturing and the Life Cycle Conference, American Society of Mechanical Engineers, pp. 703–712.
[14] Weckenborg, C., Kieckhäfer, K., Müller, C., Grunewald, M., and Spengler, T. S., 2020, “Balancing of Assembly Lines with Collaborative Robots,” Bus. Res., 13(1), pp. 93–132.
[15] Filz, M.-A., Herrmann, C., and Thiede, S., 2019, “Simulation-Based Data Analysis to Support the Planning of Flexible Manufacturing Systems,” 18. ASIM Fachtagung Simulation in Produktion Und Logistik, Verlag Wissenschaftliche Scripten, Auerbach, Chemnitz, Germany, pp. 413–422.
[16] Leiden, A., Thiede, S., and Herrmann, C., 2019, “Agent-Based Simulation for Multi-Criterial Planning and Control of Automated Electroplating Lines,” 18. ASIM Fachtagung Simulation in Produktion Und Logistik, Verlag Wissenschaftliche Scripten, Auerbach, Chemnitz, Germany, pp. 111–120.
[17] Riddalls, C. E., Bennett, S., and Tipi, N. S., 2010, “Modelling the Dynamics of Supply Chains,” Int. J. Syst. Sci., 31(8), pp. 969–976.
[18] Akhoondi, F., and Lotfi, M. M., 2016, “A Heuristic Algorithm for Master Production Scheduling Problem with Controllable Processing Times and Scenario-Based Demands,” Int. J. Prod. Res., 54(12), pp. 3659–3676.
[19] Englberger, J., Herrmann, F., and Manitz, M., 2016, “Two-Stage Stochastic Master Production Scheduling under Demand Uncertainty in a Rolling Planning Environment,” Int. J. Prod. Res., 54(20), pp. 6192–6215.
[20] Alamerew, Y. A., and Brissaud, D., 2020, “Modelling Reverse Supply Chain through System Dynamics for Realizing the Transition towards the Circular Economy: A Case Study on Electric Vehicle Batteries,” J. Clean. Prod., 254, p. 120025.
[21] Poles, R., 2013, “System Dynamics Modelling of a Production and Inventory System for Remanufacturing to Evaluate System Improvement Strategies,” Int. J. Prod. Econ., 144(1), pp. 189–199.
[22] Herrmann, C., Frad, A., and Luger, T., 2008, “Integrating the End-of-Life Evaluation and Planning in the Product Management Process,” Prog. Ind. Ecol. An Int. J., 5(1/2), p. 44.
[23] Herrmann, C., Luger, T., Kernbaum, S., and Seliger, G., 2007, “From Disassembly Planning Approaches to Remanufacturing Planning: Sustainable Manufacturing V,” Global Symposium on Sustainable Product Development and Life Cycle Engineering, Rochester, New York, USA.
[24] Scheller, C., Schmidt, K., and Stefan, T., 2020, “Decentralized Master Production and Recycling Scheduling of Lithium - Ion Batteries : A Techno - Economic Optimization Model,” J. Bus. Econ.
[25] Meyer, C., Wichmann, M. G., and Spengler, T. S., 2016, “Management of Recycling Operations for Iron and Steel Making Slags,” J. Bus. Econ., 86(7), pp. 773–808.
[26] Kenné, J.-P., Dejax, P., and Gharbi, A., 2012, “Production Planning of a Hybrid Manufacturing–Remanufacturing System under Uncertainty within a Closed-Loop Supply Chain,” Int. J. Prod. Econ., 135(1), pp. 81–93.
[27] Rohde, J., Meyr, H., and Wagner, M., 2000, “Die Supply Chain Planning Matrix,” PPS Manag., 5, pp. 10–15.
[28] Nuss, C., Sahamie, R., and Stindt, D., 2015, “The Reverse Supply Chain Planning Matrix: A Classification Scheme for Planning Problems in Reverse Logistics,” Int. J. Manag. Rev., 17(4), pp. 413–436.
[29] Audi, 2018, “Neue Kraft Aus Alten Zellen: Audi Und Umicore Entwickeln Kreislauf Für Batterie-Recycling” [Online]. Available: https://www.umicore.de/de/presse/news/neue-kraft-aus-alten-zellen-audi-und-umicore-entwickeln-kreislauf-fur-batterie-recycling/.
[30] Nissan, 2018, “Zweites Leben: Nissan Recycelt Lithium-Ionen-Batterien in Neuem Werk” [Online]. Available: https://germany.nissannews.com/de-DE/releases/release-426224580-zweites-leben-nissan-recycelt-lithium-ionen-batterien-in-neuem-werk.
[31] Volkswagen, 2019, “Li-thi-um Zu Li-thi-um, Man-gan Zu Man-gan” [Online]. Available: https://www.volkswagen-newsroom.com/de/storys/lithium-zu-lithium-mangan-zu-mangan-4662.
[32] Blömeke, S., Mennenga, M., Herrmann, C., Kintscher, L., Bikker, G., Lawrenz, S., Sharma, P., Rausch, A., Nippraschk, M., Goldmann, D., Poschmann, H., Brüggemann, H., Scheller, C., and Spengler, T., 2020, “Recycling 4.0,” Proceedings of the 7th International Conference on ICT for Sustainability, ACM, New York, NY, USA, pp. 66–76.