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Editorial

Dear Readers, This 'special' SNE Special Issue SNE 34(3) is extending our publication field by conference proceedings. SNE and ARGESIM, SNE's publishing house, had always a strong relation with EUROSIM and the EUROSIM Societies. Some of the Proceedings Volumes or Abstract Volumes of the EUROSIM congresses have been electronically published by ARGESIM in the Series ARGESIM Reports, and selected papers of the EUROSIM congresses have found their way into a SNE Special Issue.
DBSS, the Dutch Benelux Simulation Society, organizer of the EUROSIM Congress 2023 in Amsterdam, has developed a new structure for the Congress Proceedings: the contributions are published in five parts in special issues of journals or series (for details see Special Issue Editorial), one of them being SNE – Simulation Notes Europe.
SNE's structure with Technical Notes and Short Notes corresponds well with the contribution types of the EUROSIM 2023 congress: in SNE 34(3), the Proceedings Special Issue, four Technical Notes publish congress contributions of medium length, and eight Short Notes (three of them also Educational News) publish short contributions of the congress.
Many thanks to the authors and to the special issue editors, and many thanks to the SNE Editorial Office for layout, typesetting, preparations for printing, electronic publishing, and much more. And have a look at the info on forthcoming conferences.

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Editorial Special Issue EUROSIM 2023 Proceedings

DBSS, the Dutch Benelux Simulation Society, organizer of the EUROSIM Congress 2023 in Amsterdam, has developed a new structure for the Congress Proceedings. Instead in a separate proceedings volume, the contributions are published in five parts in a series and in (special issues of) journals. Selection followed the peer review and the contribution type:

- *Communications in Computer and Information Science* (Series); long contributions, congress peer review and editor review
- *Computers and Industrial Engineering*
  long and medium-length contributions,
  congress review, postconference submission call
- *SIMULATION: Transactions of the Society for Modeling and Simulation International*
  type and selection as above
- *Case Studies on Transport Policy*
  type and selection as above
- *Simulation Notes Europe – Special Issue (SI)*
  medium-length and short contributions
  congress review, SNE Special Issue Review Board with invitation of authors

We are glad that the publication of the various proceedings is generally in a final stage, and we can present here the SNE Special Issue *EUROSIM 2023 Proceedings*.

The motto of the congress *Simulation for a Sustainable Future* invited a broad area of tracks: passenger operations, simulation/optimization, simulation in agro-industries, simulation and data, simulation for digital twins in industry and logistics, methodology and risk assessment, supply chain management, logistics and transportation, industrial case studies, adaptive and autonomous systems, environment and sustainability applications, simulation and ML technology, rare events analysis, gaming, epidemiological systems, multimodal transport simulation, simulation in human behaviour, simulation in education, agent-based simulation, energy transition, aviation, monitoring and control, healthcare applications, manufacturing applications, circular economy, military applications, and some more.

The contributions in this issue reflect some of the above topics. In the four *Technical Notes*, M. Leißau and C. Laroque present a systematic literature review for backward-oriented decision and planning approaches in production scenarios, P. Kołodziejczyk et al. evaluate logistical concepts with simulation studying increasing freight train length at ports, M. Kexel and W. Wincheringer discuss data acquisition and preparation for truck shuttle simulation, and R. Torres Mendoza et al. present simulation as tool to improve the medical equipment production line.

It is of importance that this SNE Special Issue also publishes some of the EUROSIM 2023 short contributions as *SNE Short Notes*, the only publication possibility for short contributions. The careful review decided for eight contributions. The topics range from optimization and validation via machine learning and simulation-based learning to model complexity and agent-based simulation, mainly in applications.in specific applications. Three contributions were classified as *Educational Note*, discussing simulation-based teaching in modelling and simulation in inverted classroom format, mulation-based learning in aviation management and risk analysis.

Many thanks to SNE's publisher ARGESIM, which opened EUROSIM's scientific journal now also for EUROSIM congress proceedings, extending the previous possibilities with SNE special issues with postconference publications (see covers below). And furthermore, also many thanks to ARGESIM for publishing the *EUROSIM 2023 Abstract Volume* in ARGESIM's series *ARGESIM Reports* (see below). It is to be noted, that in these series also proceedings volumes and abstract volumes of previous EUROSIM congresses have been published (examples below, details see *www.argesim.org/argesim-reports*).

Sincerely, the EUROSIM 2023 Proceedings editors

Miguel Mujica Mota, Chairman DBSS
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Backward-Oriented Decision and Planning Approaches in Production Scenarios: A Systematic Literature Review and Potential Solution Approach

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Abstract. Manufacturing processes are increasingly driven by new product needs, innovations, and cost efficiency. Planning Staff and decision makers face the challenge of achieving fixed production programs and subsequently individual orders in a certain quantity and within a certain period at a guaranteed completion date. A systematic approach to scheduling and tracking resource requirements is necessary to ensure efficient flow of manufactured products. Forward- and backward-oriented planning strategies are most used by manufacturers to meet their demands for existing orders. The current application of such approaches is very time and resource intensive due to the complexity and dimension of the decision and planning problems to be considered; it is difficult to react to short-term changes within the production program. To address this gap, this paper provides a systematic literature review of backward decision and planning approaches in production scenarios and presents a potential over-arching solution approach of a simulation- and machine learning-based decision support combination for operational production planning.

Introduction

Global business, an advancing digital transformation, and the need for on-time production and delivery are defining competitive factors for manufacturers. For production planning and control (PPC), the efficient flow of manufacturing processes is indispensable.

Companies need to be constantly aware of the continuous adoption screws for PPC to establish and maintain an "optimal operating state" and therefore an efficient organization of all manufacturing processes. Uncertainty in PPC and the resulting adjustments can have unexpected repercussions on the performance of production systems and result in monetary and time resources being misused. A permanent (effective) adjustment of PPC also requires flexibility regarding structuring within manufacturing companies to be able to adapt to continuously changing market situations and correlating customer requirements.

Planners and decision makers are faced with the challenge of achieving fixed production programs and subsequently individual orders in a certain quantity and within a certain period at a guaranteed completion date. The success in terms of an efficient flow of manufacturing processes demands a systematic approach to scheduling and tracking of resource requirements.

Orders can be planned in a variety of ways, depending on the specifics of a given company and the characteristics of an order. The most common strategies are forward- and backward-oriented planning approaches [1].

In a series of experiments, the authors have shown that the use of a backward-oriented application of material flow simulation models (SimBack) can be a powerful tool for operational production planning, see [2][3]; however, the current usage of such approaches is also very time-consuming and resource-intensive due to the complexity and dimension of the decision and planning problems considered. In addition, it is difficult to react to short-term changes within the production program.

The authors intend to provide an extended solution approach to the given problem. Before, a systematic literature review on applications of backward decision and planning approaches in production scenarios was conducted.

This includes identifying applications of backward scheduling and backward simulation, as well as implementation challenges. We intend to answer the following research question for production scenarios: “What applications of backward scheduling and backward simulation exist in the field of production planning and control?”.

To answer these research questions, we give a short definition and delimitation of the terms backward scheduling and backward simulation in Section 1, followed by the applied review methodology in Section 2. Section 3 presents the results of our analysis. Section 4 addresses the potential of simulation models for targeted data generation and evaluation (data farming, cf. for example [4]) as well as their application for further optimization of target values, which is rarely used today, and presents a potential overarching solution approach of a machine learning-based decision support for operational production planning based on the extension of the methodological SimBack approach to generate a scheduling by backward simulation to a targeted data generation and evaluation based on the approach of data farming. Finally, a conclusion is given in Section 5.

1 Terminology

1.1 Backward Scheduling

Scheduling is a continuous decision-making process that involves scheduling tasks over time periods. The goal is generally to optimize one or more objectives. This can be used in manufacturing and services industries, as well as other industries where demand changes almost daily [5].

The procedures of a forward and backward scheduling can be described, which serve as solution procedures for scheduling and a correlating scheduling logic. The schedule logic is the process of organizing activities into a predictable and repeatable order. Scheduling steps often include assigning times, establishing priorities (priority control), prioritizing resources from highest to lowest priority and tracking progress towards completion, among others [6].

Forward scheduling is a process that sets deadlines for each work task and moves from a certain starting point (date) to complete the work within a specified period, with no waiting times between tasks. In contrast, backward scheduling is a technique for determining the latest possible start date of individual orders based on pending completion dates. This procedure is particularly useful for scheduling orders promised to customers with guaranteed completion dates.

The primary advantage of backward scheduling is that orders are not manufactured until the latest possible date. This allows for a capital commitment to be minimized, which in turn minimizes downtime from disruptions in production. However, there is always a risk that a disruption cannot be absorbed by the production process [7].

Manual scheduling procedures, which include forward and backward scheduling, provide a good basis for decision-making according to the insertion of a given production program and detect possible delays of individual orders. However, changing the scheduling framework such as by short-term insertions is usually complicated.

1.2 Backward Simulation

In addition to existing methods of mixed integer optimization, simulation-based heuristics, and simple forward or backward scheduling, simulation-based optimization is becoming more and more important for manufacturing companies in many industries, see [8][9]. Gutenschwager et al. [10] point that, it is regularly shown that the use of simulation in the planning of complex dynamic production and logistics systems leads to secured and more comprehensible planning results. Accordingly, existing methods of mixed integer optimization often use only rather simple models to keep computation time within reasonable limits; however, discrete event-oriented simulation (DES) can handle much more complex models.

Models for discrete event-oriented simulation describe systems already in existence or in the planning stages, regarding their operation over time. These models can be parameterized well and consider variability of reality by including random events into the models. Discrete event-oriented simulation can also be used to consider nested interactions between resources to be modelled, maintenance actions, and characterization rules according to sequences of steps, batch processing, and setup. Discrete event-oriented simulation is suitable in general and in connection with an input of a concrete production program in particular – to consider feasibility of concrete production program as well as adherence by firms to completion and/or delivery dates promised in advance, see [3].

Discrete event-oriented simulation models are used individually or in combination with heuristics in the context of simulation-based optimization to study forward-time decision and planning problems.

One approach of discrete event-oriented simulation with respect to time-backward decision and planning problems has been described in the literature as backward simulation and concretizes a reversal of the flow logic of the simulation along with the implemented control and priority rule procedures and the resulting backward execution of the same.

According to Jain and Chan [11] and Laroque [12], a backward simulation can be used to make well-founded statements about the target values to be achieved in the context of promised delivery dates. Furthermore, backward simulation is an efficient tool for implementing the procedures of (simple) backward scheduling, whereby both the solution quality of a conventional production planning and scheduling mechanism and the execution speed of simulation-based scheduling approaches become effective, see [11]. For a validation of the resulting solution set, a forward simulation is to be connected following an inversion of the solution set on the time axis for the generation of a valid injection planning. Such a combination of a forward and backward simulation shall be understood as a combined execution in the sense of the backward simulation (SimBack).

2 Research Methodology

This paper provides a systematic overview of existing applications of backward-oriented decision and planning approaches in production scenarios, following the five-step approach developed by Denyer and Tranfield [13].

2.1 Question Formulation

Any research requires a decision about its focus. Relating to the authors' research interest and their research work towards backward simulation, the authors want to address the question related to the applications of backward scheduling and backward simulation: "What applications of backward scheduling and simulation exist in the field of production planning and control?".

2.2 Selection of Database and Definition of Search Strings

The authors conducted a keyword search in journal and conference papers, keyword lists, and abstracts where the authors classified their work in backward decision and planning approaches, thus excluding works where the terms backward scheduling or backward simulation (or backward termination or backward planning) were not used. As shown in Figure 1, the search strategy consisted of two major steps: first, the identification of all possible papers using the search terms; then, filtering out all those papers that had no relevance in terms of the focus of this literature review.

In the first step, relevant keywords were selected with respect to the aim and scope of our literature review.

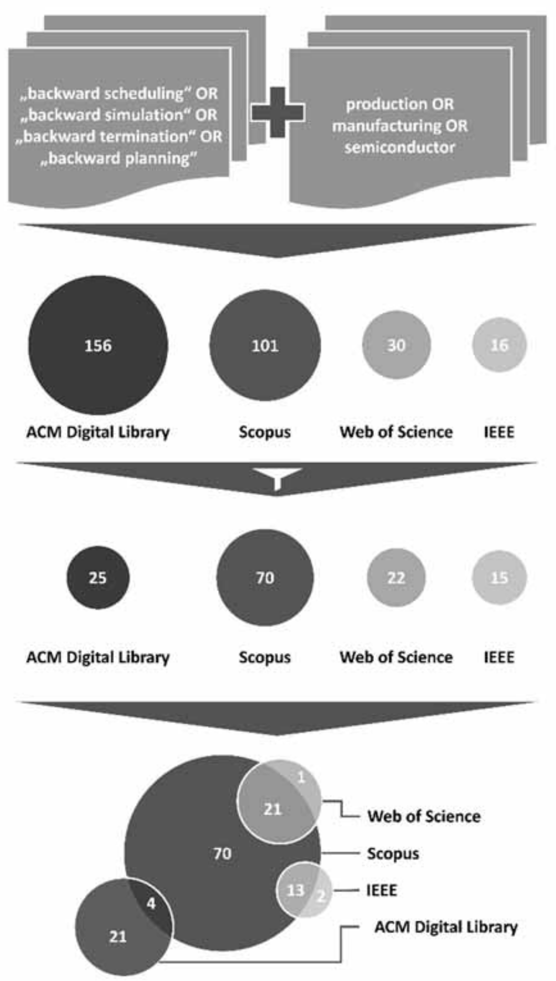

Figure 1: Search process and total number of papers.

These keywords can be seen in relation to backward decision-making approaches and in relation to the concrete context. The keywords were then constructed as a search string with the operators OR and AND between them: (("backward scheduling" OR "backward simulation" OR "backward termination" OR "backward planning") AND (production OR manufacturing OR semiconductor)).

The keyword semiconductor is most important for the solution approach proposed later, as it represents the most important research area explored by the authors over the last few years. They have focused on developing a methodical approach to generate a scheduling by backward simulation considering stochastic model influences in semiconductor manufacturing.

For this study, the authors chose the ACM Digital Library (ACM-Association for Computing Machinery), Scopus, Web of Science, and IEEE Xplore (IEEE – Institute of Electrical and Electronics Engineers) databases to collect scientific papers.

Only scientific papers published online that were written in English before the end of August 2022 were included. Figure 2 shows the growth in the number of relevant publications from the first paper identified in this study, from 1982 to 2022.

2.3 Article Selection and Evaluation

Denyer and Tranfield [13] note the importance of transparency in conducting systematic reviews, which they explain by citing a set of explicit selection criteria that they use to assess each study found and see if it does address the review question. In a first step, as already described in Section 2.2, the authors used a manual abstract screening to filter out all papers that were not relevant to the focus of this literature review. The accepted 94 papers were then screened by full text according to the following criteria: full text accessibility and thematic focus on backward decision and planning approaches in production scenarios. Applying the full text accessibility criterion reduces the total to 54 papers from 1989 to 2022, which are subsequently processed using a KNIME workflow.

The KNIME workflow processes abstracts and full texts of remaining papers and breaks the text into fragments. These fragments are subsequently combined in pairs as N-grams, which are the result of breaking a text into fragments and allows for the following in section 2.4, that papers and linking studies can be related to each other.

In this step, the pairwise summary of the individual fragments as N-grams offers the opportunity to assess the suitability of a paper according to the thematic focus of backward decision and planning approaches in production scenarios. Accordingly, the N-grams can be specifically summed up per paper, in this case, for example, based on the occurrence of the term backward; a more specific consideration of papers based on their numbers can be made.

It should be noted that a low number does not automatically equate to a low relevance of papers for analysis.

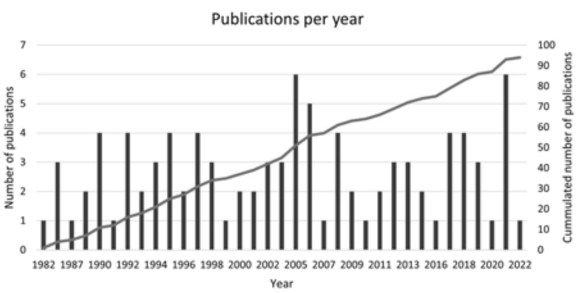

Figure 2: Number of publications per year and cumulated number of publications.

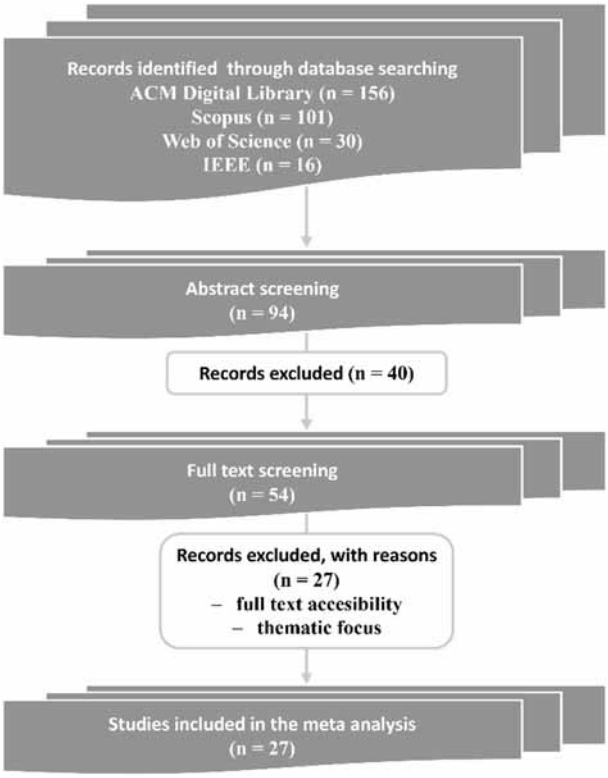

Figure 3: PRISMA flow diagram. The PRISMA flow diagram for the systematic review detailing the database searches, the number of abstracts screened, and the full texts retrieved.

The resulting systematization of the term backward* was further narrowed by a more specific consideration of abstract and full text, resulting in 27 papers for the meta analysis, see Figure 3.

2.4 Analysis and Synthesis of Results

The data analysis and synthesis stages of research begin with the collection of relevant sources. The aim of analysis is to break down individual studies into constituent parts and describe how each relates to the other. The aim of synthesis is to make associations between the parts identified in individual studies, see [13].

In this step, a deeper content analysis of the 27 identified core papers and the results of the literature review were synthesized to consider similarities and differences within and between two highlighted backward decision and planning approaches in production scenarios. The results of this step revealed that 12 papers focused on backward scheduling while 15 papers focused on backward simulation.

2.5 Evaluation of the Results

The results of the analysis and synthesis of the 27 core papers identified in the literature review are organized below in Section 3 according to the formulated research questions.

3 Review Analysis

Most of the reviewed papers on production scenarios and scheduling falls into the (here relevant) category of problem solving, with the goal of finding an improved solution approach for a specific production scenario that can deal with high cost, time, and quality pressures as well as planning uncertainties and/or unforeseen events.

3.1 Backward Scheduling in Production Scenarios

In the first paper (within this consideration), Agrawal et al. [14] propose a solution approach for scheduling the production of large assemblies and using a mate-rials requirements planning system with the goal of manufacturing products on time with minimum lead times and low production costs. The proposed solution approach includes an effective lead time evaluation and scheduling algorithm. Detailed backward scheduling is used to achieve the goal of minimizing lead times. Following up on this, Lalas et al. [15] presented a hybrid backward scheduling method for discrete manufacturing environments and evaluated it through several relevant performance indicators in a typical textile industry. The method applies a set of transformation relationships to transform a finite capacity forward scheduling method that can employ different allocation strategies into its backward counterparts. In contrast, Chen et al. [16] propose a solution to the problem of resource-constrained scheduling using particle swarm optimization. Specifically, the authors propose a rule for local delay search and a rule for bidirectional scheduling that are designed to facilitate the search for a global minimum and, further, a minimum amount of time. In the case of the bidirectional planning rule for particle swarm optimization, the authors propose a combination of forward and backward scheduling to expand the search range in the solution space and obtain a potentially optimal solution.

Kamaruddin et al. [17] evaluate the effectiveness of forward and backward scheduling in a job shop and a cellular layout. They compare the performance of both scheduling approaches, finding that backward scheduling in the job shop layout has lower average lead time, lower delay, and higher labor productivity than forward scheduling under all conditions.

In contrast, forward scheduling in the cellular layout has lower average lead time, lower delay, and higher labor productivity than forward scheduling under all conditions.

Chen et al. [18] develop an advanced planning and scheduling system to automatically generate production schedules for a colour filter factory with multiple lines. Both a forward and backward scheduling approach are used to balance the workload and control capacity losses by considering sequence-dependent setup times. In contrast, Hanzálek and Šůcha [19] study a lacquer production planning problem that is formulated as a resource-constrained project planning problem with general time constraints. They propose a parallel heuristic to solve it. This heuristic uses a temporal symmetry mapping that allows for simple construction of a schedule in the backward time orientation. Following up on this and to deal with the increasing size of wafers and demand for production in semiconductor manufacturing, Wang et al. [20] present a periodic scheduling algorithm for single-arm cluster tools with multitype wafers and shared processing modules. They derive analytical expressions for schedulability testing using a modified backward scheduling strategy. Accordingly, the backward strategy is the most widely used and efficient strategy for single-arm cluster tools.

Kalinowski et al. [1] likewise focus on the scheduling problem of minimizing lead time but refer to job store class systems and production orders arising there. Their proposed method supports both forward and backward scheduling, using an additional backward pass to calculate the latest possible release date of a given production order. In a further paper [21], the authors consider the problem of scheduling in flexible manufacturing systems considering additional resources and discuss both forward and backward scheduling strategies as well as serial and parallel scheduling schemes. Following on from this, Suryadhini et al. [22] apply backward scheduling to the batch scheduling model they developed to achieve the goal of minimizing the expected average lead time for a three-stage flow production. The batch scheduling model is thereby proposed for such a flow production along with an algorithm to solve it.

Finally, Viady et al. [23] consider a specific use case from textile production and aim to minimize the prevailing scheduling problems by reducing bottlenecks at workstations and excessive quantities. To solve the problem, the authors propose the drum-buffer-rope method and the Campbell Dudek and Smith (CDS) algorithm, applying backward scheduling to minimize waiting times and control work in process.

The result of this research is a reduction in lead times and, at the same time, a reduction in delays. In contrast and in the context of material requirements planning, Seiringer et al. [24] proposed a multistage and multipart production system with a rolling planning horizon, random customer demands, lead times, and machine setup times. The objective of their simheuristic algorithm was to optimize total cost; backward scheduling counted as one step in this optimization process. The results demonstrate that the proposed approach is promising for MRP systems under uncertainty conditions.

3.2 Backward Simulation in Production Scenarios

The authors themselves have repeatedly published application studies in the field of backward simulation in recent years [2][3]. The presented results based on a real-world use-case from semiconductor manufacturing show in a very practical way, that the methodical approach for generating a production schedule by backward simulation works under the given specifics, while stochastic influences can be considered. Already in Scholl et al. [25], the authors describe how they applied a backward-oriented simulation approach in their research on semiconductor manufacturing and identified restrictions and limitations.

However, the first research (within this consideration) has been done by Jain et al. [26]. The authors describe an application of advanced concepts of artificial intelligence in conjunction with simulation modelling and state-of-the-art computer hardware for effective real-time factory control. This application proves that disciplines such as AI and simulation modelling can be used synergistically for a practical purpose. The authors employ the concept of backward simulation to construct reliable schedules.

On the other hand, Ying and Clark [27] proposed a deterministic simulation to determine order release times in the forward or reverse direction. They developed a bidirectional algorithm that includes a series of forward and reverse simulation runs. A backward simulation run determines potential order release times; if these are all nonnegative, the algorithm modifies them to determine order release times for the subsequent forward simulation run. A final forward simulation run determines order completion times. The experimental results show that the bidirectional algorithm results in significantly improved mean lead time and that it can improve mean delay in some cases.

Having previously introduced in detail the concept of backward simulation as a means of determining a required state based on a desired target state [28], Watson et al. [29] address the challenge of order call scheduling for a customer-based production facility, which is characterized by the interfacing problems among order processing, capacity planning and production scheduling. The authors state that conventional order-call planning strategies often result in infeasible plans and make it difficult to manage customer orders. They discuss an approach called resource scheduling based on queue simulation, which simulates a queue in a manufacturing environment by using backward bill-of-material explosion logic like material requirements planning except that it uses a queue simulation model of the plant.

The approach proposed by Jain and Chan [11] to determine lot release times based on backward simulation has been highly cited in the literature, but it does not lead to improvements in a highly complex semiconductor manufacturing scenario. In their paper, the authors describe the approach, its implementation, and limitations found in the more complex scenario.

Chong et al. [30] propose a planning approach that includes one forward and one backward run using discrete event simulation. In the first run, bottlenecks are identified, and in the second run, strategies to reduce the load on those bottlenecks are used. Following up on this, Werner et al. [31] focus their research on the aspect of optimizing the process flow and calculating exact release dates for lots. This five-step procedure combines methods from scheduling rules, heuristic optimization, and analytical calculations. The basic principles highlighted are applicable not only in the semiconductor industry but also in other industries.

In Mejtsky [32], a metaheuristic algorithm for simulation optimization is described and applications of the algorithm to traveling salesman and job store scheduling problems are presented. To account for due dates, the author applies backward simulation and a pruning rule. In contrast, Zhai et al. [33] presented a special planning model based on simulation technique and genetic algorithm for precast production with two critical resources. The authors developed three simulation approaches with different simulation heuristics and directions, which were then compared using their resource and production schedules. A satisfactory resource and production schedule was produced by applying the critical precast component rule and bidirectional simulation.

Moreover, Dori and Borrmann [34] propose a combination of forward and backward simulation, addressing the extension of the discrete-event simulation method to include the calculation of buffer times. To determine the buffer times, the authors believe that it is important that the order of task execution is the same for both forward and backward simulation. Therefore, an extension of the simulation concept is presented that controls execution order. The authors illustrate application by means of a comprehensive case study.

Ju et al. [35] consider the application of backward simulation to analyse shipbuilding production and show how a shipyard's planning process can be improved. The authors' developed planning system, based on backward simulation, could be connected to an existing advanced planning system for ship construction. A major advantage of this system is that data input and preparation work for running simulations are simple; therefore, compared to forward simulation, backward simulation can be performed faster for different conditions and many cases, and by selecting best results from those simulations, production plans could be improved.

Finally, Okubo and Mitsuyuki [36] propose a method for modelling and representing the complex data sets of an entire factory structure. They prove that backward simulation is an efficient tool for meeting a given production program with guaranteed completion dates at short lead times. Moreover, they show that the effectiveness of their method and the validity of their production plan are confirmed by using actual factory processes and real data.

4 Potential Solution Approach

In the semiconductor industry, production systems and processes have an above-average level of complexity compared to other industries and will continue to gain complexity, see [37][38][39]. Recent developments in the areas of product diversity, smaller batch sizes and a more rapidly changing product range are documented by increased interconnections between plants due to automation. Possible dependencies relevant for planning result from limited plant capacities, stochastic processing, changeover, waiting and transport times, preventive mainten-ance, setup changes or dynamic time and/or capacity restrictions in queues or along several production stages [9].

The manufacturing technologies used in the semiconductor industry are considered particularly sensitive and involve complex local control logics.

Depending on various characteristics defined in advance, individual production batches do not run through linear process sequences, but rather circular process sequences and up to 700 individual steps, see [3][39]. Individual production batches are sometimes processed several times under cleanroom conditions via special equipment (re-entry cycles). Failure to comply with planning rules often leads to relevant rejects of intermediate and end products that must be compensated for at short notice by additional infeeds [3].

In order to ensure competitiveness, today's manufacturers must develop production plans that keep inventories as low as possible while meeting quality requirements and delivering on promised delivery dates. In addition, they must increase throughput and overall equipment effectiveness. Approaches to achieving these goals include optimizing overall planning processes, which require overarching optimization methods, see [3][11].

While application studies on backward simulation methods have appeared continuously over the years, promising results are described in Laroque et al. [2][3] according to a methodological approach to generate a scheduling by backward simulation under the specifics of the semiconductor industry and considering stochastic influences. The application of several simulation models and a series of experiments shows that backward simulation can be a powerful tool for operational production planning. However, backward simulation methods can be very time-consuming and resource-intensive depending on the complexity and dimension of the decision-making and planning problem under consideration and the interfacing issues; thus, highlighting a need for research in this area. In addition, the underlying data within the methodological approach to generate a scheduling by backward simulation remains largely unchanged so far (in terms of further optimization). Accordingly, potentials in terms of targeted data generation and evaluation as well as application of resulting findings for further optimization remain largely unexplored at present.

Such a targeted data generation and analysis can be understood as data farming and should efficiently and effectively increase the amount of data and furthermore the information concerning a decision and planning problem to be considered and connecting questions and enable the derivation of recommendations for action, see for exam [4][40]. According to Lendermann et al. [9], under the condition of a valid modelling, huge amounts of data have to be generated and processed in the sense of a forward as well as in the sense of a backward execution of a simulation model, in order to be able to make high-quality statements about the simulated system by a sufficiently careful experiment design (Design of Experiments, DoE). The extension of a backward simulation in the sense of a combined design by the approach of data farming shall considerably increase the informative power of the simulation study to be performed and at the same time address the difficulty to include the dynamics and stochastic of production systems and processes sufficiently accurately.

The described combination presents difficulties when implementing this procedure repeatedly from scratch for a new and/or adaptable planning horizon (in the case of additional and at the same time sometimes short-term infiltrations). This procedure is associated with a considerable expenditure of time, as well as the associated question of economic benefit. Moreover, sufficient knowledge of methods and/or procedures mentioned is assumed, which means that this procedure is sometimes not directly applicable for decision-makers.

Mönch et al. [41] states that executing concrete factor configurations, for example by simulation, can be part of the training phase of machine learning methods, see [9]. Machine learning as a subfield of artificial intelligence describes approaches that enable technical systems to extract and expand knowledge from training data and/or experience values (historical data) to solve an existing problem better than before [42].

In the semiconductor industry, discrete event simulation models and machine-learning methods are being used to develop self-learning algorithms that control and monitor production processes.

This approach is primarily concerned with the development of decision and planning algorithms addressing only temporally forward decision-making problems, see [43][44][45][46][47]. For the investigation of temporally backward decision and planning problems in a sense of scheduling and sequence planning, little research has been conducted so far. A need for research concerning ordering concrete production orders emerges for contract manufacturing within the semiconductor industry, where the development in last decade has been above all regarding an intensification of global enterprise and continuing digitalization. These changes have led to an increasing demand for semiconductors; therefore, challenges arise for the industry. The signs point to growth; therefore, it is necessary for companies in the value chain to adjust their research and development capacities, production facilities and material purchasing to this development, see [48].

The authors intend to address the difficulties surrounding the adherence to promised delivery dates and other performance indicators by developing a methodical approach for generating a scheduling by backward simulation to a target-oriented data generation and evaluation based on an approach called data farming. As in previous studies [2][3], in contrast to the known research, stochastic influences will be considered to obtain more robust schedules.

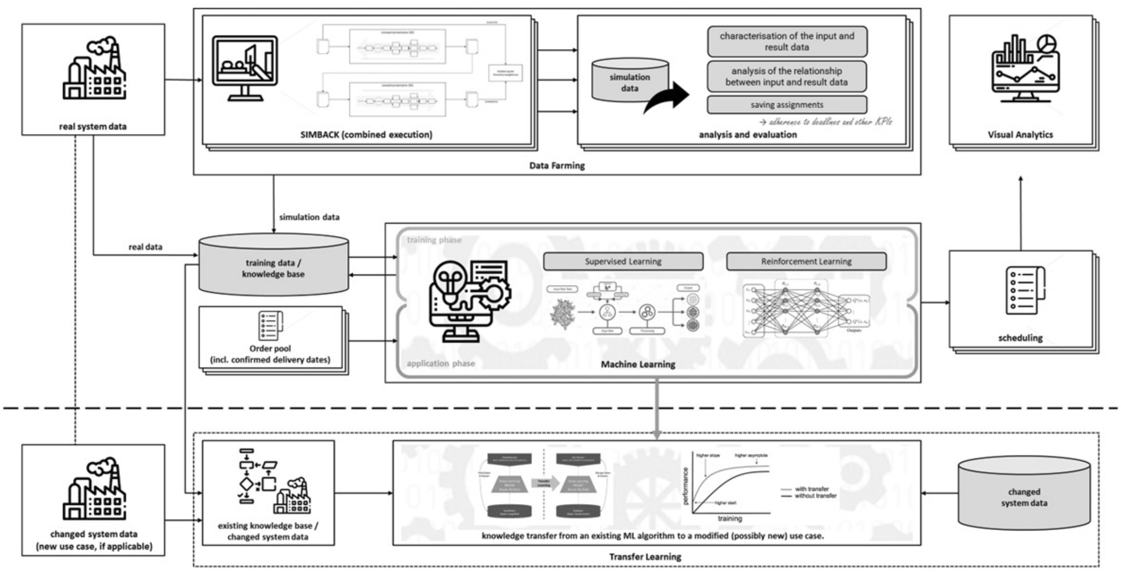

Figure 4: Solution approach.

They intend to use their resulting set of data as part of a training phase for machine learning methods, which will subsequently provide a powerful tool for scheduling and sequencing decisions in semiconductor manufacturing. This will ensure immediate applicability of the developed solution approach for decision makers and minimize substantial amounts of time and resources tied up in methods. Figure 4 illustrates the (envisioned) solution approach described here.

This results in various sub-objectives, which will be explained in the following:

4.1 Model Development and Validation

The developed method will be evaluated on various realistic use cases, including a model of a semiconductor industry. Specifically, it is planned to select at least one realistic system for evaluating the method's ability to emulate dynamic aspects of semiconductor manufacturing – for example, stochastic processing, changeover, waiting and transport times, control, and priority control procedures (also in the sense of characteristic re-entry cycles) or time or capacity constraints in queues or along several production stages. For example, this could be one of the Semiconductor Manufacturing Testbeds (SMT2020), see [49].

4.2 Data Generation and Analysis

A comprehensive mapping of the impact space corresponding to the system under consideration is required to generate sufficient data for the method of data farming and the combined execution of a simulation model by means of forward and backward simulation described in the previous section. This raises a variety of issues with respect to the scope and relevance of individual system, input, and result data for further use.

First, it has to be conceptually investigated which system data are of importance for the later development and implementation of a decision support based on machine learning in the mentioned problem space. This can be followed by a characterization of relationships between input and result data. Finally, the storage of mappings with respect to a statement regarding the adherence to promised delivery dates and further selected performance metrics is to be performed.

As described in the previous paragraph, concrete parameter configurations using simulation models and the amount of data generated by data farming address the challenge in production planning and control to be able to fall back on a comprehensive data stock and a sufficient quality of the same.

Accordingly, an extensive experimental design is necessary for each model to increase the amount of data efficiently and effectively and furthermore the information concerning the system under consideration according to its complexity and dimensionality. In view of this, suitable methods from statistical experimental design must be reviewed and selected and adapted for application in this work.

4.3 Technical Implementation

The objective of this sub-objective is to develop and implement a decision support system based on machine learning for operational production planning. To achieve this objective, the sub-objective first deals with the technical implementation of data generation in the context of a targeted data generation by the method of data farming and simultaneously focuses on data management as well as analysis and evaluation of resulting data. For this purpose, suitable simulation tools for combined execution of simulation model and connecting experiment design must be selected in advance. Following on from this, suitable procedures such as extensive data analysis and evaluation and machine learning must also be researched, adapted, and embedded in uniform framework.

The prototypical implementation of the machine learning based decision support for a use case from the semiconductor industry shall test different methods of ma-chine learning (especially methods of supervised and reinforcement learning) regarding the business benefit and prove the feasibility in principle of the elaborated concept.

4.4 Transfer Learning

This sub-objective addresses the difficulty to train the machine learning based decision support and the underlying predictive model from scratch with new industry and problem specific data (simulation and real data) as soon as input data change significantly and/or similar use cases are to be considered. The necessity of model adaptation as well as new model validation, linking data generation by the method of data farming and data analysis and the resulting time and resource requirements again highlight a considerable need for research.

Transfer learning as a method of deep learning deals with approaches based on so-called convolutional neural networks (CNN) to use the model trained on one use case as input for another (related) use case. Transfer learning can thus result in a reduction of the required amount of data (training data or experience) and the time needed for the training phase of machine learning methods, or an increase in the predictive performance and faster convergence of the model, see [50][51][52][53].

This sub-objective tests the method of transfer learning in the context of the concept elaborated and a modification of the considered use case from the semiconductor industry. By successfully implementing the method, possibilities arise to prove not only that it is feasible, but also that it has economic benefit compared to conventional production planning and scheduling mechanisms. Accordingly, once prediction or planning models have been generated, they can be adapted to related applications by using corresponding data sets.

5 Conclusion

Simulation requires effort and time; even if a preexisting model just needs to be updated with new parameters, there is still the runtime required to run the simulation, see [54]. Today's manufacturers must develop production plans that keep inventories as low as possible while meeting quality requirements and delivering on promised delivery dates. One way to address this objective is by optimizing overall planning processes, which require overarching optimization methods, see [3][11]. The purpose of this paper was to provide a systematic literature review on applications of backward decision and planning approaches in production scenarios.

The present work demonstrates that backward decision and planning approaches already are of high importance within production scenarios. There are differences between the industries; semiconductor production is often mentioned in connection with the method of backward simulation; accordingly, some application studies can be found in this industry. However, backward scheduling and backward simulation methods can be time-consuming and resource-intensive depending on the complexity and dimension of decision making and planning problems. Accordingly, the authors have identified a need for research in this area. In addition, cur-rent methodological approaches to generate scheduling by backward simulation remain largely unchanged so far (in terms of further optimization). Thus, potentials for targeted data generation and evaluation as well as application of resulting findings for optimization remain largely unexplored at present.

The proposed solution approach is intended to help exploit the findings highlighted in the systematic literature review and to address existing challenges related to the implementation of backward decision and planning approaches.

Furthermore, the proposed solution approach is intended to further develop the backward simulation method towards a targeted data generation and analysis based on the data farming approach. The use of the resulting set of data as part of the training phase of machine learning methods and thus the provision of a powerful tool (application phase) as an operational decision support for scheduling and sequencing in the semiconductor industry shall subsequently ensure the applicability of the developed solution approach for immediate decision makers and minimize a considerable time and resource requirement linked to the methods.

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Evaluating Logistical Concepts with Simulation: A Case Study of Increasing Freight Train Length at ports

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Abstract. The European freight rail network will have to handle increasing volumes largely due to a shift from road to rail to reach the sustainability goals defined in the European Green Deal. Efforts are being undertaken to define and evaluate measures that will allow an already busy network to handle more volumes. One of the promising measures is the usage of longer freight trains going up to 740 metres. Increased length of trains means more cargo per service, but also means new challenges. Although this measure seems straightforward, the devil sits in the details, most notably operational details. In this paper, we present our investigations into the operational details of freight trains handling at one of the important endpoints of the network, the Port of Rotterdam. In order to account for details, we have developed a micro-simulation that incorporates the operational processes of freight train handling. Using this model, we have compared scenarios using various compositions of trains, among which a scenario with a high level of long trains. In the experiments, we have considered each individual siding and shunting yard of the port to have insights into the operations. While longer trains can help in handling more volumes, it will also create more additional congestion at shunting yards that needs to be considered.

Introduction

Increasing freight train length is often given as a simple and effective solution to either increase transport volume at a low cost, or to alleviate congestion and reduce bottlenecks while retaining the same cargo flow with lower train number.

This is necessary given increasing volumes that need to be transported in an ever so important sustainable way. Current predictions and plans in the European Union show a doubling of volume by rail by 2030 [1]. Often analysis of the effects of increasing train length considers only the corridor or line requirements and possible gains are evaluated by congesting cargo on tracks and resulting headways [2], [3].

Yet careful consideration is required in analysing expected capacity increase resulting from longer trains. In the case of a high-level analysis, we risk on missing operational issues that will hurt future capacity. We therefore opt for microlevel modelling that incorporates operational and physical properties, as the length of trains is not merely a volume parameter but imposes physical limitations.

In this paper we argue that from a tactical logistics standpoint, the problem is not that straightforward and requires detailed analysis in several key areas, especially around the transportation hubs and cargo terminals.

Background

Rail freight transportation volume is increasing in the EU much faster than the network capacity [4]. More trains are being run which increases network congestion and in turn intensifies detrimental network effects like queuing or proliferating delays. Freight trains are especially affected as they are slower and less visible than the generally prioritised passenger trains.

There are many proposed interventions to improve the network capacity in the European Union, one of which is to promote usage of longer freight trains, going up to 740 metres in length instead of the current maximum of 650 metres. If more cargo can be transported by a single train, then fewer of those trains are needed in total. Additionally, expected line effects from a single longer train are negligible, with trains generally achieving the same top speeds, and only marginally increased headways, block occupation, or acceleration as well as braking times. Finally, most modern freight train processing facilities were designed to handle 740-metre-long trains.

Yet, the main difficulty for long freight trains does not occur on the main line, but rather near its destination. Firstly, there are typically fewer sidings where long train can stop and sometimes even splitting is necessary. In busy networks, occupying an additional siding might already be a problem. Still, inspection and shunting operations typically would not take much more time in comparison with processing times for loading and/or unloading the train. These, due to greater volume of cargo, can take up significantly more time per train. Terminal operators favour that as their production siding occupancy rises and is more predictable.

Related research

Increasing the length of freight trains is currently being considered broadly within the European Union. Extensive research is thus available on the topic. Recent publications have considered this: [5], [6], and [7] all introduce some of the research being done in the European Union to face increased volumes on rail. Their main aim is enabling transition from road to rail transportation and ensuring network-level capacity only. [8] offer an extensive overview of all measures being evaluated worldwide to increase capacity on freight rail networks, where optimisation and simulation are named as leading evaluation methods. More specifically to modelling increasing train lengths, [9] introduce a model in OpenTrack focussing on corridors. Yet, it concentrates line effects and does not cover cargo handling operations.

Some research applies economic costs analysis aspects to transportation, where long intermodal freight trains are just one viable alternative to other trains or modes of transport [10], [11]. Others focus on tactical and operational issues in rail networks, like [12], where a Simul8 package model explores the dependencies among the rail network elements. Mesoscopic simulation, however, omits important network elements and train interaction. There are also specific case studies in port networks, like [13], [11] or [14], where a particular rail network is studied in part or whole. They, however, generally do not aim at maximising the transported volume or go as far as investigating a full spectrum of train behaviour and network effects.

1 Rail Scheduling and Simulation Tooling

As introduced before, the challenge of analysing increased train lengths go beyond the mere volume calculations. In order to have a proper understanding of the operational capacity, we need to understand several aspects, among which:

- Physical constraints and operations: the rail infrastructure needs to be proper for handling lengthened trains. Due to the physical aspect of the problem the analysis should include a precise use of trains on the infrastructure to provide insight into capacity constraints.
- Train handling: freight trains do not have a simple point-to-point route that they follow, rather a complex set of operations are undertaken to attribute individual cargo to any of the many terminals present at a port.
- Logistical concepts: due to the increased cargo on individual lengthened trains, the cargo mix will likely be more scattered in terms of source of destination of it within the port. Due to this, increased complexity arises in determining operations that are required to isolate the right cargo for the right terminal.

To address the physicality of the analysis and the operational details, we have developed a microsimulation for freight rail operations called RailGenie [15]. It takes advantage of discrete event simulation to give a data-driven prediction of what is to come. In RailGenie Macomi utilises a two-step approach. The first step is to run an optimisation algorithm to schedule arrivals and compositions of trains as well as determine their routes. The second step is to execute a discrete event simulation run to determine the performance of that schedule and analyse the interdependencies among the trains.

As rail freight operations differ from passenger ones, different requirements are set to model them. Firstly, train dynamics is an outcome of the type of locomotive(s) used and the load it needs to pull, that changes after discharge and loading. A locomotive has a tractive force that pulls the weight of an entire train. Drag is applied to counteract that force, as a function of speed. Another important aspect is to account for acceleration resulting from track gradient. Slow acceleration is common among heavy trains and causes operational issues.

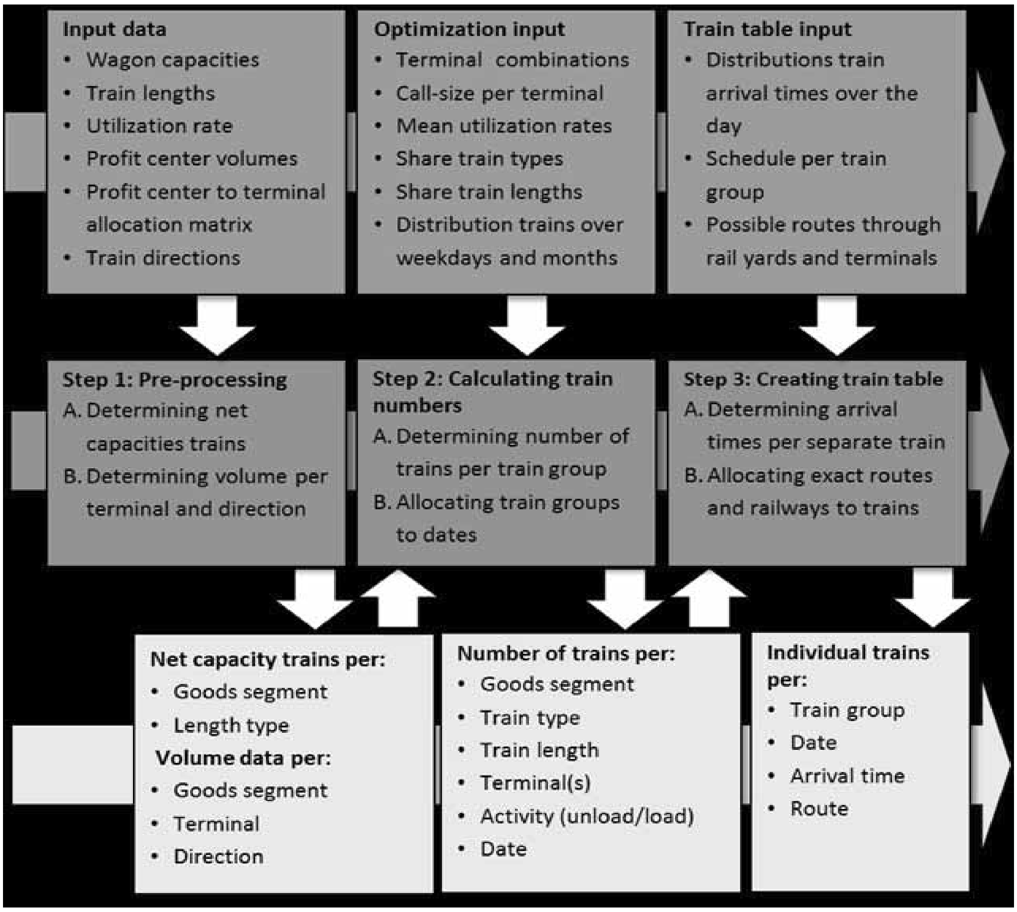

Figure 1: Volume to Trains scheduling algorithm operation [13].

Braking and safety distance calculations differ between freight and passenger trains as according to ETCS and freight trains utilise braking percentage coefficient

A train model must look ahead at least its braking distance to make sure the speed limit will not be breached at any point, while the maximum allowed lane speed might change even several times in that braking distance.

Secondly, freight trains require a lot of supporting processes at transportation hubs, which include loading/discharge operations, train splitting, locomotive swaps, and cargo/train inspections. These processes have varying durations and often further process or resource dependencies. Finally, freight trains have higher flexibility on routing changes.

For the abovementioned reasons, a typical train simulator where the vehicles follow a detailed schedule (i.e. passenger trains having pre-determined minute-based stops at the stations) is not sufficient for the problem area.

1.1 Scheduling Algorithm

Scheduling freight trains differs significantly from the scheduling of passenger trains. The future transportation volume requirements per destination per goods type are used to comprise an overall schedule for the port. Allowed physical characteristics of the trains, timing constraints as well as routing types are part of the optimisation input.

A mixed integer linear programming (MILP) method is used to solve three main optimisation problems: transport all the goods, minimize the number of trains in groups, create a realistic train schedule. See Figure 1 for details.

The optimisation algorithm distributes business (profit centre) volumes per commodity types per import/export direction to locations (cargo terminals). Yearly volumes have monthly/weekly/daily distributions to account for variability, like commodity seasonal patterns. Trains might be direct to a single terminal or visit multiple terminals to discharge and/or load cargo.

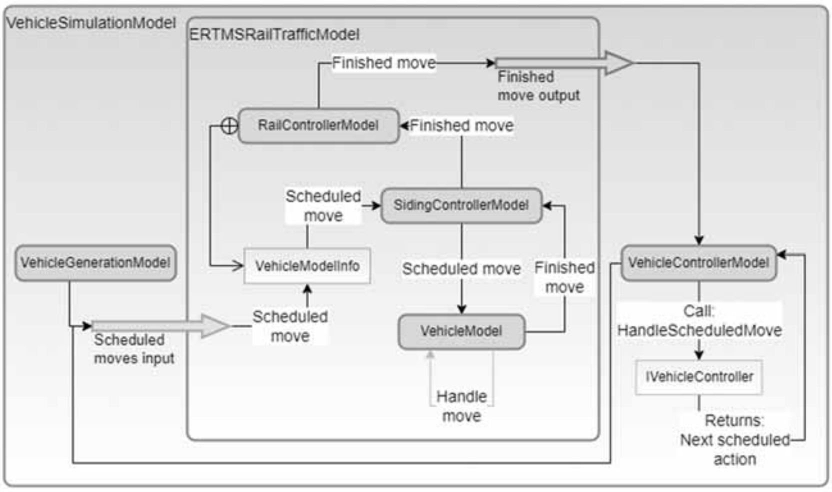

Figure 2: Main vehicle flow in the simulation.

1.2 Simulation Engine

A generated schedule is simulated for performance using Macomi's proprietary simulation engine, which bases on the discrete event system specification (DEVS). It is inspired by the service-based simulation library called DSOL made by TU Delft [16], later refined and extended in .Net and using the Azure infrastructure for computational scaling.

The simulator conforms to fundamentals and structure as set out in the Framework for Modelling & Simulation [17].

Choosing from available physical train configurations, the algorithm tries to fill the desired distribution patterns. Constraints can be imposed on commodity direction, load factors or daily schedule.

A schedule describes physical composition, cargo, arrival time and exact route and stops of every train. Train turnaround time, i.e., difference between train arrival at and departure from the port is determined by the simulation based on process duration and network interdependencies.

In any rail simulation, the most important logic concentrates on how rail vehicles move on the rail network. Figure 2 provides an overview that logic in RailGenie.

In RailGenie a train schedule is divided into individual moves that together comprise the total route of the train in the system, from a source to a sink (network end points). In between moves processes can be performed on the trains (e.g., loading), and these can only happen on designated tracks called sidings. These need to have sufficient length for a train to fit.

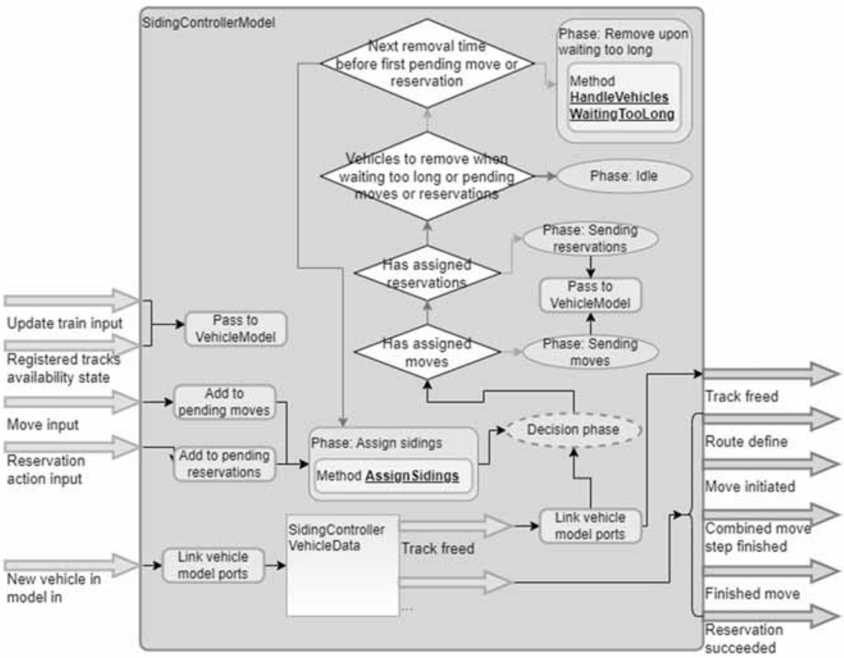

Figure 3: Siding controller logic schematic.

Before a move can be performed, the algorithm must make sure the next siding will be available when the train reaches it. As such trains can wait on sidings indefinitely for their next destination to become available.

Concurrently, deadlock prevention becomes important for the system in two main aspects:

- Avoiding trains being unable to move from their sidings due to interdependency with other train locations.
- Execute the move while making sure no trains facing opposite directions get stuck.

Figure 4: Port of Rotterdam rail network schematic in RailGenie.

For dedicated freight train networks deadlock problem has different characteristics than in passenger networks due to less frequent logical track designation as unidirectional, much higher unpredictability of the time the individual move needs to start (lower reliance on schedule), and generally higher complexity of network (due to number of endpoints as well as e.g., use of dated signalling and protection systems). Yet, a reservation system for all tracks in the entire move would be inefficient as these can be lengthy and such reservation would block position of switches and in the end perform worse than in a real system. Figure 3 provides a concept for the siding controller.

A RailGenie configuration for a specific case creates a simulation model, then utilises the simulation engine to execute experiments that can be further analysed.

2 Case Study: Port of Rotterdam

A case study is carried out utilising the infrastructure of the Port of Rotterdam as a representative example of a major and complex European transportation hub, where only freight trains are operated. A network layout is presented in Figure 4. There is only a single point of rail entry and exit to the hinterland that amplifies interdependencies in the network.

In the future rail volumes are projected to increase significantly, requiring more trains to carry the cargo. It is expected that even with the currently envisioned infrastructure investments, the future rail network will experience significant operational difficulties and delays due to congestion.

Furthermore, it will likely not be possible to service all destinations fully, unless additional improvements are made.

One of the possible interventions is to increase the length of trains. This case study explores the extent of benefit of that solution and whether it alone is sufficient to attain the desired cargo volumes. The following main assumptions as preferences from the Port Authority are used: only direct shuttles, no train splitting, mimic current train distributions and process times.

The port rail network consists of several areas that grew incrementally. Older parts are on the right side, closer to the port exit. Despite investments over time, the original design choices still influence the network. Most modern infrastructure layout is on the left side of Figure 4, in the man-made Maasvlakte area [18].

In this case study we utilise the train length of 740 metres as the maximum according to the European Agreement on Main International Railway Lines (AGC), as well as maximum for studied infrastructure characteristics.

2.1 Base Case Scenario

A base case scenario is created established on the current operational composition of trains in the port network and goods forecast for year 2040 supplied by the Port Authority.

Different commodity types are transported by various types of trains without carrying more than one commodity type per train. 740-metre trains are present in the mix, especially for dry bulk transportation, but also for other uniform import goods.

Train composition, their routing and expected volumes are obtained from the available operational data of the port. The same commodity volume is used for all scenarios, yet based on the train length mix the resulting number of planned trains differs, as per scheduling algorithm described in section 1.1.

In total, a yearly schedule of almost 42 thousand trains is created to transport 12 commodity types on 24 physical train configurations to one of the 44 distinct terminal locations. Longer trains carrying the same commodity type have accordingly a longer processing time at shunting yards and terminals.

2.2 Experiments

Several experiments are carried out to test out the performance with a higher mixture of longer trains. During a configuration of the scheduling algorithm, inputs are configured to include higher ratios of longer trains. No new train configurations are used, yet due to the same transportation volumes there are fewer trains scheduled. All experiments utilise the same duration of a month of operations, same volumes, and processing times per train type. A summary is provided in Table 1.

	Base Case	Longer Trains	Longest Trains
Train Number	3229	2954	2751
Ratio of 740m trains	50% where possible	75% where possible	100% where possible

Table 1. Experiment summary.

3 Results

If it is not possible to execute all trains moves within the set period, the simulation will stop generating new arrivals and only terminate when the last train arrives at a sink. This way it is possible to determine locations suffering from the highest capacity issues. It is a theoretical measure, as in reality some of the trains would need to be cancelled or diverted.

Figure 5 shows the number of arrivals per location that did not fit the desired schedule per location. Every arrival is counted, and trains have at least three of those during a visit. Locations were anonymised, and those with designation "_E_" in the middle are shunting yards, while with "_T_" are terminals.

Increasing train length does have a beneficial effect on the system, as fewer trains overshoot their schedule. The gains are the lowest for the most modern infrastructure, where terminals already prefer as long trains as possible.

When looking at properties of locations where bottlenecks form, these are mainly based on too high number of trains. When the number decreases, the negative network effects are alleviated. This is because a shunting yard, shared among arriving and departing trains, is most common location of delays.

Figure 6 shows the occupation of ten busiest rail truck bundles in the port shunting yards for the three scenarios. A bundle is a set or cluster of tracks with shared entry and exit tracks and full interconnectivity, where trains can stop.

While the average occupation in the entire port decreased from 30%, through 27,5% to 25% accordingly, it differs per area. The occupation in some bundle decreased significantly in some areas with the increased length of trains, for others it rose slightly.

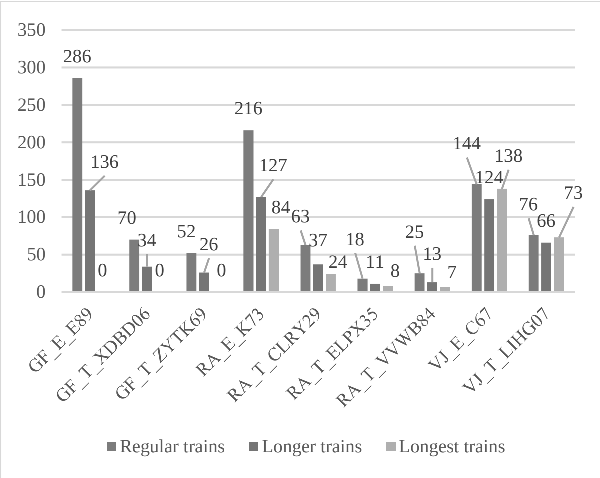

Figure 5: Late train arrivals per selected locations.

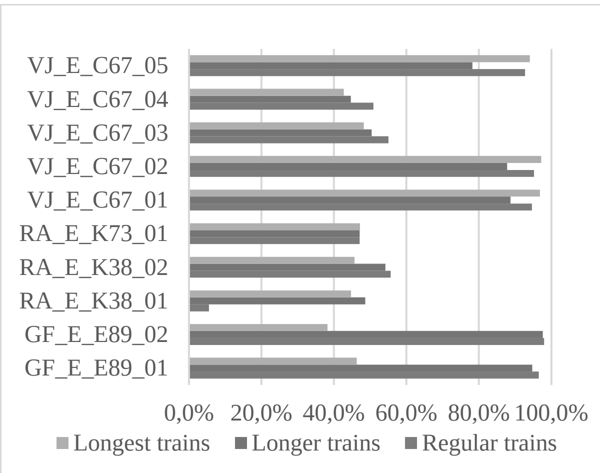

Figure 6: Comparison of occupation in 10 busiest bundles in shunting yards.

The biggest gains in reducing occupation come from alleviating network interdependency effects, when capacity is needed for trains exiting the port network while sidings are used by incoming trains, which in turn cannot proceed due to terminals being full.

	Regular Trains	Longer Trains	Longest Trains
Average [h]	27.2	25.4	24.1
Std. dev. [h]	18.9	16.9	16.1
Min [h]	8.4	8.4	8.4
Max [h]	118.9	107.0	84.3

Table 2: Train turnaround times.

This is especially visible for shunting yards servicing several locations of similar transportation volume, where traffic can overlap. Currently, the deadlock prevention algorithm only ensures that there is a way for trains to carry out their routes but does not balance the incoming and outgoing trains.

In some locations though, where infrastructure is older, a new type of problem starts to occur with a greater percentage of long trains. Where not all sidings can accommodate long trains bottlenecks form around those sidings, while the remaining sidings remain underutilised. Furthermore, the processing times at shunting yards for longer trains are also longer accordingly, thus in some busy, though manageable, locations the total occupancy can increase.

A similar improvement pattern to late arrivals can be seen when looking at the turnaround times of trains, as presented in Table 2. It also shows the extent of congestion experienced in the port, with very high standard deviation and unrealistically high turnaround times of many trains. While such schedule would be impossible to execute, it is possible to model the outcome if one nevertheless tries.

A one-tailed t-test between the regular and longest scenario results shows a significant difference between the means of the subsets with a p-value of 6.63E-12. Thus, using longer trains in this case has a positive impact on reducing train turnaround times. That is despite the effect that longer trains should have longer turnaround times due to longer processing times.

4 Conclusions

This paper investigates how increasing train length can influence transportation of goods in a port rail network, whether it is possible to maintain the total volume while decreasing congestion and delays. Means to carry out the shift to rail in the European Union are urgently needed and the evaluated case has often been proposed as one of the main solutions. It has, however, not been sufficiently studied within port areas and for cargo handling operations. We utilize a MILP optimization to create a schedule and a microscopic discrete-event simulation to evaluate it on the infrastructure of the Port of Rotterdam. Only by accounting for actual train operations and interactions among them a representative picture of network-wide effects be achieved.

Increasing train length has beneficial effects on the overall ability to transport more cargo and reduce train delays. This is visible in the lower number of trains exceeding the schedule, shorter turnaround times, and lower shunting yard occupation on average. While it will not be sufficient to allow the Port of Rotterdam to manage all envisioned cargo, especially that in some areas the benefits are very limited, it certainly is a viable partial solution. Fewer trains transport the same volume that results in lower congestion in the system and less waiting time.

The gains due to longer trains are limited by the maximum train length, existing infrastructure, and the fact that some trains already are this long. Then, with longer processing and supporting operation times on fewer suitable sidings more congestion forms around them, while shorter one may become underutilised.

Further interventions need to be explored before the full expected volumes can be realised. To alleviate congestion on shunting yards with varying siding length, splitting trains should be considered, despite its operational difficulties. Improvements to routing, especially performing supporting processes in less congested shunting yards and then longer shunting with diesel locomotive to the terminal should be considered as well. Furthermore, measures to balance the number of incoming trains with regards to trains already in the system, would likely be advantageous. However, that would require consideration of possible alternatives in the real system, i.e., where to park the trains that is not on the main line. In the end it is possible, that additional infrastructure investments are necessary to realise the predicted cargo volume.

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Truck Shuttle Simulation between Production Plant and Logistics Centre: Data Acquisition and Preparation

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Abstract. The present text reports on data acquisition and preparation in a simulation for evaluating a planned truck shuttle operation from a production facility to a logistics centre. Special aspects include the development of time intervals for the provision of finished goods that must be transported to the logistics centre by truck. Furthermore, the text describes how the travel time between the production facility and the logistics centre can be determined using various approaches. Finally, the results demonstrate the impacts that a more detailed consideration of the aforementioned aspects can have, particularly with regard to dynamic truck allocation and production planning.

Introduction

Manual loading and unloading using forklifts involves considerable truck downtime, forklift operation and corresponding costs. Therefore, automated truck loading systems (ATLS) are increasingly used for regular transport routes [1].

Figure 1: Picture of an automatic truck loading system [2].

This applies in particular to short transport distances, as the time spent on loading and unloading is greater in relation to the travel time and automatic loading and unloading therefore offers considerable savings potential [3].

Automatic loading systems are also suitable in the case of a correspondingly high loading volume [4]. Depending on the selected loading system, the loading time can be reduced from approx. 40 minutes for manual loading and unloading to approx. 5 to 8 minutes for automatic loading [5].

In addition to the benefits of minimized loading time, ATLS increase occupaional safety and can be directly connected to appropriate warehouse management systems.

Furthermore, ATLS offer the possibility of loading outside regular working hours, as no forklift personnel are required [7].

In addition to the benefits of minimized loading time, ATLS both, the installation of the loading and unloading equipment in the production plant and logistics center and the equipment of the truck trailers, involve significant investments [8].

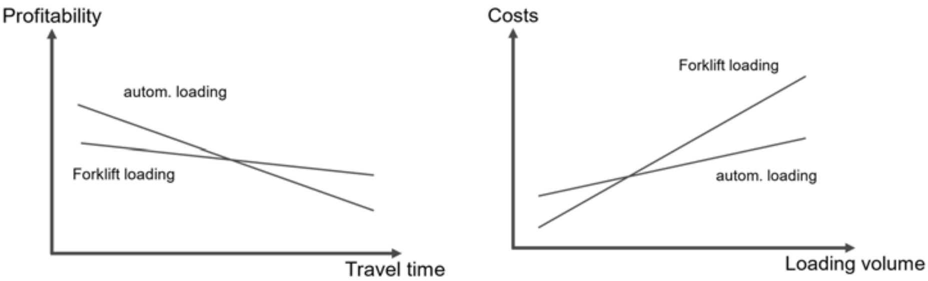

Figure 2: Profitability vs. travel time & costs vs. loading volume [6].

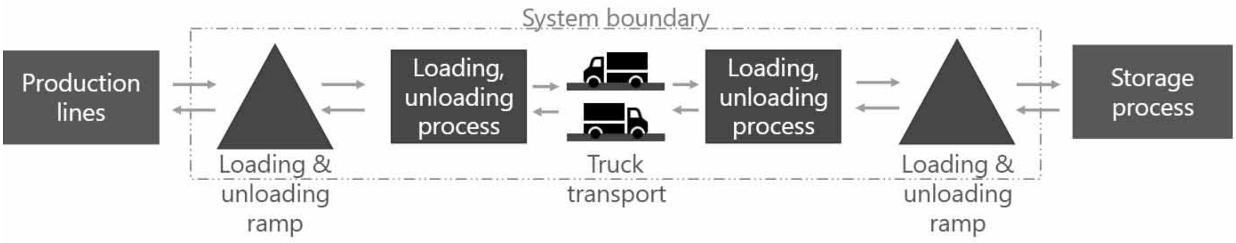

Figure 3: System boundaries.

Therefore, the number of necessary loading and unloading facilities as well as the number of truck trailers must be determined as precisely as possible during the design phase. However, a static consideration with average travel times and average loading and unloading times is not sufficient. A dynamic consideration over time is required.

Thus, the process from the provision of the finished goods to the loading and unloading process as well as the transport is mapped. A mapping of the respective production and detailed putaway processes does not take place.

Overall, the production plant is divided into two production areas.

1 The System

A company from the beverage industry is also facing this challenge. In cooperation with AcuroSim, a transport concept (including automatic loading systems) from the production site to the logistics centre, approx. 20 km away, is to be developed and optimized.

The following questions are in the focus:

- What influence do different routes have on the transport capacity on the respective weekdays and at the different times (24/7)?
- What influence do different production schedules and product/line combinations have on the transport requirements?
- Which concept of automatic loading systems in the production area and in the logistics centre are most suitable?

In order to investigate these issues also taking into account the dynamic aspects, especially due to the influence of traffic or the different production schedules, the company decided to use a simulation.

Figure 3 shows the system to be modeled including the corresponding system boundaries.

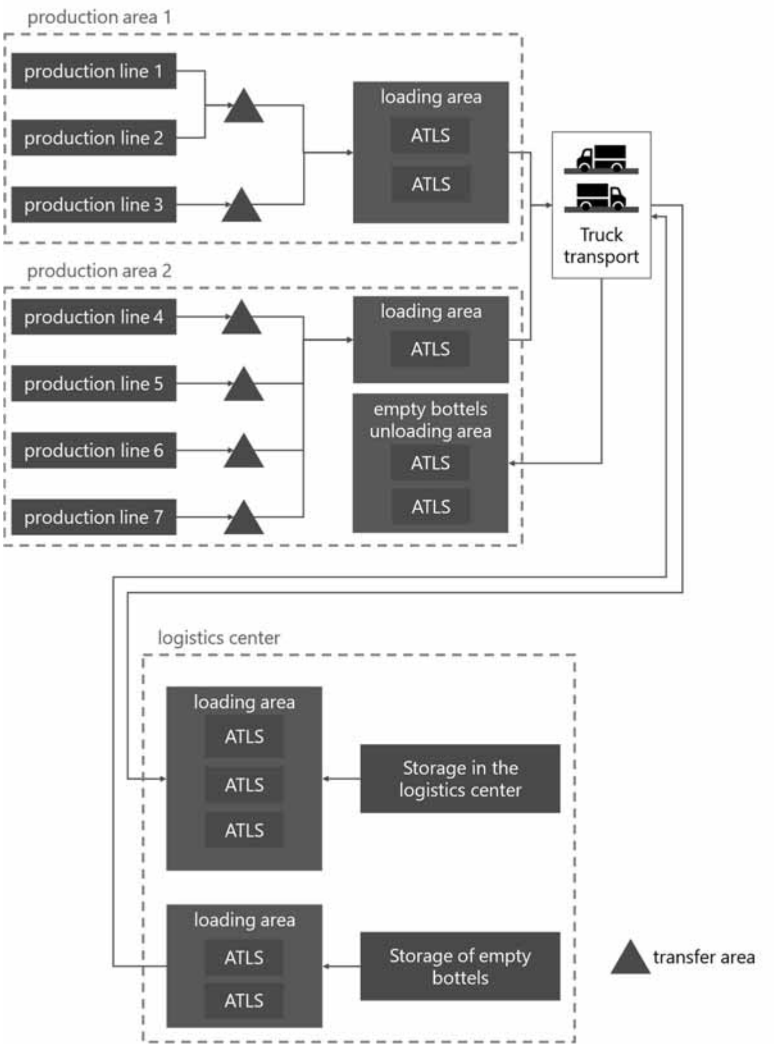

Figure 4: Simplified representation of the material flow.

In production area one, there are a total of three production lines that produce finished goods ready for transport. The finished goods are provided on a corresponding Euro pallet (EPAL).

Two automatic loading systems are available for this area. The corresponding production lines are connected to the respective automatic loading systems by means of appropriate conveyor technology (continuous conveyors). Production lines 1 and 2 fill the first ATLS, while production line 3 supplies the second ATLS. The installed production capacity of line 3 is about twice as high as that of lines 1 and 2.

In production area two, there are a total of four more production lines, but with a significantly lower production output compared to lines 1-3. One automatic loading system is available for loading the finished goods onto the corresponding truck. The production lines in production area 2 (production lines 4 to 7) are also connected to the automatic loading system. In addition, there is the option here of manual removal and feeding of EPAL by a forklift operator. This is not provided in production area one. In addition, two further automatic loading systems are available in production area two. These are intended exclusively for the delivery of empties.

Three potential routes are available for transport between the production plant and the logistics center. These differ on the one hand in their length and travel time and on the other hand in the traffic load (see Table 1).

Route	Length [in km]	Ø travel time [in min]	Traffic load
1	12.1	20.1	medium
2	8.6	17.5	high
3	17.4	22.5	medium

Table 1: Comparison of the routes.

Once at the logistics center, three automatic loading systems are available for receiving finished goods. Two ATLS are provided for receiving finished goods from production area 1, while the third ATLS is provided for receiving finished goods from production area 2.

Furthermore, two additional automatic loading systems are provided in the logistics center, which supply the required empty bottels to production area 2. Depending on the demand in the production plant, corresponding empties can be picked up and transported to the production plant.

2 Problem / Challenge

A total of several hundred different products are manufactured, packaged and then palletized on seven production lines.

The execution of the simulation study to validate the transport concept is oriented in the procedure of VDI 3633. Thus, following the goal description and the task definition, the planned system was first analyzed and described in a concept model. This was followed by formalization and implementation. In parallel, the collection and preparation of the required data as well as a V&V of the respective phase results took place [9].

In particular, the acquisition of the data in the necessary quality proved to be a complex and time-consuming process. This is especially true for the data that have a significant impact on the simulation results.

Among other things, the time period in which finished goods are made available for removal from the production line has a significant influence. This data is needed to simulate when the capacity limits of the buffers between the production lines and the loading systems are reached and an automatic shutdown of the production lines, due to the backlog, is required.

Likewise, the transport route and thus the travel time of the trucks has a relevant influence on the simulation results. This time can vary depending on the selected route, day of the week and time of day. Accordingly, a correspondingly meaningful data basis is also required here.

In addition to obtaining the necessary data, other restrictions must be taken into account in the simulation model. For example, the truck capacity for the number of pallets is limited to 30. These are arranged in the truck on 3 rows of 10 pallets each, whereby the loading of the 3 rows always takes place in parallel with an article from one production line. This is necessary because the finished goods are to be stored in the logistics centre in an article-specific manner with a triple stacker. The article-specific loading sequence of the 3 rows is determined by the incoming production quantity per production line. Due to the load securing specifications, care must be taken during loading to ensure that complete rows of pallets are always loaded. Thus, the number of EPAL is always a multiple of three. (see Figure 4)

In addition, it must be ensured during loading that the maximum permissible load of 22.5 t per truck is not exceeded. With the variety of different products, the weight per pallet varies between 600 kg and 1,000 kg per pallet.

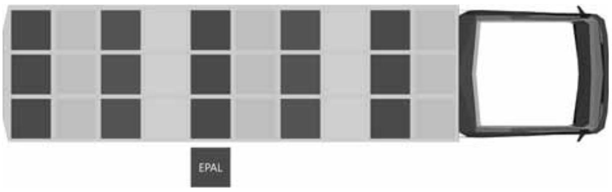

Figure 5: EPAL layout on the truck.

Thus, depending on the product produced, the maximum payload can already be exceeded after 21 pallets (worst case). Theoretically, it is still permissible to take on an additional pallet due to the payload of 22.5 t, but this is not permitted due to the restrictions on load securing described above.

The production schedule and the articles to be produced also influence the output of the different production lines. Thus, the output varies between 8 EPAL and 40 EPAL per hour.

3 Determination of the Data

In the area of finished goods provision, only the peak output of the respective production lines is known. Due to technical malfunctions, setup times, cleaning times, etc., the real data deviates from these theoretical peak outputs, in some cases considerably.

Furthermore, different products, packaging forms and production schedules influence the throughput of the respective production lines. Thus, the representation of the peak output in the simulation model does not provide a sufficient data basis.

In order to obtain the required data, it is possible to perform a manual time recording per production line and product [10]. However, this is associated with a high effort. Alternatively, it is possible to install an automatic counting device temporarily. This is associated with corresponding costs and also, due to the short recording period, does not result in sufficient data accuracy.

In practice, data is often collected and stored in certain application areas for various reasons (energy consumption, quality aspects, etc.), but not used further. This is also the case on production lines, in the area of palletizers.

At the end of the respective production line, each finished goods pallet is provided with a pallet label and the number of the shipping unit, or NVE for short [11]. This is applied by an automated label application. During this process, data on item number, order number, batch number, number of products, weight per pallet, and a corresponding time stamp, among others, are recorded and stored in a database for tracking purposes.

By means of the recorded time stamps and the differentiation per article number, the time intervals for each product can be de-termined by a corresponding data analysis.

For this purpose, with 7 existing production lines and more than 200,000 data entries per production line and year, over 2 million data records have to be cleaned and evaluated. Furthermore, these data have to be combined to meaningful product families.

In order to transfer the data into a distribution for the corresponding arrival interval of the article-specific pallets, the data preparation was automated. This procedure allowed realistic arrival intervals per product to be taken into account in the simulation model.

For this purpose, the time difference per EPAL was first determined for the same article. The respective intervals were then subdivided into corresponding product families. The assignment to the respective product families was specified by the industrial company. In the next step, the time intervals were transferred to a histogram and analyzed. In some cases, significant differences in the time intervals were identified. The time intervals were between approx. 1 minute and 1.5 days. These differences were caused by longer downtimes of the production lines or manual interventions. Reasons for this include technical malfunctions, as well as maintenance or repair measures or extensive cleaning.

In cooperation with the industrial company, corresponding upper limits were then defined for the histogram depending on the production family and production line. These still include the influence of corresponding course time disturbances, but filter out the influence of major disturbances and maintenance.

The final distributions were then saved in an appropriate file format and made available to the simulation model. In addition to the time intervals, the pallet weights were also evaluated and assigned to the respective product families in order to also take these into account in the simulation model.

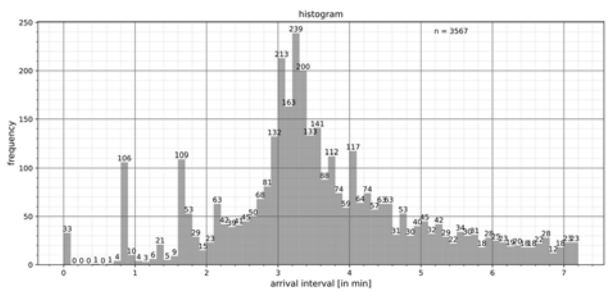

Figure 6: Processed data of a product.

No data is available for truck travel time because the logistics center is still under construction. Here, three possible methods were evaluated for determining the missing information:

The first method is the calculation of an estimated time of arrival, or ETA. Here, the estimated time of arrival is determined on the basis of the current vehicle speed, the day of the week, the time and the current traffic situation. By using historical data, it is possible to evaluate different transport times for the respective weekdays and times. The accuracy depends on the number of available data sets and the vehicle used (car vs. truck). Furthermore, the accuracy is much better for longer distances than for short distances, since individual stops have a much greater impact for short travel times than for longer distances. Sufficient data is available for heavily traveled routes and highways, such as long-distance traffic. For rural or county roads, these are often missing. This makes an ETA calculation for these routes inaccurate.

Due to the rural region of the production plant and logistics center and the use of predominantly rural and county roads, this approach does not provide sufficient data quality for determining travel time. Furthermore, depending on the service provider, the calculation of the ETA does not distinguish whether the vehicle under consideration is a car or truck.

An alternative to the calculation of the travel time can be provided by data from electronic traffic counts. These can be used to derive speed profiles for certain subroutes depending on the day of the week and the time of day. However, the number of such facilities in rural areas is also limited. In the context of the project, a maximum of two facilities were available that could be used to generate speed profiles for partial routes. Due to this, a sufficient amount of data cannot be provided via this approach either.

Thus, a manual time recording of the transport times had to be resorted to. For this purpose, it was precisely defined from which point the time recording starts and from which point it ends. The time, the day of the week and other comments were also recorded. This was done several times for each route using GPS trackers carried in the truck. The average travel time for each time of day and route is shown in Figure 7.

The data obtained in this way revealed in some cases considerable time differences. In particular, slow vehicles, such as agricultural vehicles, which cannot be overtaken in some sections, cause the average transport time to increase from about 20 minutes per trip to up to 30 minutes and more.

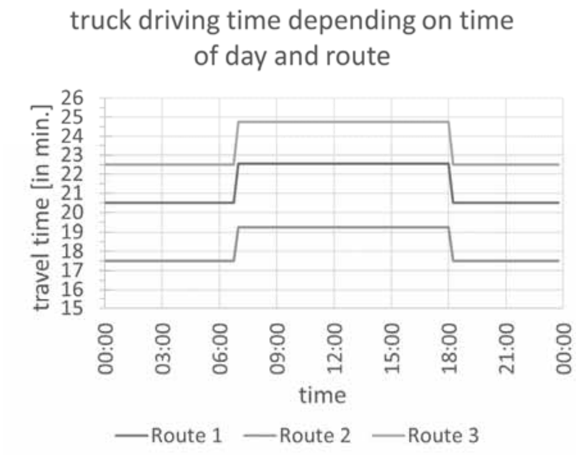

Figure 7: Average travel time per route and time.

In order to take these dynamic influences into account in the simulation as well, a transfer of the recorded trip data into an appropriate distribution (per weekday and time) is necessary. However, the amount of recorded data was not sufficient to derive such a distribution. Only the average transport time from Figure 7 was determined and confirmed by the empirical experience of the truck drivers.

Nevertheless, in order to derive an appropriate distribution of travel times, empirical values of the statistical fluctuations in the ETA calculation for short distances (10 to 30 km) were used [12]. With this information, the distribution of travel time for the simulation was modeled. Figure 8 shows such a distribution for Route 1 and the time of day 12:00. Finally, these distributions were also validated with the experienced truck drivers and checked for plausibility.

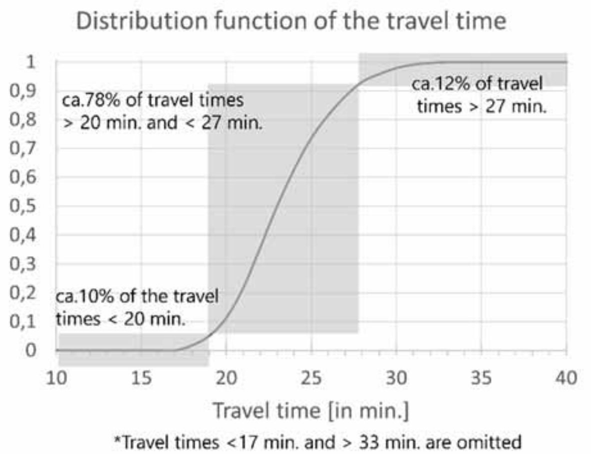

Figure 8: Distribution function of travel time for route 1 (12 o'clock).

4 Simulation Model

The simulation model is mapped in the WITNESS Horizon simulation software. For this purpose, the system components described in chapter 2 and the re-strictions explained in chapter 3 (load securing and maximum permissible load) were mapped, verified and validated.

The production lines are stored in the simulation model as a corresponding source. A production plan including setup times and cleaning shifts can be stored for each production line. The time to generate an EPAL is product-specific using the histograms described in chapter 4.

The transfer area maps the capacitive buffers between the respective production lines and automatic loading systems. In addition, a minimum dwell time is provided for this area, so that the corresponding transfer times are taken into account. A mapping of the control logic of the conveyors as well as like the respective conveyor speed is not necessary due to the negligible influence.

Following the transfer area, the simulative mappings of the automatic loading systems take place. The area ATLS-L marks the systems which are used for loading a truck. The area ATLS-U marks automatic loading systems, which are used for unloading a truck. An automatic loading system that performs both loading and unloading operations is not currently intended. With the loading systems shown, 30 EPALs can be loaded in approx. 2.5 minutes. In addition, the simulation model also provides for a reversing process of the automatic loading systems.

This is carried out as soon as there are residual pallets on the automatic loading system after the loading process. This occurs, for example, if there are 30 EPALs on the automatic loading system, but only 27 EPALs can be picked up due to weight restrictions. The three remaining EPALs then go through the reversing process.

In the case of the implemented ATLS, which are intended exclusively for unloading a truck, a simplified storage process is also implemented. This represents a simplified unloading of the corresponding ATLS. This ensures that after unloading a truck, another truck cannot be unloaded immediately. This is only possible once the corresponding EPALs have been removed from the respective ATLS. Since these storage processes are a manual activity, the storage time is provided with a corresponding Erlang-K distribution [10].

In the SE area is the provisioning of the empties. This is generated as soon as the demand is triggered in the production area. Subsequently, the provision of the necessary empty material takes place in a quantity of 30 EPAL in a time interval of approx. 25 minutes. After provisioning, the material is picked up by a truck. Due to the manual provision of the empties on the corresponding loading system, this time is also provided with an Erlang-K distribution.

The area R marks the implementation of the different routes. Here, the corresponding travel times incl. distribution (as described in chapter 4) are stored in the simulation model.

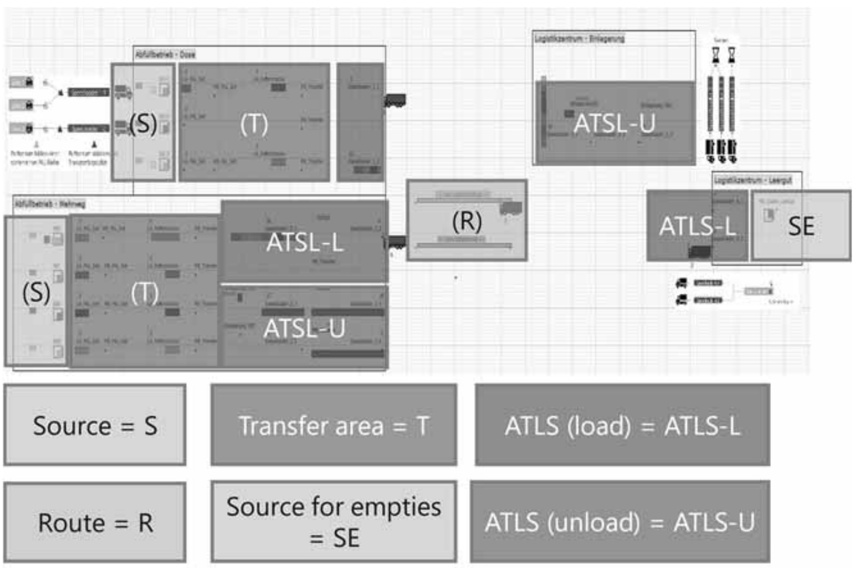

Figure 9: Simulation model overview.

For the outward as well as for the return journey one of the three routes can be selected in each case and thus the influence on the total system can be examined.

For the later analysis of the simulation model, various parameters and performance diagrams are implemented.

For example, the number of the respective transports including the number of EPALs transported, the weight of the payload and the kilometers traveled are recorded.

In addition, the utilization of the respective trucks per shift or the backlog behavior of the production lines are recorded.

This information can be used, for example, to examine how many trucks are needed depending on different production schedules and routes, and whether it is advantageous to use jumpers during breaks for the truck drivers.

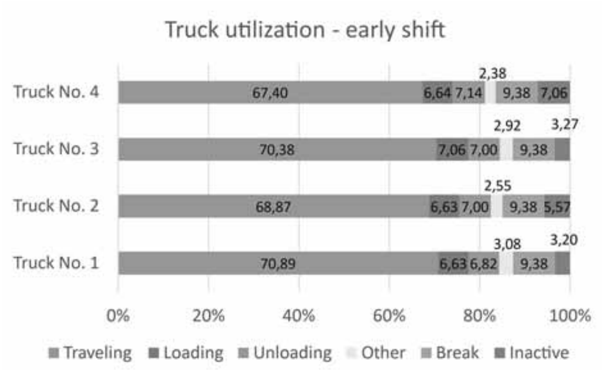

Figure 10: Example diagram - truck capacity utilization.

5 Results

With the help of this data, it was possible to evaluate different, realistic influences with regard to production planning and the significant influence of the driving time of the trucks. With only an average driving time and the respective peak load per production line, this would not be possible and a significant overdimensioning of the installations would be the consequence.

Among other things, it was possible to show what effect different production schedules (high output products vs. low output products) have on the risk for backlogging (see Figure 10). Especially during daytime periods with increased traffic volumes. This made it possible to derive corresponding recommendations for production planning, for example the production of certain product-line combinations at certain times of the day.

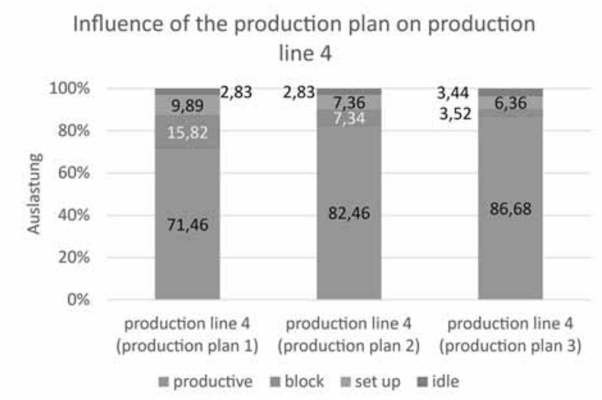

Figure 11: Comparison of the backlog of production line 4 with different production schedules.

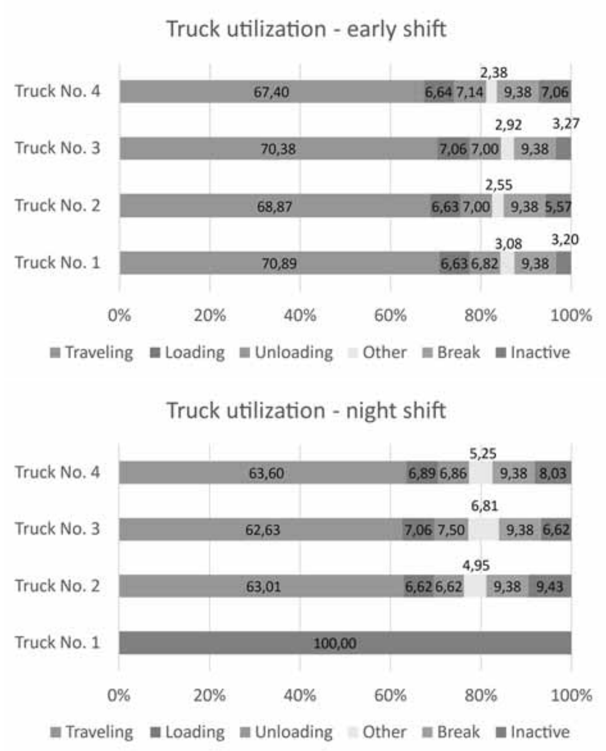

Figure 12: Utilization of trucks in early and night shift.

In addition, it was possible to show when there is an additional need for trucks or when a lower number is sufficient. For example, a number of four trucks is required for the production schedule in the early shift. During the night shift, on the other hand, 3 trucks are sufficient (see Figure 12). This led to initial considerations about implementing flexible personnel deployment in the area of truck transport and a dynamic break arrangement for truck drivers.

Furthermore, it could be shown that a higher loading capacity is available in production area 2 than for the unloading of finished goods from production area 2 in the logistics center. This resulted in waiting times for the trucks, as only an automatic loading system was provided for unloading the finished goods. The bottleneck here is not the unloading speed of the automatic loading systems, but the storage time in the downstream block storage. Thus, there was the possibility to invest in an additional loading system for the unloading of finished goods from production area 2. However, the simulation showed that breaking the strict allocation of an automatic loading system for the unloading of finished goods from production area 2 is sufficient to reduce waiting times to a minimum. Thus, no additional investment in another loading system is required.

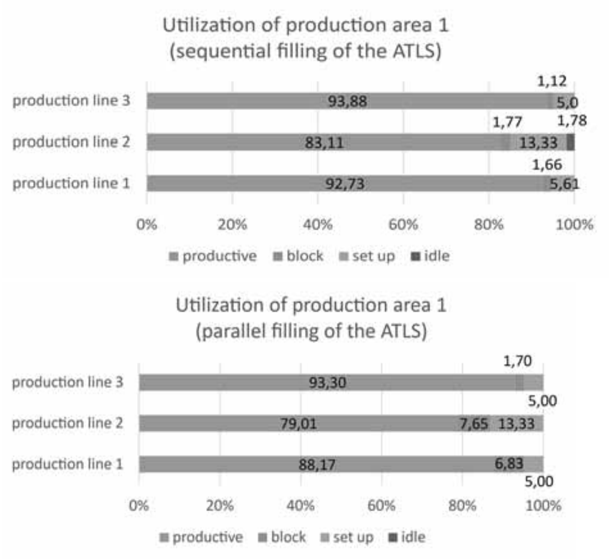

Figure 13: Influence of parallel and sequential filling of ATLS in production area 1.

The simulation was also used to check the connection of the production lines from production area 1 with the corresponding automatic loading systems. In initial concepts, as already described in Chapter 2, it was envisaged that production lines 1 and 2 would be connected to an automatic loading system, while production line 3 would be connected to the second loading system. Thus, production lines 1 and 2 fill the first ATLS while, in parallel, production line 3 fills the second ATLS. In the simulation, however, this led to a corresponding backlog in production lines 1, 2 and 3 (see Figure 12 - block). Only by adapting this concept was it possible to resolve the backlog. In the future, both automatic loading systems in production area 1 will be filled sequentially from production lines 1, 2 and 3.

In addition, further measures could be developed to optimize the corresponding transport concepts and reduce the risk of a production stop.

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Simulation, a Tool to Improve the Medical Equipment Production Line

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Abstract. Population growth affects human activities and increases the demand for healthcare goods and services. This results in companies seeking to serve customers better while maintaining quality, timeliness, and fair pricing. This paper presents a discrete event simulation exercise carried out by implementing a 6 steps methodology of our own to achieve greater efficiency in the production of orthopedic products and be able to meet sales commitments. For this, different preliminary activities were carried out, such as the identification of work areas, the process mapping, the recording of operational data linked to production and their analysis, the elaboration of an influence diagram and the development of the model for the simulation.

Using simulation allowed us to identify factors of use in machinery and operators, bottlenecks, use of resources (raw material), among other aspects. Likewise, variations were made in the model to solve the problems encountered and prepare the final recommendations to achieve a better operation. The significance of implementing a related methodology and the advantages of using scientific knowledge to resolve issues are highlighted by this simulation exercise. The article's value is demonstrated using prescriptive simulation as an analytical tool for decision-making in small businesses.

Introduction

Mexico is a country with a medical industry that is growing exponentially. According to the institution "Instituto Nacional de Estadística y Geografía" (INEGI - for its acronym in Spanish), the production value of the disposable medical material sector in Mexico reached 740 million dollars in 2021 growing 11.1% with respect of 2020. Mexican exports of medical equipment experienced a growth of 8.6% year over year from 2003 to 2020 [1].

The market intelligence company "Espicom" points out that in 2011 the Mexican medical equipment market valued at 3.5 billion dollars, and thus consolidates as the second most important in Latin America, behind Brazil [2]. In addition, ever since 2017 Mexico has maintained the eighth place in exportation of medical devices globally, and it is also the leading supplier to the biggest market in the world (United States of America) with a market value that reached 9 653 million dollars in 2021 [1].

Due to this information, it is easy to perceive how important the medical sup-ply industry is for the Mexican economy, or at least it is perceivable how much potential this industry has in said country. Due to this, we have decided to con-duct research in a small company dedicated to the production and distribution of medical equipment to analyze the opportunity areas it has in terms of its production line and how simulation can help improve its processes.

The research will mainly focus on what this small company´s owner has detected is its main problem: Delays. This will have especially insight value due to being a common problem among small Mexican companies whose failures to deliver on time often results in them losing the confidence of their clients and, therefore, also results in financial loses.

The research this will also be extremely useful in understanding how this kind of problems affect at a big scale Mexican economy since, as stated by research conducted by the United Nations, as the size of the companies increases, the added value and investment also rise. The greatest dispersion is located in micro companies and large companies [3]. Meaning the smaller the company, the less productive it is, this is quite problematic they represent 99.8% of the total businesses in Mexico [4].

Researching this scenario, we worked on a discrete event simulation model that compared the system as it is to a proposed process with an additional number of workers performing in each sample of the process.

We also approach a solution corresponding with the implementation of new production machines for some of the most time-consuming activities (bottlenecks), and finally comparing the full time of a process (in certain products) against the older machine models as well as total production for a typical day.

1 State of the Art

As previously stated, and since this paper´s focus is on a small company, minimizing production costs is critical to keep the process of this company flowing. Therefore, analyzing the efficiency of the machinery utilized by the company is critical, since it is speculated that poor maintenance and years of work of the machinery is one of the primary causes of the company's production problems.

As stated, every tenth of a second shorter production cycle led to severe cost advantages, but machinery is not only important because of this, but also because some parts are only produced in the desired design and characteristics, if primary shaping technologies are used [4], for this reason we are not only analyzing and simulating the as is process with just the already available assets of the company, but also considering the comparison between only using the old machinery and utilizing newer models to prove the hypothesis that this is a major problem in the production line.

Obsolete machinery is one of small businesses main issues, especially in the medical products manufacturing industry. The advancement in various technologies have changed the way the healthcare industry approaches its work and the way they take corrective steps for betterment in their work routine [5].

Due to the pandemic, the healthcare and medical industries were forced to adopt newer technologies. This was a huge blow to small manufacturing companies like the one we are studying, that's why analyzing the upgrading of equipment is so important papers must be written in English. Make good use of the spellchecker and ensure that automatic hyphenation is activated.

2 Methodology

[6] affirms that simulation can be defined as the imitation of the operation of a real-world process or system over time. It can be classified by the variables being used as: static or dynamic, stochastic, or deterministic and discrete or continuous events; depending on the use case you can use one or another.

To conduct the simulation project for this paper we used the following 6 steps, to identify the problem of the company and construct a model that represents reality for it to be adjusted to propose changes. These 6 steps align to [8] and [9] proposed methodologies (Figure 1).

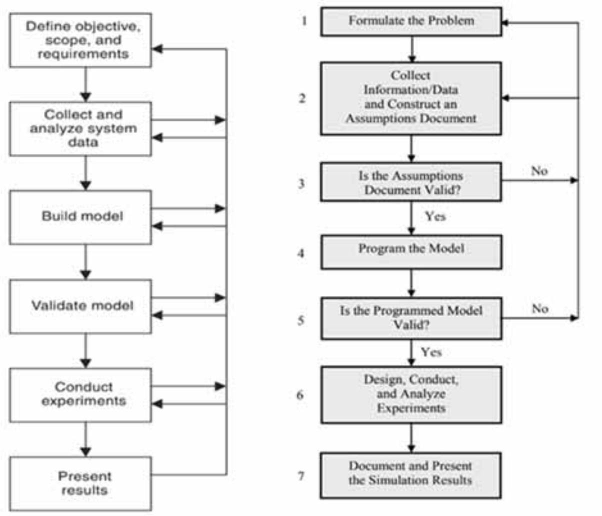

Figure 1: Proposed methodologies to conduct a simulation study by Harell (left) and Law (right). Source: [7] & [8].

2.1 Problem formulation

Small and medium Mexican companies are trying to fulfil the increase in medical equipment demand due to greater consciousness of health necessity. In this paper we discuss about a small company dedicated to the manufacture and distribution of a wide range of orthopedic products.

There are six workers at its facilities located in Mexico City, the roles are composed by a general manager, a person in charge of the director's personal administration area, the reception area, one person in the manufacturing area, one in the billing area, and another one in the shipping area where the finished product is received and distributed, the layout of the facilities is presented on Figure 2, as seen the company has little space to work with, this may result challenging when proposing changes to the system, the material flow diagram will be discussed in a later section, providing a more detailed analysis of the physical arrangement of the company's infrastructure.

The main focus of the analysis is on the company's total production output. This includes an examination of the production process, capacity utilization, and any factors that may impact the company's ability to meet production targets.

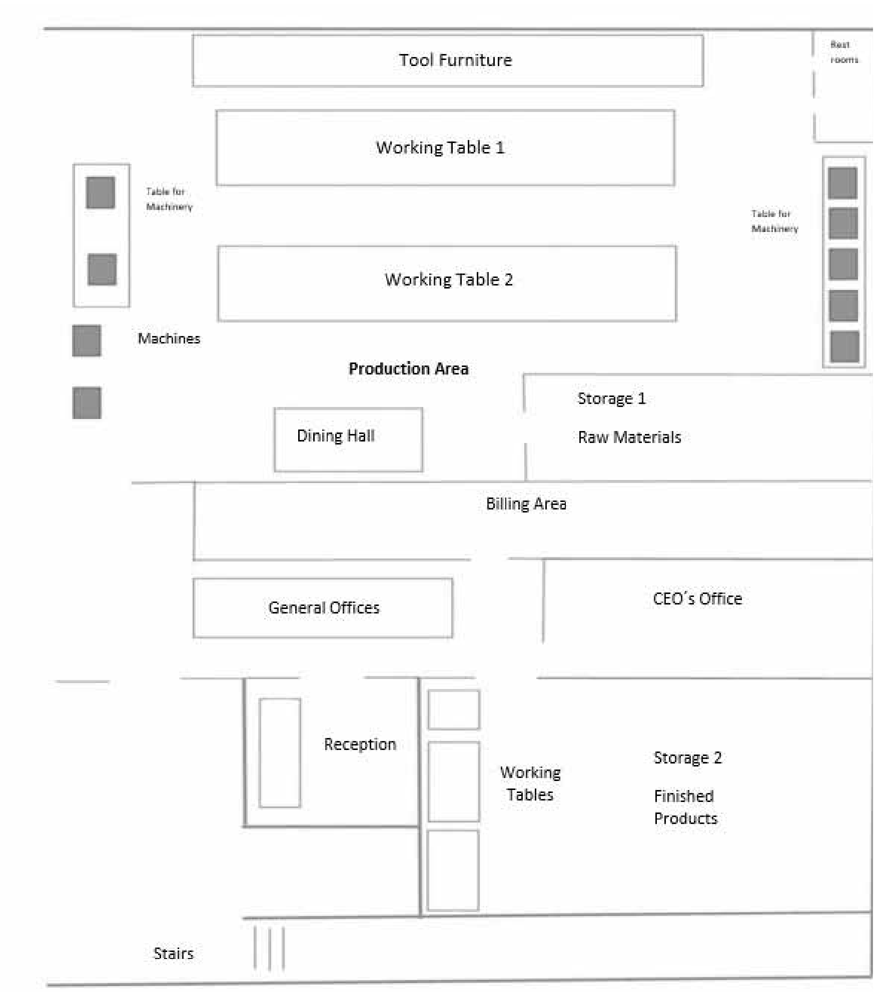

Figure 2: Company layout. Source: Own elaboration.

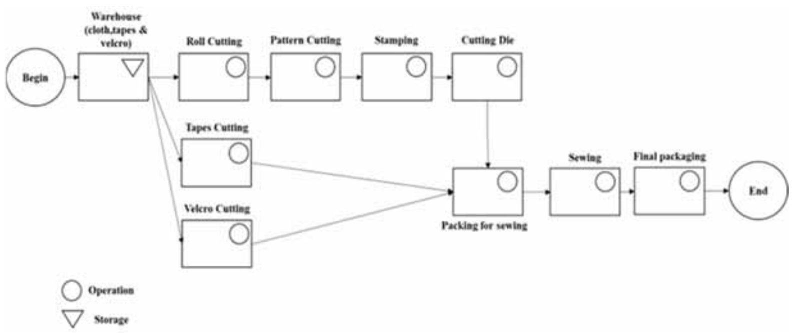

Figure 3: Slings production process. Source: Own elaboration.

By assessing these factors, and with the help of simulation, we can identify areas for improvement and implement strategies to enhance overall production efficiency.

The company must fulfill daily orders of at least 30 slings to keep up with demand, have a positive return of investment and not damage client relationships. Upon analyzing the process, it becomes apparent that the operator faces challenges in meeting their delivery targets. Additionally, the operator relies on only two fabric cutting machines, which are now deemed outdated and may result in potential delays in meeting deadlines.

To identify the root cause of issues within the production line, it was determined that a discrete event simulation could be employed.

During the formulation stage, the objective was defined as simulating the production line of a slings order to ascertain daily production rates and determine the utilization factor of both the operator and machinery.

2.2 Data Collection

For collecting the data, we used a mixed methodology in which we recorded the production of various badges of slings as well as using stopwatches and verifying the times with the managers and owners. The collection was done in different days and times considering external factors that may affect the productivity, such as operator fatigue, climate, and light conditions.

To identify the data to collect used the classification propose by [7]; first structural data what refers all the areas, objects and resources of the system to simulate, operational data this explain how the system objects are processed in the different areas using the resources of the system and finally the numerical data some examples of numerical data are the number of resources (machines, people, etc.), process times and routing probabilities.

Area	Activity	Activity Resource	Next area	Distance meters	Moveent Resource
Warehouse	Supply	Operator	Cut	2.3	Operator
Roll cutting	Cut	Operator	Pattern cutting	1.1	Operator
Ribbons cutting	Cut	Operator	Packing for sewing	2.2	Operator
Velcro cutting	Cut	Operator	Packing for sewing	2.6	Operator
Pattern Cutting	Cut	Operator	Stamping	1.6	Operator
Stamping	Stamp	Operator	Cutting Die	1.3	Operator
Packing for sewing	Pack	Operator	Sewing	4	Operator
Sewing	Sewing	Operator	Final Packing	4	Operator
Final packing	Pack	Operator	-	4.6	Operator

Table 1: Flow chart description (operational data). Source: Own elaboration.

The structural data for the production line are warehouse (cloth, ribbons and velcro), roll cutting, pattern cutting, stamping, cutting die, ribbons cutting, velcro cut-ting, packaging for sewing, sewing and final packaging (see Figure 3). The operational data consists in observing the sequence of the processes of the different components in the areas (see Table 1). Some numerical data are showed in table 1, this refers to the distance between areas.

Additional numerical data that was collected includes process times for each activity we used 50 data points and this data was analyzed with descriptive statistics, independence tests and goodness-of-fit tests.

In the Figure 4 we show one example of the scatter plot used to determine the independence of the data, this scatter point diagram represents the data in a plane composed by the current data point observed vs the next data point [xi+1,xi], in Figure 5 see an example of an autocorrelation dia-gram, another way to determine the independence of the data, in the x axis 1/5th of the data introduced to the analysis is presented since data was collected in an stationary production thus the variance for the whole sample can be used to represent the variance of any subset. For a simulation study, this may mean discarding an early warm-up period [10].

And finally in the Figure 6 we show an example of run test (median & turning points) on the software StatFit® which determines the randomness of a dataset considering first the number of runs of points above or be-low the median and then the number of times the series changes direction, here level of significance must be low for it not to reject the hypothesis that the data set is random.

Additional numerical data that was collected includes process times for each activity we used 50 data points and this data was analyzed with descriptive statistics, independence tests and goodness-of-fit tests.

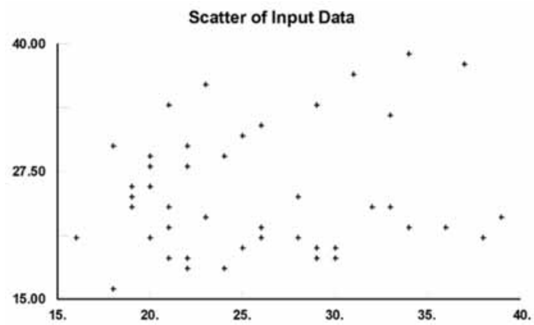

Figure 4: Example of scatter point diagram. Source: Own elaboration.

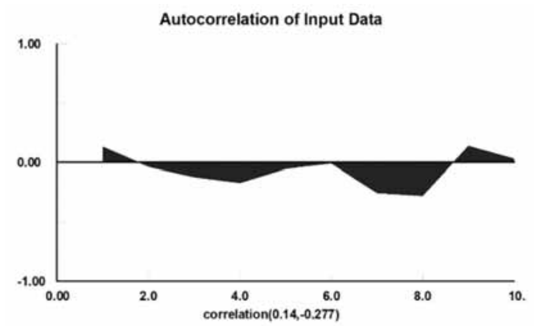

Figure 5: Example of autocorrelation diagram. Source: Own elaboration.

In the Figure 4 we show one example of the scatter plot used to determine the independence of the data, this scatter point diagram represents the data in a plane composed by the current data point observed vs the next data point [xi+1,xi], in Figure 5 see an example of an autocorrelation dia-gram, another way to determine the independence of the data, in the x axis 1/5th of the data introduced to the analysis is presented since data was collected in an stationary production thus the variance for the whole sample can be used to represent the variance of any subset.

Area	Roll Cutting	Pattern Cutting	Ribbons Cutting	Velcro Cutting	Stamp-ing	Cutting Die
Mini-mum	252	1,057	301	5,083	9	1.8
Maxi-mum	284	1,129	338	5,445	33	2.19
Mean	262.72	1,094.6	320.1	5,279.3	18.34	1.9864
Median	262.5	1,090	320	5,287.5	16.5	1.975
Mode	263	1,126	325	5,280	9	1.865
Standard deviation	6.01712	21.2948	10.8801	78.9653	6.69636	0.114031

Table 2a: Descriptive statistics for process time part a (seconds). Source: Own elaboration,

Area	Packaging for Sewing	Sewing	Final Packaging
Minimum	16	316	16
Maximum	26	344	39
Mean	21.44	327.36	25.38
Median	21.5	327	24
Mode	20	327	19
Standard deviation	2.56475	7.92506	5.92432

Table 2b. Descriptive statistics for process time part b (seconds). Source: Own elaboration.

Area	Scatter Plot	Autocorrelation Di-agram	Run Test Median	Run Test Turn-ing Points
Roll Cutting	Ind	Ind	Ind	Ind
Pattern Cutting	Ind	Ind	Ind	Ind
Ribbons Cutting	Ind	Ind	Ind	Ind
Velcro Cutting	Ind	Ind	Ind	Ind
Stamping	Ind	Ind	Ind	Ind
Cutting Die	Ind	Ind	Ind	Ind
Packaging for Sewing	Ind	Ind	Ind	Ind
Sewing	Ind	Ind	Ind	Ind
Final Packaging	Ind	Ind	Ind	Ind

Table 3: Results of independence of data. Source: Own elaboration.

For a simulation study, this may mean discarding an early warm-up period [10] and finally in the Figure 6 we show an example of run test (median & turning points) on the software StatFit® which determines the randomness of a dataset considering first the number of runs of points above or be-low the median and then the number of times the series changes direction, here level of significance must be low for it not to reject the hypothesis that the data set is random.

In Tables 2a and 2b, is shown the summarize about descriptive statistics for the process times of the nine activities (roll cutting, pattern cutting, stamping, cutting die, ribbons cutting, velcro cutting, packaging for sewing, sewing and final packaging), the range of each of the 9 activities is small and this can also be seen by looking at the standard deviation.

The independence test used with the data are scatter plot, autocorrelation diagram, run test (median & turning points), in the Table 3 summarize the results of the four tests for each of nine activities; in this case all the data are independent.

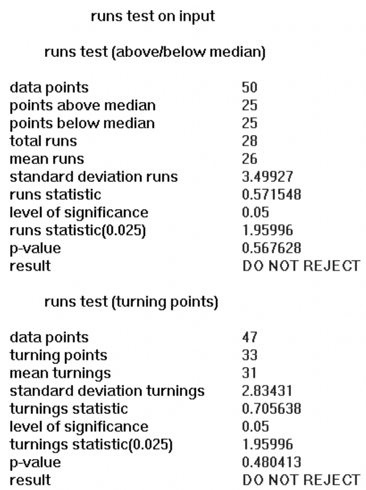

Figure 6: Example of runs tests (median and turning points). Source: Own elaboration.

Finally in the table 4 summarize the distributions used to represent the process times for each activity, this is the result of goodness-of-fit test (Chi square, Kolmogorov Smirnov & Anderson Darling).

Area	Theoretical Distribution	Parameters	Values (seconds)
Roll Cutting	Lognormal	(μ, σ, min)	(244,2.9,0.302)
Pattern Cutting	Uniform	(min, max)	(1060,1130)
Ribbons Cutting	Normal	(μ, σ)	(320,10.8)
Velcro Cutting	Normal	(μ, σ)	(5280,78.2)
Stamping	Lognormal	(μ, σ, min)	(2.78,0.391,0.892)
Cutting Die	Uniform	(min, max)	(1.8,2.19)
Packaging for Sewing	Lognormal	(μ, σ, min)	(6.63,0.00337, -733)
Sewing	Lognormal	(μ, σ, min)	(2.88,0.414, 308)
Final Packaging	Lognormal	(μ, σ, min)	(2.49,0.451,12.1)

Table 4: Distributions used for process time (seconds). Source: Own elaboration.

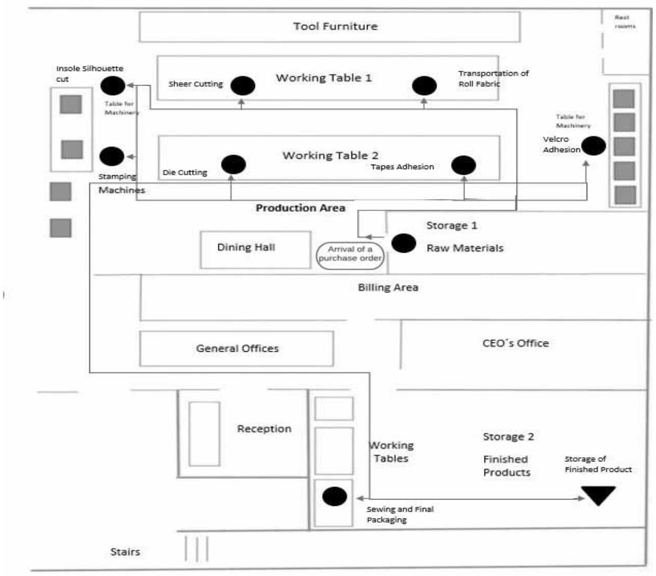

Figure 7: Material flow diagram over layout of the process to simulate. Source: own elaboration.

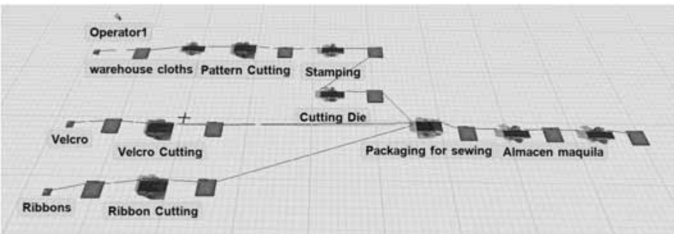

Figure 8: Base model simulation using FlexSim®. Source: own elaboration

2.3 Conceptualization & building a Base Model

Collected data (structural, operational, and numerical data) are used to document the process as closely as possible to the reality and understanding the added value of each step, this conceptualization of the system first was used to elaborate the material flow diagram of the process showed in the Figure 7 which describes how the product is moved from one station to the other in the facilities of the study company. After that a model of the process was created, a representation of this model is in Figure 8.

2.4 Validation of the Model

This step included the verification stage, first the simulation model was executed in the FlexSim software, verifying that no errors were reported and that it operated properly without reporting inconsistencies and checking that the material flow through the production line was respected.

Consequently, with the results obtained from the simulation run, we held a meeting with the stakeholders to determine if the model represented the reality of an 8-hour production of slings in a normal day, doing this meant not only having the approval of the stakeholders but remeasuring each step of the real process to compare the data obtained with the software with the data measured by us. While doing the validation we observed that the model did not present mayor inconsistencies and generally it represented the reality of the production of slings in the company.

2.5 Experimentation

The use of simulation offers a unique advantage in that it enables the generation of various scenarios by adjusting multiple factors, such as changing the layout of the production line, adding new machinery, increasing personnel, modifying parameters, among other possibilities.

By simulating these different scenarios, we can evaluate the impact of each change on production output, efficiency, and resource utilization. This allows for a more comprehensive analysis of potential solutions and provides decision-makers with valuable insights to identify the most effective strategies for optimizing the production process.

Area	Theoretical Distribution	Parameters	Values (seconds)
Pattern Cutting	Uniform	(min, max)	(41.2,48.6)
Ribbons Cutting	Normal	(μ, σ)	(30.8,3.85)
Velcro Cutting	Normal	(μ, σ)	(3.6,5.22)

Table 5: Distributions of new machinery (seconds).
Source: Own elaboration.

Area	Mean	Standard Deviation	Minimum Maximum
Base model	30	0	30, 30
2 Operators	60	0	60, 60
New machinery with 2 operators	85.89	3.496	75, 90

Table 6: Scenarios of sling production (daily).
Source: Own elaboration.

Different scenarios were tested to increase production output; the two main ones were: having an extra operator to help with the first steps of production and buying machinery to help with the most time-consuming process by replacing old machinery with new one.

The first scenario was discussed as the creation of working stations for each operator, by doing this we ensure both work without crossing and disturbing each other. Operator 1 oversaw Roll Cutting, Pattern Cutting, Ribbons Cutting, Velcro Cutting, Stamping and Cutting Die process, while Operator 2 had Packaging for Sewing, Sewing and Final Packaging process. Operator 2 started to work later than Operator 1 since he depends on the later to finish the first batch. For the second scenario we used the data collected to identify the bottleneck, we determined that Pattern Cutting, Ribbons Cutting and Velcro Cutting, were the slowest processes.

With the help of the supplier's expertise and the machine datasheet we developed and iterated two mathematical models to generate a similar distribution for each addressed process and finally using Statfit® software we obtained the parameters for each process. To generate a normal distribution, we used (1) and to generate a uniform distribution we used (2). In addition to the new machinery, a second operator was introduced in the same manner as the first scenario.

$$Ln(F^{-1}_{(p|\mu,\sigma)}) = x \qquad (1)$$

$$(\mu - \sigma/2) + (\sigma * p) = y \qquad (2)$$

Here

Ln is the natural logarithm,
$F^{-1}_{(p|\mu,\sigma)}$ is the inverse of the lognormal distribution,
p is a random probability,
μ is the mean of the expected distribution, and
σ = is the standard deviation.

Finally in Table 5 we present the distributions and its parameters for the new equipment:

2.6 Results Presentation to Stakeholders

The results of the simulation and of the different scenarios were presented to the stakeholders for them to use as best suits them.

3 Results and Discussion

This section presents the study's findings and provides an in-depth analysis of the findings. The collected data was analyzed using descriptive statistics in the form of box and whisker plots, and the results were compared to the collected data to deter-mine whether the objectives had been met.

The discussion will delve into the implications of the findings and their significance in the manufacturing facilities. The sections that follow provide a detailed overview of the results and discussion.

The study aimed to compare the total production of slings in one day under three different scenarios: base model, two operators, and new machinery with two operators.

According to the study's findings, the average sling production in the base model scenario was always 30 slings being the maximum production for one opera-tor. The 2-operators scenario, on the other hand, resulted in a constant production of 60 slings with the same consideration of the first scenario.

Finally, adding new ma-chinery and with the same roles for the two operators the scenario produced 85.89 slings with a standard deviation of 3.496.

These findings suggest that combining new machinery with a two-operator system can significantly increase total sling production in one day when compared to the reality and two-operator scenarios.

In Table 6 we present a summary of production metrics obtained using the FlexSim® Experimenter.
The study also looked at how three different scenarios affected the utilization factor of operators 1 and 2. When compared to the two-operators scenario, the results showed that implementing new machinery in conjunction with a two-operator system significantly increased the utilization factor of operator 2.

In the new machinery and 2-operators scenario, operator 2's mean utilization factor was 94.137 (see figure 13), whereas in the 2-operators scenario, operator 2's mean utilization factor was 78.6294 (see figure 11). In the new machinery and 2-operators scenario, the utilization factor of operator 1 was slightly lower than in the 2-operators and reality scenarios.

In the new machinery and 2-operators scenario, the mean utilization factor of operator 1 was 98.32793 (see figure 12); in the 2-operators scenario, it was 99.30062 (see figure 10); and in the base model scenario, it was 99.32453 (see figure 9). The box and whiskers diagrams show that the differences in the mean utilization factor of operator 1 between the scenarios were relatively small.

Overall, these findings indicate that implementing new machinery in conjunction with a two-operator system can significantly increase operator 2's utilization factor while having a minor negative impact on operator 1's utilization factor. Making the process more productive while balancing the operator capacity. In addition, standard deviation went from 0.2634 to 0.1223 making the production process more consistent and predictable, therefore improving the quality of the final product.

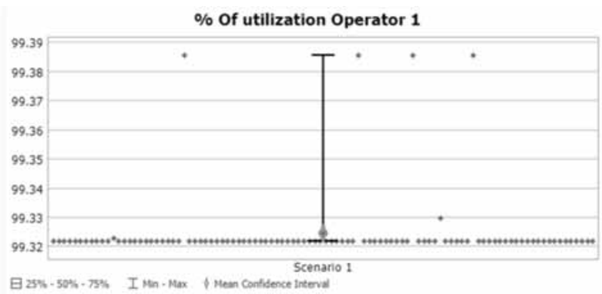

Figure 9: Percentage of operator utilization for base model. Source: own elaboration.

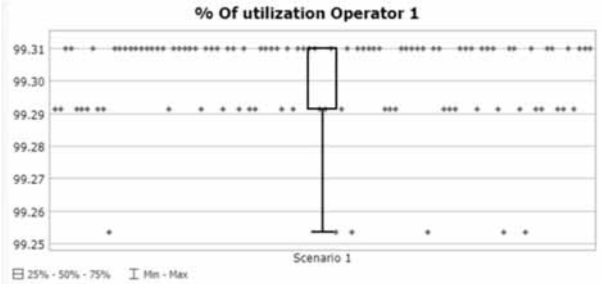

Figure 10: Percentage of operator 1 utilization in the 2 operators' scenario. Source: own elaboration.

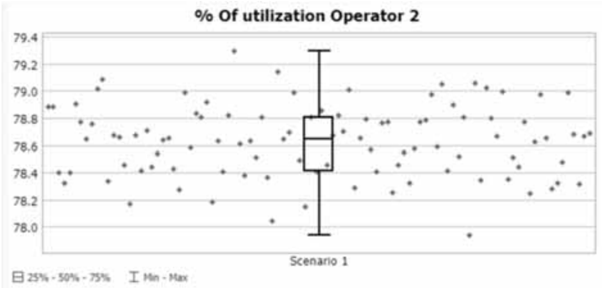

Figure 11: Percentage of operator 2 utilization in the 2 operators' scenario. Source: own elaboration.

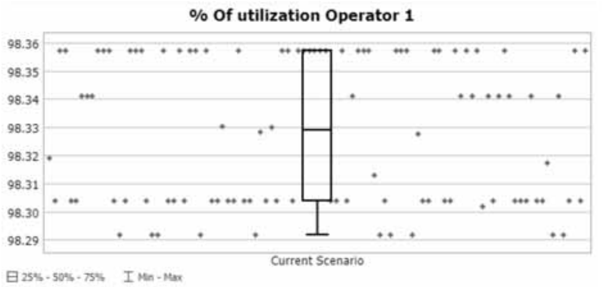

Figure 12: Percentage of operator 1 utilization new machinery with 2 operators' scenario. Source: own elaboration.

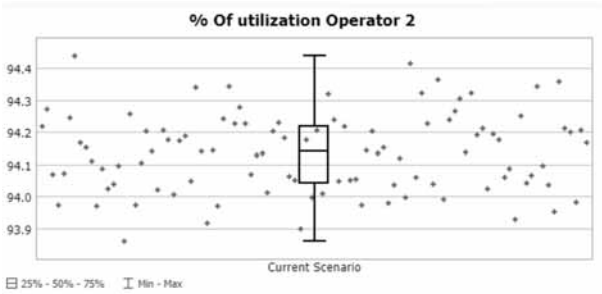

Figure 13: Percentage of operator 2 utilization new machinery with 2 operators' scenario. Source: own elaboration.

4 Conclusions

As we can see, the simulation results prove the initial hypothesis that both the number of workers and the quality of the machines had a significant influence on the production of the company that´s the subject of our study. The time improvements and the elimination of dead time allows us to prove that one of the main causes for delays on deliveries is the lack of workers, since the time the first worker spends preparing the machine and moving the materials around is extremely wasteful.

We can also see how the outdated machinery´s need for time is also a key factor in the delay of the process, since its speed and the time it needs to be prepared is too much in comparison to the one, we can see in more modern machines.

As theorized before, we can see that the main problem of this small Mexican company, which is like most small Mexican companies in the medical supplies industry, is that it tries to save money on things that usually process owners seem un-necessary but eventually, it ends up damaging the production process and generating delays which heavily damages the company's reputation.

In retrospect, the results of this simulation can be used to prove the damaging results of poor planning and the common desire of small businessmen to spend the least amount of money. This study highlights the importance of doing a good analysis of the resources a company has and the steps and methodologies employed in each process in order to understand if they manage to achieve the desired results or if it is necessary to modify anything in order to improve performance, something that unfortunately is done very little in small businesses in Mexico and something that should definitely be changed.

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MCSimulRisk: an Educational Tool for Quantitative Risk Analysis

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Abstract. MCSimulRisk (Monte Carlo Simulation for Risk Analysis) is an application developed in MATLAB for Monte Carlo Simulation and quantitative risk analysis. In the Master's Degree in Project Management at the University of Valladolid, "Risk Management" is taught. Quantitative risk analysis is an essential part of teaching this subject. In the last few courses, students have used commercial applications that allow Monte Carlo Simulation in this subject. To correct the problems detected while students did laboratory exercises, we decided to develop this educational tool with the following main objectives: (1) allow students to efficiently carry out Monte Carlo Simulation for any project network, regardless of its complexity; (2) easily integrate different types of uncertainty (aleatoric, stochastic and epistemic) that can impact project objectives into the model. In addition to the above, this tool should help research tasks by extending research lines not yet addressed in the literature to integrate distinct types of uncertainty.

Introduction

The Risk Management course, which runs throughout the first semester of the Master's Degree in Project Management at the University of Valladolid, provides specifically theoretical knowledge on quantitative risk analysis. Practical exercises where students solve, interpret and discuss the results reinforce theoretical knowledge. Specific commercial software applications exist for Monte Carlo simulation, such as Crystal Ball (Oracle) or @Risk (Palisade).

These applications run as extensions of a well-known spreadsheet application. However, the experience in this subject has made us see that students spend too much time configuring the project proposed as a problem, a time that turns out to be unproductive, taking away time dedicated to the observation and commentary on the results obtained.

This paper aims to present a tool implemented in Matlab®, specifically designed to facilitate the project configuration with which the Monte Carlo simulation is to be performed. The teachers who teach this subject have developed the application. The results obtained from the tool provide the data that students need to solve the exercises. These results are provided attractively and visually, including the possibility of exporting the simulation data as external files for processing in auxiliary applications. This tool eliminates unproductive time for students, allowing them to dedicate it to solving the problem and finding an explanation for the results.

The rest of the paper is organised as follows. The following section introduces the context where Monte Carlo simulation is used to perform quantitative risk analysis. Next, we describe the educational tool developed, including the explanation of the results it offers. The results of students' use of this new tool are presented below. Finally, we present the conclusions of our work.

1 Risk Management

Project risk management identifies, analyses, and proactively responds to potential project risks. Project Risk Management objectives aim to increase the probability and impact of positive events and to decrease the likelihood and impact of adverse events for the project. We understand project risk as any uncertainty that, if it occurs, may affect project objectives (Project Management Institute, 2021).

The vast majority of standards and methodologies dealing with risk management (European Commission, 2018; Project Management Institute, 2021, and others) include a specific process for risk assessment.

The risk assessment process can be divided into two parts. The first consists of performing a qualitative analysis to prioritise individual project risks. The second consists of performing a quantitative analysis to quantify the combined effect of the individual project risks and other sources of uncertainty on the overall project objectives. In this context, Monte Carlo Simulation is a widespread quantitative technique that allows analysis of this uncertainty's impact (Rezaie et al., 2007).

Monte Carlo Simulation is a method that focuses on solving problems of a mathematical nature with a statistical model to generate possible scenarios resulting from an initial set of data. This method tries to simulate a real scenario and its different possibilities, allowing us to predict the behaviour of the variables according to the estimations made.

Monte Carlo simulation is beginning to be used more widely in the areas of cost and schedule management for the calculation of project cost contingencies or time margins to determine how likely it is that the project budget will be met or what the project duration will be with a given percentage probability (T. Williams, 2003).

Nowadays, all the above can be easily solved with standard project management software, such as Microsoft Project or Primavera, and complementary Monte Carlo simulation applications, such as @Risk or Crystal Ball. Another standard option is to use spreadsheets, such as MS Excel.

The education tool presented in this paper focuses on quantitative risk analysis and uses Monte Carlo simulation for data processing. The application will be developed using Matlab as the programming language.

2 MCSimulRisk

MCSimulRisk (Monte Carlo Simulation for Risk analysis) is an application developed in the Matlab® environment for Monte Carlo Simulation. The application, developed as a set of Matlab functions, offers various graphical and numerical results related to quantitative risk analysis. It allows the user to obtain graphical and tabular data of the problem to be solved, interacting through menus with different options (Figure 1).

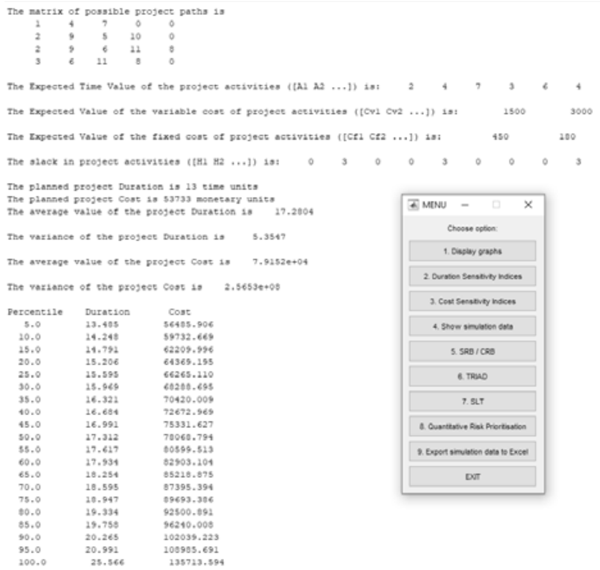

Figure 1: MCSimulRisk working environment.

Figure 2 shows the application flowchart, which includes the sequence of steps we have followed in its programming and the utilities this application offers users.

The student must have information about the project he/she wishes to complete before executing the application. For this purpose, it is necessary to encode in a supplementary Excel table the information relating to project activities, characterised by the duration and cost (fixed cost and variable cost) of the activities; project risks, which can come from aleatoric, stochastic or epistemic uncertainties; the relationship of precedence of activities; and the number of simulations to be carried out.

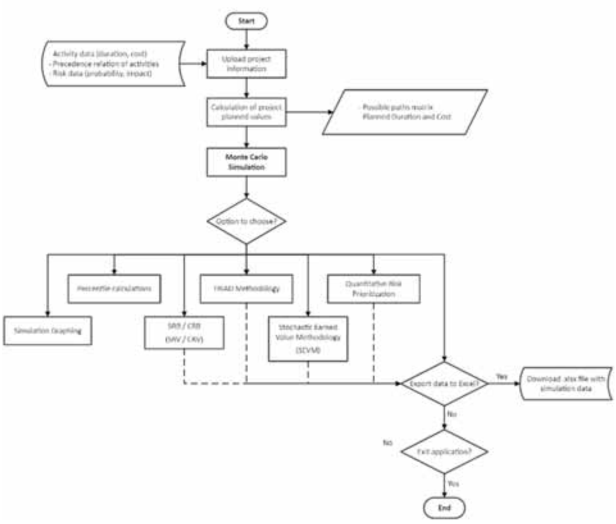

Figure 2: Flowchart describing the simulation process followed by MCSimulRisk.

Once the application loads the project information, it runs the Monte Carlo simulation. It offers a drop-down menu with a wide range of options that can be selected depending on the exercise the student is doing in class. Therefore, we can obtain the probability distribution and cumulative probability curves corresponding to the project's total duration and cost (Figure 3).

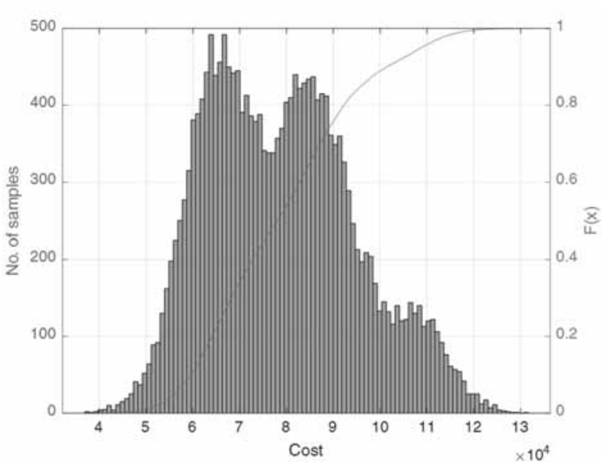

Figure 3: Probability distribution curves and cumulative probability for the total project cost.

In addition to graphical data, MCSimulRisk offers numerical data that the user can download locally if he/she intends to process the data further.

MCSimulRisk incorporates different utilities that allow the monitoring and control of projects considering the uncertainty of the activities (ScoI/CcoI (Pajares & López-Paredes, 2011), Triad methodology (Acebes et al., 2014) and SEVM (Acebes et al., 2015)).

It also offers information on the prioritisation of the importance of project activities (Criticality Index (Martin, 1965) (Figure 4), Cruciality Index (T. M. Williams, 1992), or Management Oriented Index (Madadi & Iranmanesh, 2012)).

For each of the chosen options, MCSimulRisk offers the possibility to display graphical and numerical results and, in addition, to export the results to a '.xlsx' file for further statistical treatment if the student wishes. Finally, MCSimulRisk allows students to quickly obtain graphical and numerical simulation results to solve the tasks assigned in their laboratory classes. In addition, this tool can be used by researchers who need to extend their studies on the contribution of the diverse types of uncertainty to the project's total risk.

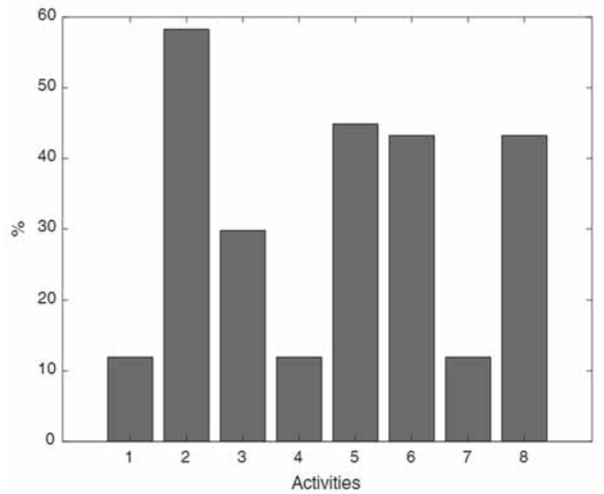

Figure 4: Graphical representation of the Criticality Index.

3 Teaching Using the Application

During the present course, it was decided to introduce the MCSimulRisk application in test mode to check its effectiveness and usefulness as a teaching tool for students in Risk Management classes. After the students had completed their exercises using the commercial tool (@Risk), they were asked to repeat the same exercises using, in this case, MCSimulRisk.

The students used the same problem statements, describing the project activities and the identified risks. They have incorporated this information into the MCSimulRisk application and have directly obtained the desired results.

Before the end of the course, we conducted a questionnaire for the students. The questionnaire aims to collect the students' impressions while solving the exercises using the new tool introduced in class (MCSimulRisk). The aim is for the students to compare the effort made and the teaching usefulness of this tool compared to the commercial one.

Eight questions were asked; seven were closed questions, with a score between 1 and 5 points, "1" is a highly negative score, and "5" is an incredibly positive score for the question asked. The last question corresponds to an open question where the student can comment on suggestions, improvements or negative aspects not included in the previous questions. We have configured the questionnaire based on existing literature (Yin et al., 2021).

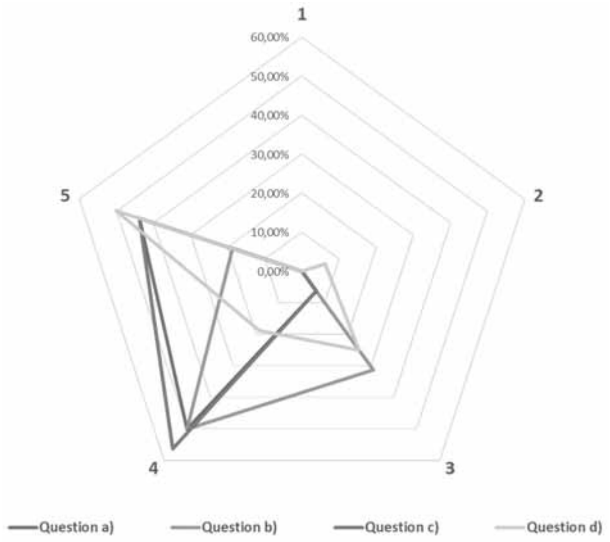

Figure 5: Feedback received from students. A vertex in a polygon represents the percentage of students who gave a particular rating to the tool according to the specific questions.

Figure 5 includes some of the questions given to the students. The percentage score given to each question by the students surveyed is also included.

If we look in detail at the questionnaire and the answers given by the students, they consider the application to be easy to use and helpful in teaching the subject, and they recommend it for use by other students.

As teachers of the subject who have observed the students using the application, we can affirm that the time they have invested in conducting the practice has been much less using MCSimulRisk than the time invested with other applications. The students entered the problem data into the application, and the application provided the results. Subsequently, the students spent their time evaluating the results obtained, reasoning whether they were appropriate or not, proposing solutions to the problem posed, and eliminating the time spent on other occasions modelling the project in MS Excel.

4 Conclusions

Although there are commercial tools specifically designed to perform Monte Carlo simulation for project quantitative risk analysis, our experience has shown that their use requires students to devote much time to the project setup, reducing the available time for interpretation and discussion of the simulation results.

The application 'MCSimulRisk' bridges this gap. It fulfils a dual purpose. On the one hand, it is a tool that allows the configuration of any project type with complex structures, even with many activities, without taking up excessive configuration time for students (definition of activities, sequencing, definition of risks, and others). In this way, students can use this time to reason about the configuration parameters of the problem project and the results obtained according to the programmed parameters.

On the other hand, 'MCSimulRisk' allows the integration of any uncertainty beyond aleatory uncertainty, which is the only type of uncertainty considered by commercial software.

Therefore, this tool allows for a comprehensive quantitative risk analysis that integrates not only aleatory uncertainties but also stochastic and epistemic uncertainties (Curto et al., 2022; Hillson, 2009).

The results offered by the application are very varied, as we can determine the duration and cost contingency margins (depending on the chosen percentile), prioritise activities according to different sensitivity indexes, or monitor and control the project by incorporating uncertainty in the project activities, among other applications.

The software application has been used during the present course as a test version; however, we intend to incorporate it in the following academic years as an educational tool for solving the risk management exercises proposed in the course.

As future lines of research, we plan to expand the application's functionalities, focused on quantitative risk assessment. The medium-term objective is also to change the programming environment and develop the same application as the Python language.

Under this new programming environment, the possibilities for developing and disseminating the software application would be greater than in the Matlab environment.

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Technology-supported Teaching of Modeling and Simulation in Inverted Classroom Format

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Abstract. Modeling and simulation is an interdisciplinary field requiring several competences. Due to this interdisciplinary nature and diverse set of skills that it imposes, teaching modeling and simulation in a university setting poses specific challenges. To confront this issue and contribute to the ongoing discussion on alternative methods of teaching, this paper proposes an inverted classroom approach, combined with a digital training system, as a means of teaching modeling and simulation.

The proposed approach aims to address this challenge of teaching multiple aspects in the right quantity and pace for all participating students. The paper presents a teaching concept for a lecture and exercise on modeling and simulation and evaluates the effectiveness of different tools in various settings of the course from the lecturer's perspective. The importance of appropriate technology integration and an engaging learning environment as the means of supporting the students in independent studies is also discussed

Introduction

Modeling and simulation is a field that uses mathematical and physical methods to derive and build structural models based on equations and physical principles (known as first principal modelling).

The interdisciplinary nature of modeling and simulation makes it challenging to teach in a university course. It typically takes several semesters for students to learn the basics and even then, there is still much to do before in-depth teaching can begin.

Modeling and simulation have long been used to teach STEM (Science, Technology, Engineering, and Mathematics) subjects, emphasizing the significance of applied mathematical methods. In this context, alternative methods to teach modeling and simulation in these subjects were discussed at the beginning of this century; see, e.g. [6] and [7]. It is noted that, when teaching basic courses in modeling and simulation, several aspects should be covered: mathematical methods, physical principles and programming. However, teaching all these subjects in the right quantity and at the right pace to meet all the requirements of the participating students is challenging. One possible solution is to change the teaching style from a classical lecture and exercises to an inverted classroom, also known as a flipped classroom, combined with an accompanying digital training and testing system.

While the integration of technology has been shown to be effective at all ages and can be beneficial for students with special learning needs [1], it is important that it is used appropriately and not simply transferred from one medium to another [2].

Seeking to address these findings and encouraged by the proven effectiveness of the inverted classroom approach, we present the teaching concept in a lecture and exercise on modelling and simulation for mathematics students at TU Wien.

We will specify the use of different tools in different settings of the course and discuss their effectiveness from the lecturer's perspective. Another objective of this approach is to increase the support for independent learning typical of the inverse classroom environment and address the negative influences in the inverted classroom setting in a university context, as reported by [8].

1 Course Structure and Educational Components

Courses in the curriculum of mathematics at TU Wien are divided into lectures for theoretical foundations and exercises for independent application of methods. Modelling and simulation is an elective course taken by students at the end of the Bachelor's program and the beginning of the Master's program. The course instructors are confronted with an inhomogeneous variety of students' knowledge.

Prerequisites for following the course are basic knowledge of analysis, linear algebra, differential equations, and programming - preferably MATLAB©. Analytical aspects needed to understand modeling approaches, such as behavioral models and transfer functions, can be effectively presented in the lecture. However, solving differential equations and programming in MATLAB requires a more hands-on approach. To equip the students with the tools to gain a comprehensive understanding of the matter and allow them to progress at their own pace, the exercises have been enhanced with eLearning tools.

1.1 Technology-enhanced Exercises

The traditional exercise setting consisted of homework and project work that students had to complete. Starting both aspects in parallel with the lecture was not possible due to the lack of programming skills for the project work and some missing skills related to differential equations. Incorporating eLearning tools to cover the training of differential equations and MATLAB programming in the first part of the semester enabled students to equalize their knowledge and receive higher-quality teaching.

For MATLAB training, the TU Wien license offers an online academy for students and staff. This academy consists of webinar lessons on various topics, and lecturers can decide which lessons are necessary for the course.

By providing only these academy lessons, students will benefit significantly.

For evaluation of students' skills and timely provision of feedback MATLAB Grader is used, see [3]. Handily, the grader environment can be connected and integrated into established learning management systems, e.g. Moodle, by learning technology interface (LTI).

MATLAB Grader puts us in a position to support students' learning by providing them with relevant examples. The tool manages randomization, automatically grades students, and provides feedback to help them improve their skills in a targeted manner. In the typical setup for an example specified in the MATLAB Grader environment in Moodle, the task specification is located in the upper part, the middle part is reserved for the student's MATLAB code, and the lower part provides automated feedback and assessment.

Enforcing students' skills in handling differential equations requires another eLearning system. Möbius, a testing and assessment system based on the computer algebra system Maple, with its randomization and grading capabilities, was our tool of choice. Importantly, for modeling and simulation education, the system allows instructors to select and create assignments on the pertinent chapters of differential equations that students need to understand in order to pass the course. The system's randomization capabilities allow for a continual offering of new exercise material on demand. It also provides immediate feedback and enables a more personalized and active learning environment. In [4] an in-depth instruction on the use of Möbius, formerly named Maple T.A., and its application in engineering education at TU Wien is presented.

1.2 Inverted Classroom Lecture

Since the COVID-19 pandemic, more non-classical teaching strategies have been adopted at TU Wien. One such format is the inverted classroom approach, which allows for a different approach to teaching in higher education, exemplarily see [5]. This concept was deemed suitable for addressing a diverse group of students and enabling them to progress through the lecture material at their own pace.

In line with this idea, video streams of the different lecture content modules were provided to the students.

The distribution was managed through the Moodle system of TU Wien, where a plug-in called “lecture tube” was developed for this purpose. The in-person lectures turned into Q&A sessions for the videos being provided. To give a link to the exercises, the specifications of the future exercises were also discussed and questions from the students were answered live.

The Q&A sessions were used to support the students with use cases of MATLAB examples in preparation for their project work. The specification of the project work was handed over after the MATLAB academy and grader sessions, and the submission and presentation of the project work were at the end of the semester. During the semester, the small examples given during the meeting sessions guided and instructed the students latently.

2 Discussion

The proposed didactic approach of an inverted classroom for modelling and simulation courses at TU Wien addresses the challenges that the teaching of interdisciplinary university courses poses. It extends the conventional inverted classroom approach by incorporating a digital training system in the domain-specific context.

Digital training systems offer immediate feedback to students, which helps them to better understand the material and become more engaged with the subject matter. This approach allows for a more active, hands-on learning experience in an inverted classroom setting, while still allowing students to equalize their knowledge and learn at their own pace. Additionally, instructors can provide personalized guidance and support in form of Q&A sessions.

Over the years, student feedback has been very positive, particularly regarding the effective use of time to better link lecture content with exercises. The on-demand availability of resources for interactive exercises is another appreciated feature of this approach. Its scalability makes it a suitable solution for a wide range of courses, allowing for a greater number of students to benefit from it. With this teaching approach, lecturers have a reliable tool to effectively instruct students and provide a more personalized and effective approach to teaching complex concepts.

Nonetheless, it is important to continuously evaluate and refine the approach so that it remains responsive to the changing needs of students and the academic landscape. Our goal for the future is to analyze the students' results from the MATLAB Grader and Möbius assignments and examine the correlation between these results and examination scores. This will allow us to better assess the effectiveness of the proposed approach and identify potential areas for improvement.

If we look in detail at the questionnaire and the answers given by the students, they consider the application to be easy to use and helpful in teaching the subject, and they recommend it for use by other students.

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A New Simheuristics Procedure for Stochastic Combinatorial Optimization

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Abstract. Ignoring uncertainty in combinatorial optimization leads to suboptimal decisions in practice. Nevertheless, the focus is often on deterministic combinatorial optimization problems, mainly because they are already challenging enough without stochasticity. To make it easier to address stochasticity in combinatorial optimization, Simheuristics have been developed that allow solving stochastic combinatorial optimization problems. We propose a new Simheuristic procedure that dynamically changes the optimization focus between a deterministic and stochastic perspective based upon a statistical model. By doing so, an adequate trade-off is made between exploration and exploitation of the solution space during the optimization. We numerically show that the new Simheuristic procedure solves real-life stochastic scheduling problems more efficiently than standard Simheuristics strategies.

Introduction

Many real-world problems from various domains, such as logistics, manufacturing, healthcare, and finance, can be stated as combinatorial optimization problems (COPs).

These real-life COPs are often NP-hard, meaning there is little hope for an efficient algorithm that allows finding the optimal solution for all realistically-sized problem instances [4]. Another complicating factor is that the (input) parameters of COPs are often uncertain in practice [3].

In this work, we focus on these *stochastic* COPs (SCOPs) of the form

$$\min_{\pi \in S} \mathbb{E}\left[f(X,\pi)\right],$$

where π denotes a solution from the discrete solution space S, $f(\cdot)$ is the objective function, and X represents the random variable(s) of the parameter(s) with known (empirical) distribution(s).

The objective function $f(\cdot)$ is either a closed-form expression or something that can be simulated (for example, a complex production process). A challenging aspect of SCOPs is that $\mathbb{E}\left[f(X,\pi)\right]$ is generally intractable, and we have to resort to (time-consuming) Monte Carlo simulations to get sample-average approximations [3]. In both academia and practice, one often replaces the unknown objective $\mathbb{E}\left[f(X,\pi)\right]$ by $f(\mathbb{E}\left[X\right],\pi)$ and optimizes the corresponding *deterministic* COP (DCOP) [3]:

$$\min_{\pi \in S} f(\mathbb{E}\left[X\right],\pi).$$

Indeed, evaluating a solution π in DCOP is done quickly via one function evaluation, whereas finding a good approximation to $\mathbb{E}\left[f(X,\pi)\right]$ requires many function evaluations. However, this comes at a price that a good solution to DCOP can behave poorly in the corresponding SCOP since $\mathbb{E}\left[f(X,\pi)\right] \neq f(\mathbb{E}\left[X\right],\pi)$ in general. Ignoring this is also known as *flaw of averages* [5].

The combination of NP-hardness and the time-consuming objective approximations via simulations make SCOPs challenging to solve in practice. Fortunately, so-called *Simheuristics* have shown to be able to find good solutions to practical SCOPs in recent years [3].

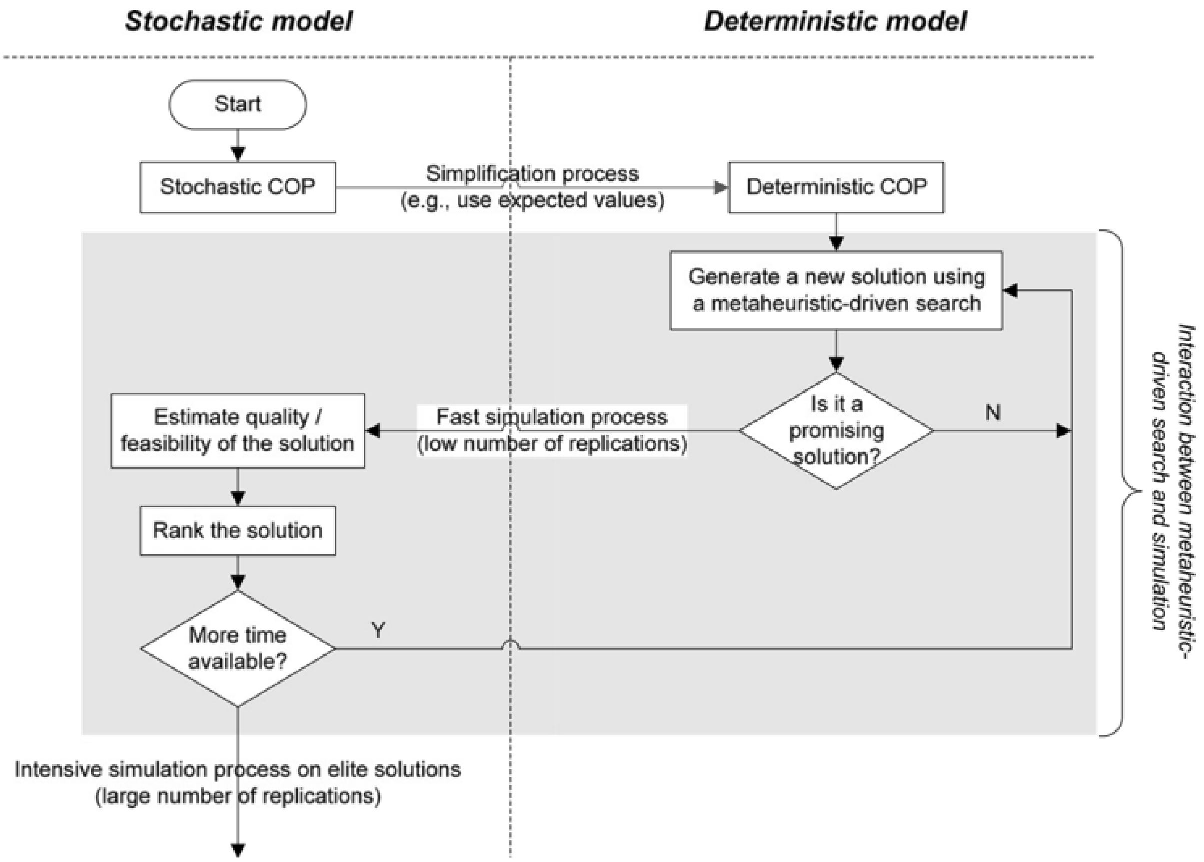

Figure 1: Overview of a Simheuristics framework from [3].

1 Simheuristics

Simheuristics provide a general framework to solve largescale SCOPs by combining DCOP (meta) heuristics with simulation [3]. In particular, the DCOP heuristic is used as a relatively fast way to generate new solutions for SCOP. Instead of simulating all newly found solutions, only the promising solutions are *briefly* simulated to approximate their expected objective values.

When approaching the computation time limit, the most promising solutions are awarded more simulations for identifying the best solution to SCOP finally (Simheuristic process illustrated in Figure 1 (from [3])).

Simheuristics are particularly effective for solving SCOPs when: (i) efficient (meta)heuristics already exist for the DCOP, (ii) most gain is obtained in the first part of the DCOP optimization, and (iii) $f(\mathbb{E}[X],\pi)$ and $\mathbb{E}[f(X,\pi)]$ are positively correlated for varying π. As a result, the DCOP heuristic guides the optimization relatively fast to more promising SCOP solutions [3].

However, when the DCOP optimization stagnates, shifting the optimization focus to simulation is likely more beneficial, i.e., identifying the best SCOP solution out of the most promising DCOP solutions.

The key to an effective Simheuristic application is to determine when to switch this optimization focus: switching too early misses out on the chance to find better SCOP solutions efficiently, whereas switching too late increases the chance of picking poor SCOP solutions.

2 Proposal: OCBA-guided Simheuristic

We propose a generic procedure for Simheuristics, called *OCBA-guided Simheuristic*, that dynamically determines when to focus on optimizing DCOP and when to focus on simulation to obtain better expected objective values approximations.

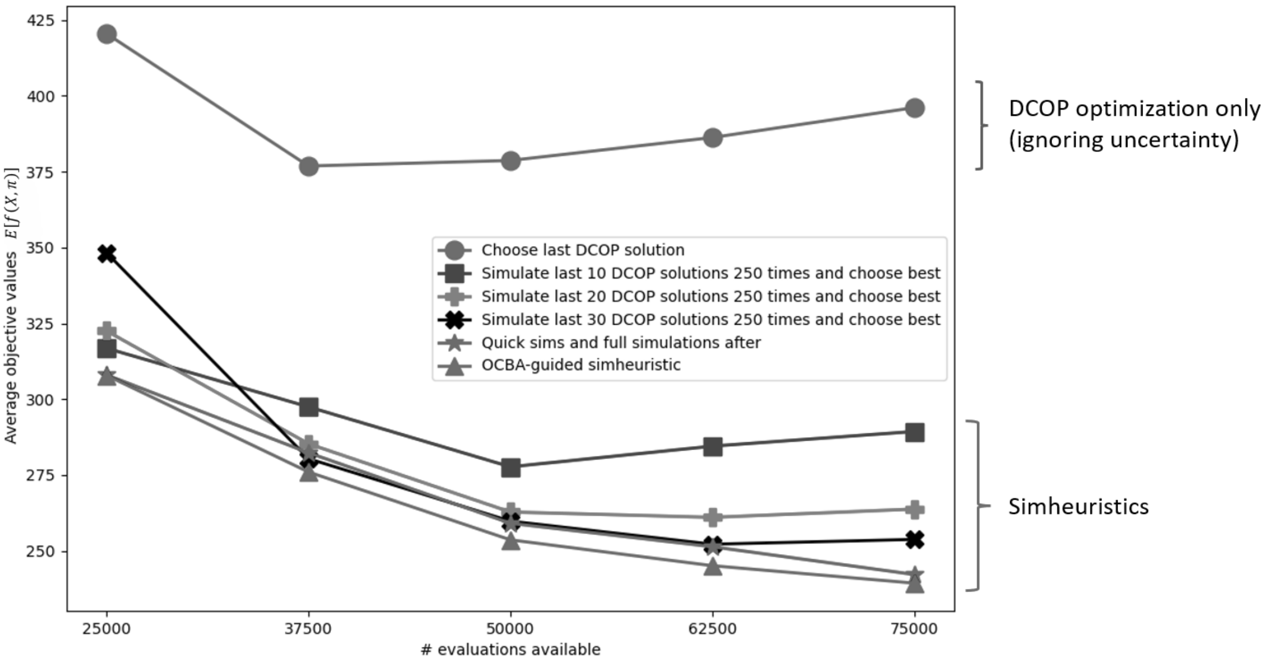

Figure 2: Results of solving a stochastic scheduling problem from [1] when optimizing DCOP only and using different Simheuristics including our OCBA-guided Simheuristic that dynamically shifts the optimization focus between DCOP and SCOP.

The idea is to keep track of a fixed-sized elite set of the most promising solutions. At any time during the optimization, we want to be "sure" about their expected objective values. To that end, we want the expected opportunity cost of the elite set to be smaller than a user-defined threshold at any time.

The opportunity cost of the elite set is the difference between the expected objective values of the solution identified as best and the true best solution, and its expectation is calculated efficiently using Bayesian probability theory [2]. When the expected opportunity cost exceeds the threshold (meaning we are "unsure" about the expected objective values), the solutions from the elite set will be simulated (and we temporarily stop the DCOP optimization).

The simulation of the elite set is done efficiently by making use of the Optimal Computing Budget Allocation (OCBA) from [2]. OCBA prescribes how to efficiently allocate simulation budget among different solutions to minimize the expected opportunity cost. Once the expected opportunity cost drops below the threshold, DCOP is optimized again to find new solutions that may replace solutions from the elite set.

This process continues iteratively until the computation budget is spent. Then, the best solution from the elite set is returned.

3 Preliminary Numerical Results

The OCBA-guided Simheuristic is tested by solving a stochastic version of a parallel machines scheduling problem with sequence-dependent setup times faced in the cattle feed industry [1].

In particular, we considered for different computation budgets, 50 instances based on real-life data (of 50 jobs, 4 parallel machines, and lognormally distributed production durations) and computed the average expected objective values (which is the weighted sum of the tardiness and the makespan) of the solutions found. The results can be found in Figure 2. For comparison, also the results of optimizing DCOP only and several standard Simheuristics are added.

4 Conclusions

Preliminary results show that our OCBA-guided Simheuristic outperforms other typical Simheuristics for a stochastic scheduling problem. This shows the potential of adequately switching the optimization focus between DCOP and SCOP.

In future research, we want to conduct more experiments. Also, we want to incorporate past simulation information in the OCBA-guided Simheuristic and tailor the simulation budget allocation rule to our purposes.

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Validation of Data-Driven Reliability Models in Manufacturing - Work in Progress

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Abstract. Reliability modeling enables deriving reliability measurements and illustrating relevant fault-dependencies in manufacturing systems. Data-driven reliability modeling uses data generated in systems to either automate or at least support extraction of reliability models. To use these extracted models for decision support, we need to ensure models' validity. In this extended abstract, we discuss our initial approach for validating data-driven reliability models. The challenge with validating data-driven models lies in the fact that these models are continuously generated and updated, implying that we need a new or updated validation approach to enable an ongoing validation of these models. The upside is that the systems of interest generate large amounts of data, which can significantly support the quantitative validation processes. Additionally, we briefly address the implications that could result from our proposed approach.

Introduction

Advancements in manufacturing technology have led to the generation and collection of vast amounts of data that are stored within information systems, such as Manufacturing Execution Systems (MES) and Supervisory Control and Data Acquisition (SCADA) systems.

This data, generated from equipment control systems, such as Programmable Logic Controllers (PLCs) or collected from sensors monitoring equipment state, can be used to support decisions. On the flip side, modern manufacturing systems have become increasingly complex, which complicates systems' maintenance and identification of possible vulnerabilities that affect their reliabilities.

To this end, reliability modeling includes a number of techniques to assist with this. Conventional reliability modeling, however, relies significantly on expert knowledge of the system under study, which can become a bottleneck as systems become more complex and experts sparse [1]. Moreover, manufacturing systems are often subject to frequent modifications that can quickly make such conventional reliability models obsolete when systems' topologies change [2]. Thus, there is a need to dynamically generate accurate reliability models for manufacturing systems based on data to address the challenges described above and to ensure optimal exploitation of reliability models in the shopfloors [3, 4]. This is what we term as data-driven reliability modeling [5].

Validation is necessary to enable the use of the data-driven reliability models to support decisions. Conventionally, model validation is carried out by a subject matter expert after the model has been constructed. However, the automatic generation of models in data-driven reliability modeling requires an automated approach to continuous validation [6].

The vast amounts of data generated by advanced manufacturing systems can be utilized to address these challenges and enhance the accuracy and statistical significance of validation outcomes.

Here, we introduce our approach for validating data-driven reliability models (Section 1) and discuss data requirements, as well as other implications arising from our proposed approach (Section 2).

1 Validation of Data-driven Reliability Models

Figure 1 outlines the approach that we propose for validation of data-driven reliability models for manufacturing systems and how it is embedded in the general process of data-driven reliability assessment (DDRA).

The general process of DDRA consists of the following phases:

1. Definition, generation, collection and preprocessing of relevant data,
2. reliability model extraction,
3. validation of the extracted model,
4. simulation and calculation of systems' reliability measures and
5. presentation of results in a dashboard to support decision-making [5].

To validate extracted reliability models, we follow the typical two steps:

1. ensuring face validity, and
2. quantitative validation [7].

Face validity is used to describe a subjective judgment of experts whether the model and/or its behavior accurately reflect the real-world system being modeled. Face validity can be assessed by reviewing the model structure, inputs, and outputs and comparing them to the real-world system, as well as by conducting a qualitative evaluation of the results.

Quantitative validation compares data from the real system with data generated from the simulation model, with the goal of applying statistical hypothesis testing to determine the similarity of the simulation model and the real system with respect to predefined performance measures [8].

The availability of data streamed from information systems, such as MES or SCADA, as well as from sensors, offers an opportunity to automate and enhance the quantitative validation, which is what we aim to explore.

Quantitative validation can be performed through either input-output transformations, or streaming input data. Input-output transformations compare output data from the real system with the output data from the simulation model, without utilizing real data for the input variables.

However, in the case of advanced manufacturing systems, the generation of vast amounts of data presents an opportunity to feed a simulation model with sufficient data, such that the necessary number of replications can be performed with it to yield validation results with the required level of statistical significance. Since we derive reliability models from data, we can also use the same data to quantitatively validate extracted reliability models. Furthermore, the continuous recording of data in the physical system enables continuous validation in addition to periodic and on-demand validation.

If the validity of a reliability model is not refuted, it implies that the model can be used to support relevant decisions. For example, we can evaluate the impact that different resources have on the overall reliability of the system.

If the validity of a reliability model is refuted, we must regenerate (i.e., repeating the first two phases of DDRA, as described earlier) or, in case of minor issues, recalibrate the model.

2 Discussion

In this last section we describe the data requirements for validating data-driven reliability models. We then highlight various research directions for utilizing validation, such as model calibration, as well as considerations for scheduling validation and determining the appropriate timing for generating new models.

To enable validation of data-driven reliability models, it is important to gather and have access to all the necessary data that are required for the validation process. This includes, for example, event logs that capture relevant events related to material flow in a system and a state log that captures state changes in the system's production resources.

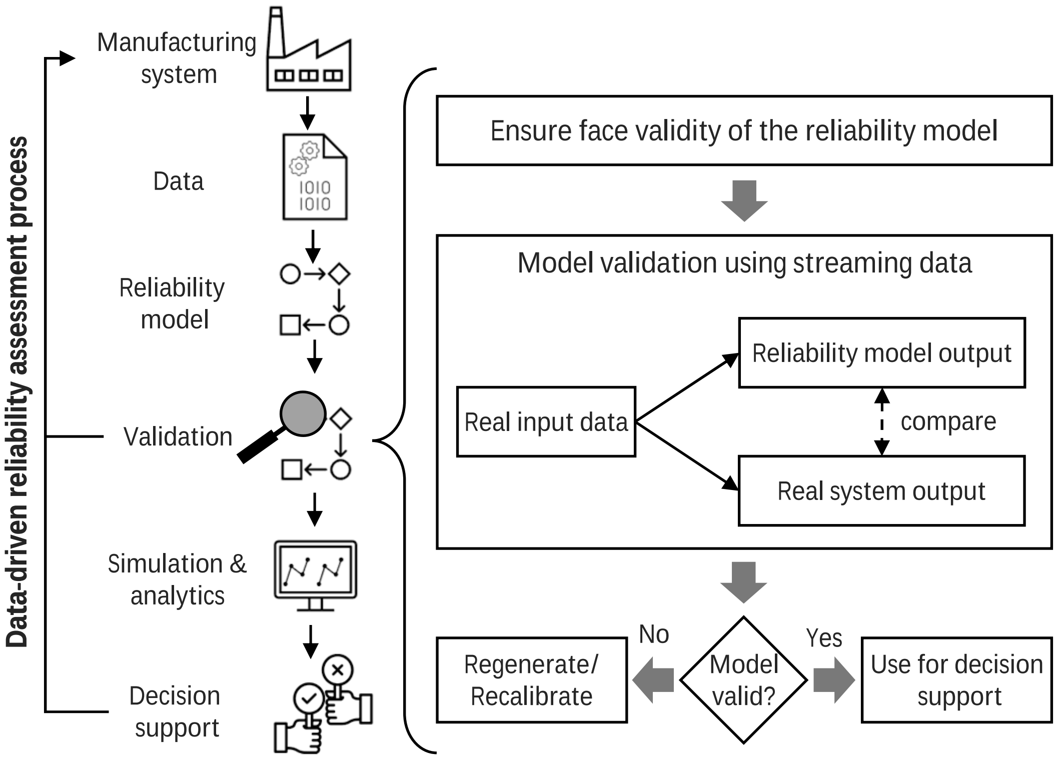

Figure 1: Proposed approach for validation of data-driven reliability models.

In the previous section, we described that the same data used to generate the model can also be used for its validation. Performance indicators such as throughput (i.e., the number of completed orders per time unit) and downtime of the system and/or its resources can be used for validation.

The information needed to calculate these indicators is readily available in the event log capturing material flow and the state log tracking resource state changes.

Validation is a vital component of data-driven simulation modeling in general, as validation can be used to calibrate extracted models [8].

One approach to quantitatively validate and calibrate an extracted reliability model is through the use of reinforcement learning (RL). RL can be utilized to optimize the models' parameters to better approximate the behavior of the manufacturing system. When the simulation model's output deviates from the system's actual output, an RL-agent can make adjustments to the model parameters.

After a each simulation run, the agent either receives a positive or negative reward based on the simulation results. RL can also be used to aid calibrating the reliability model to optimize towards a given performance indicator, such as throughput.

For example, if the agent identifies that increasing buffer sizes or reducing failure rates of production resources would lead to increased throughput, it can trigger a reconfiguration of the manufacturing system.

Another important aspect we need to consider is the scheduling of model validation. This can be either time-based or trigger-based. For example, in critical systems the reliability model should be validated in real time to ensure continuous robustness of the model. In less critical systems, validation can be scheduled, for example, once a day or once a week. A new validation run can be triggered by the handling of a new production batch, change of shift, change of resources/equipment, or simply, if the output of the model seems incorrect.

Clearly, a new reliability model must be generated and thus validated once there is a change in topology/-configuration of the physical entity (e.g., introduction of redundancy, change of production routes, change of maintenance policy).

Furthermore, the integration of new data sources can be used to enrich the data-driven reliability model, which in turn requires validation of the enriched model.

With this extended abstract, we aim to open a discussion and to stimulate research on validation of data-driven reliability models for manufacturing systems. This is especially relevant in the emerging context of digital twins. In future, we plan to test our proposed approach in a case study.

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Combined Integration of Simulation and Machine Learning in a Design Methodology for Agile Production Networks

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Abstract. An agile production network enables companies to respond quickly and economically efficiently to expected and unexpected market changes. In this context, the complexity of designing agile production networks is a major challenge. This paper proposes the integration of simulation and machine learning (ML) in a single methodology to manage and understand the complexity of designing agile production networks. Accordingly, a brief introduction to the design of agile production networks and related work will be provided. On this basis, the authors explain the integration and functionalities of simulation and ML. The paper provides a ground for further developments and shows further potentials as part of a design methodology utilizing simulation and ML.

Introduction

Agility as a concept has existed in the systems theory of organizations since the 1950s [1]. In recent decades, the term agility has been coined by agile software development. Currently, agility in the context of production networks is seen as the answer to rapid and disruptive change [2]. Consequently, agility and the ability to change have become decisive keys and competitive factors [3].

The challenge of agile production networks is the complexity of their design. In detail, it requires the consideration of all relevant changes in influencing factors and the analysis of effects on the network [2].

Due to the size and interconnectedness of the entire production network, the number and variety of products and the depth of value-added, inadmissible simplifications in the network design are selected by the human preference [4, 5]. As a result, only a few network configurations emerge, which are often inferior to the network variants that could be identified in a more-advanced design process [6]. As a solution, machine learning (ML) can be used to generate network design variants that deviate from human-known patterns [7].

1 Fundamentals

1.1 Design of agile productions networks

A production network is a network consisting of at least two production sites. The production sites are assigned to a single company in terms of their value creation. Supply Chain Networks (SCN), which represent external networks with locations of different companies, can be distinguished from this. Complementary, agility in the context of production networks describes a system that can quickly and economically identify and strategically respond to both expected and unexpected changes in its environment. The design requires the consideration of all relevant changes in influencing factors, the analysis of effects on the network, and derivation and implementation of required actions [1].

1.2 Methods of simulation modelling

A method of simulation modeling describes a general framework for mapping a real-world system to its model. Modeling methods in simulation can be divided into traditional (e.g., discrete event simulation) and less conventional methods (e.g., system dynamics or agent-based modeling) [8, 9]. Discrete event simulation (DES) provides an intermediate level of abstraction and models a process as a s series of discrete events.

DES focuses on operations of individual entities as a system and visualizes them as a process flowchart. System dynamics (SD) operates at a high level of abstraction and is focused on the overall operation of networks rather than on the individual behavior of entities [8]. Agent-based models (ABM) are made up of self-directed agents that follow predefined rules to achieve their objectives whilst interacting with each other and their environment. The system behavior emerges as a summary of the individual actions of agents and is applicable for both low and high level of abstraction [9].

1.3 Machine learning techniques

ML is the ability of computer programs to learn knowledge and strategies through parameter optimization. ML is divided into supervised learning (SL), unsupervised learning (UL), and reinforcement learning (RL), which are distinguished by the nature of the problem and the learning. In SL, a system is trained to produce a specific output given a specific input. UL is used to find patterns in input data without the learning system knowing target values or rewards. RL is used to train and learn a strategy as an agent to maximize a specific reward [10]. The learning agent interacts with an environment that represents the system to be optimized. The agent observes the environment, performs actions in it, and receives rewards or evaluations from the environment for these actions [11].

2 Related Work

In the literature, several approaches have been presented focusing explicitly on the design, evaluation, and optimization of production networks. Available approaches can be structured according to their process-related and analytical complexity into process models, mathematical optimization models, combined approaches (which include a process model and a mathematical optimization model), and approaches in general belonging to the field of multi-attribute decision making [4]. Approaches that explicitly focus on simulation and ML are, therefore, increasingly found in the research field of SCN. The following articles provide insight in the integration of simulation and ML:

- *Aghaie and Heidary (2018)* modeled a multi-period stochastic supply chain with uncertain demand and supplier disruptions. The objective was to determine the best behavior of a risk-sensitive retailer with respect to forward and option contracts during multiple contract periods. . For this purpose, an agent-based discrete event simulation approach was developed to simulate the supply chain and its transactions between retailers and unreliable suppliers. As a complement, RL was used to optimize the simulation procedure. A comparison between the numerical results and a genetic algorithm showed the significant efficiency of the proposed RL approach [12].
- *Kemmer et al. (2018)* investigated the performance of RL agents in a supply chain optimization environment. The environment was modeled as a Markov decision process, in which decisions must be made at each step about how many products to produce in a factory and how many products to ship to different warehouses. The results demonstrated that RL agents are able to understand simple market trends, regulate production levels, and efficiently allocate inventory in a simple model scenario [13].
- *Stockheim et al. (2003)* present a decentralized approach to SCM based on RL. The approach consists of loosely coupled yield-optimizing planning agents that attempt to learn an optimal acceptance strategy for sequencing production orders. In a performance comparison, the RL solution was shown to outperform the simple acceptance heuristic [14].

3 Integration into a Design Methodology

The question how simulation and ML can be integrated in a common design methodology has to be answered in three steps. First, it must be determined, how simulation and ML can be integrated in a common use case. Based on this, it must be clarified which modeling method best represents a production network. Third, it must be determined, which specific ML technique can be combined with the selected simulation method to solve the specific challenges of the design case.

The common use of simulation and ML can be implemented as integration of simulation into ML (SIM-assisted ML) or as integration of ML into simulation (ML-assisted SIM). According to the German Engineers Association VDI, Simulation-assisted ML is classified as category D and ML-assisted Simulation as category C of a hierarchical combination [15]. The simulation-assisted ML provides an additional source of information for the ML beyond the usually available data.

Typical functionalities are extending training data, defining parts of the hypothesis approach in terms of empirical functions, driving training algorithms in generative adversarial networks, or testing the final hypothesis for scientific consistency. The ML-assisted simulation is usually used to support the solution process or to detect patterns in simulation data. Typical functionalities are reduction of model order and development of surrogate models that provide approximate but simpler solutions, automatic inference of an intelligent choice of input parameters for a next simulation run, a partially trainable solver for different equations, or identification of patterns in simulation results for scientific discovery [16].

The selection of a modeling method is conducted by analyzing real-world examples and specific case studies. In this context, the selection of a suitable abstraction level for the model and the identification of entities involved as well as their properties and relationships is crucial [17]. Production networks have similar properties like SCNs [2]. However, SC entities operate with different constraints and objectives. Each decision made by any entity impacts other partners. Thus, improving the performance depends on all entities' willingness to collaborate and their ability to coordinate their activities. For this reason, SCNs and production networks can also be defined as a complex adaptive system (CAS). A CAS is a dynamic network where many agents simultaneously and continuously react to the actions of other agents [18]. An approach to model CAS is ABM, describing systems as being made up of self-directed agents. These follow rules to achieve their objectives whilst interacting among each other and with their environment. This allows for investigating the emergent behavior of a system [19].

In addition, an appropriate ML technique must be selected for the use in a design methodology. For this selection, the specific challenges of the design case provide useful indications. In the case of agile production networks, these include the lack of transparency about external and internal influencing factors, an undifferentiated assessment of their effect on the factory, low validity and traceability of the selection of situation-specific measures to increase agility, and the complex estimation of costs and benefits associated with agility measures. Consequently, there is a lack of a decision-making basis to take measures that make a network adaptable for the specific-situation [2]. A ML technique for this kind of decision-making problems is RL.

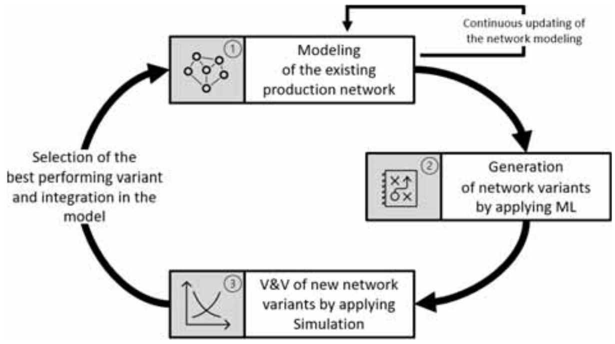

Figure 1: The design methodology is a cycle consisting of three phases.

For RL, an implicit part of the observation is whether the outcome state is good or bad relative to the agent's performance metric. On these observations, the agents can generate optimal plans that determine the proper action to take in any state [11].

Based on the proven applicability of RL and ABM in the application field of production networks, a superordinate process model for a design methodology is visualized in Figure 1 and presented below.

The starting point (Phase 1) of the design methodology is the modeling of the existing production network. In this phase, due to changes in the market and within the company, changes in the production network must be continually monitored and included in the modelling state. In Phase 2, the generation of network variants with suitable technical models (e.g., ML technqiues) is required. Here it is necessary to cover the characteristics of agility enabler in production network [20]. Finally, a validation and verification (V&V) of the network variants is carried out by applying simulation. A suitable V&V support the process of model creation, as well as the use of the model and the evaluation of the simulation results [21]. As solution objective, the most performing network variant is selected and integrated into the network modeling as the current state of the production network.

4 Conclusion and Outlook

This short paper presents how simulation and machine learning (ML) can be used and integrated in a common design methodology. By combining agent-based models (ABM) with Reinforcement Learning (RL), an approach to manage and understand the complexity in the designing of agile production networks could be identified.

With ABM, interactions in the production network can be investigated, the system behavior can be understood and the entire complexity of a production network can be captured. Consequently, it is possible to understand how individual network adjustments can affect the entire production network. Based on this, RL algorithms are used to train the ABM agents for network design variants that are more independent of human preferences. Through the RL training, the entire design process including all possible network variants is captured. As a result, the agents can create resilient and optimal design decisions that determine the correct action in each state of the production network. For further research, it remains to be investigated which specific level of modeling abstraction is sufficient for production networks. In addition, other modeling methods such as Petri Nets should be investigated. Finally, it must be determined which integration form of simulation and ML provides more advantages for the use case and which potential target values should be trained with RL.

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Simulation-based Learning in Aviation Management Studies using SIMIO Software

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Abstract. Focus on digital technologies is one of the strategic priorities in aviation. Although simulation-based learning techniques have been widely applied in the training of aviation pilots or communications, navigation, and surveillance (CNS) students, less attention has been paid to the use of modeled simulations in aviation management (AM) training.

Simulation-based learning tools and strategies can be applied in designing structured learning experiences, providing opportunities to practice skills and implement different types of instruments to support effective learning. Previous studies about AM simulations have provided various examples of how to apply experimental controls to test and validate new AM concepts.

This paper presents the learning journey of implementing SIMIO software (hereinafter platform) in the teaching of aviation industry managers at the Estonian Aviation Academy. The platform was developed jointly with the Arctic University of Norway in Tromso.

We examined the adaptation and use of SIMIO-based simulations as a platform for training and learning for undergraduate students. The paper includes an overview and analysis of theoretical concepts on simulation-based learning (SBL). The study methodology is defined as an action research project, supporting the implementation of smart digital technologies in aviation management training in higher education. In conclusion, the main outcomes of the project, students' feedback, and assessed obtained teaching outcomes are highlighted. Additionally, there are some tracks for further improvements in simulation-based learning methods.

Introduction

Aviation is a complex industry frequently facing extraordinary situations, such as the COVID-19 pandemic or changes in flight intensity, necessitating swift and efficient solutions to maintain functionality and safety. The adoption of new innovative technologies in aviation heavily relies on digital solutions, requiring personnel to possess extensive digital skills. In contemporary aviation education, various digital simulations are extensively used to replicate real-world scenarios. Simulation-based learning tools and strategies are instrumental in designing structured learning experiences, offering opportunities to practice skills and implement different types of scaffolding to support effective learning (Lateef, 2010; Chernikova et al., 2020).

While simulation-based learning techniques have been widely applied in pilot training, their use in aviation management training has received less attention. SIMIO simulation software offers a robust platform for visualizing processes and provides a true object-based 3D modeling environment, facilitating the construction of models in a single step. It grants fast access to a vast library of freely available 3D symbols, enhancing model realism (Simio, 2021). This capability has led to SIMIO's successful application in various fields, including engineering, healthcare, and aerospace, and its growing use in simulation-based learning for aviation management (Dehghanimohammadabadi & Keyser, 2017; Duca & Attaianese, 2012).

The current study addresses the discrepancy between the comprehensive knowledge and skills students should acquire about aviation's interconnected components and the actual learning outcomes, particularly regarding skills needed to work with advanced technological solutions. There is a lack of synthesized results on the role of different simulation features and instructional support (scaffolding) in effectively supporting learners (Chernikova et al., 2020).

Previous studies on aviation management (AM) simulations have highlighted numerous possibilities for applying experimental controls and testing new concepts (Blickensderfer, Liu & Hernandez, 2005; Heesbeen, Hoekstra & Clari, 2003).

Using SIMIO software in AM simulations allows the creation of an authentic learning environment that simplifies technical processes while considering students' prior knowledge and experience. This paper aims to present the learning process of implementing simulation-based learning using SIMIO software to teach future aviation managers. The courses cover airport operations, ground handling procedures, flight planning, and airline financial projections. Simulations help students understand the complexity of aviation management processes by modeling them and providing additional insights into the real world.

The paper outlines the specific action research process, beginning with a literature review on simulation-based learning activities, followed by a detailed description of the employed methodology. Subsequent sections present the research phases, discuss the results, and highlight the main findings.

1 Simulation-based Learning Competencies

A simulation is an activity designed to mimic a real-world scenario. Cook et al. (2013) stated that simulation is an "educational tool or device with which the learner physically interacts to mimic real life". This type of learning experience allows users to engage with situations they might encounter in their actual jobs (Designing Digitally, 2017).

Previous studies have demonstrated that virtual simulations are among the most effective means to facilitate learning (Statti, 2021; Chernikova et al., 2020; Duca & Attaianese, 2012). Simulations provide an authentic learning environment that contributes to learner satisfaction (Lohman et al., 2019). They enhance employability skills such as technical, functional, problem-solving, decision-making, and communication competencies (Lateef, 2010). Additionally, simulation-based learning (SBL) in aviation management (AM) offers benefits like lower operating costs, increased safety, and decreased training time in operational environments (Blickensderfer, Liu & Hernandez, 2005). Corrigan et al. (2015) highlighted that simulations and serious games can support collaborative learning and enhanced communication in the airport collaborative decision-making process.

Competencies acquired through SBL are crucial for the transfer of skills into everyday operational practice. Several motivational components support simulation-based learning and gamification. First is autonomy, where learners in "gameful design" feel they have choices and ownership over their learning. The second is mastery, involving becoming skilled in a particular area. Third is purpose and meaningfulness, where it is vital that learners are presented with relevant and authentic content. Fourth is relatedness or the social aspect of gamification, where learners benefit from interactions with co-learners, stay engaged, and feel part of a larger learning community (Designing Digitally, 2017).

2 Methodology

The study was based on action research, supporting the implementation of simulation-based learning in the air management training study track. The action-based research was conducted during 2020-21 by two organizations: the Estonian Aviation Academy (EAVA) and the Arctic University of Norway (UiT) under the project "Simulation Based Learning in Aviation."

Action research can be defined as an action-oriented approach to a prescriptive case study process, combining problem-solving with research in a way that is appropriate to the circumstances of the research to provide both academic rigor and practical relevance (McManners, 2016; Bradbury, 2015; Rowell et al., 2017). Typically, the action research model covers a spiral of cycles: planning, acting, observing, and reflecting (Altrichter et al., 2002; Dana, 2013). It is a process involving not only intellectual inquiry but also development, reflection, action, and replanning.

Action research methodology is critical in the sense that researchers not only look for ways to improve their practice but are also critical change agents of those constraints and of themselves (Altrichter et al., 2002). It is also participative, meaning that all those involved in the research process contribute equally - no one is conducting research from an external perspective but as a partner and "an owner". Considering these frameworks, a tactical plan was developed to achieve the research objectives and acquire useful knowledge from the project implementation process.

The design of action research followed stages of the process adapted from the relevant literature. Different phases of the research process are presented in Figure 1.

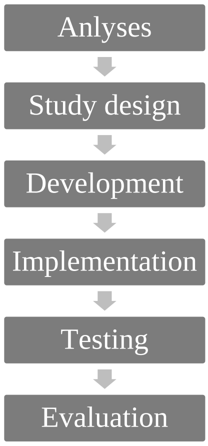

Figure 1: Phases of action research (adapted from Corrigan et al., 2015; Zon et al., 2012).

The research methodology applies to various activities during the project implementation. These activities include joint seminars and workshops, the design of SIMIO models, testing, training in simulation-based learning, and subsequent testing and evaluation.

3 Process of Research

The following explains the study phases and their outcomes.

3.1 Analysis

The analysis phase involves a systematic examination of information accumulated during the project's preparation and implementation stages. There was a clear understanding of the need to implement SBL methods in both institutions. All information gathered through curriculum development, study observations, surveys, interviews, and tests was organized systematically to support the project's implementation. Three problematic issues were identified during this phase. First, there was a need to determine how closely the developed models were linked to real industry scenarios. Second, addressing how to implement these models within the current study process and exploring the possibilities of replacing traditional teaching methods with model-based learning. Third, evaluating the sophistication level of the models to ensure their optimal use in the educational setting.

This stage also includes the research process and outcomes, considering the researcher's own actions and biases.

Based on this comprehensive analysis, an action plan was developed for the next cycle of action research. This plan aims to refine the models, enhance their integration into the study process, and ensure they are effectively aligned with industry practices.

3.2 Design

The learning module consisted of three interrelated digital courses and is called the “Aviation Operation Simulation Module.” The core of the module is a specialized platform or simulation modeling software. Based on this platform, two specialized courses (each worth 9 ECTS) and an introductory course on the software program itself (6 ECTS) have been developed. The existing software program has been acquired, and the courses are designed based on it.

Using the software, simulation models were developed to imitate operations common in the aviation industry. In perspective, students were introduced to how to use such tools in their professional careers. This approach aims to provide students with practical skills and knowledge directly applicable to their future roles in the aviation sector. Through these courses, students learned to navigate and utilize the simulation software effectively, allowing them to better understand and manage aviation operations.

3.3 Development

During the project, three courses were developed, each incorporating various simulation models. The development of these courses proceeded as follows: students will learn how to digitally simulate (i.e., model) airport or airline operations. Simulation-based imitation of real activities enables students to comprehensively understand how sophisticated aviation systems function. Besides acquiring skills in computer modeling, students will also learn about aviation processes and procedures that often cannot be simulated by computer models. For instance, they will study constraints from arctic conditions, safety requirements, and international regulations applicable to aviation. Within the courses, students will design their own simulation models (based on scenarios provided by instructors) to demonstrate their skills and creativity.

Most of these courses were integrated with the existing courses at the participating institutions. However, the project's purpose was to restructure the teaching methods of these courses.

The first integrated course is titled Airport Operations (C1), and the second set of courses is Airline Operations (C2). The first set of courses was developed by the Estonian Aviation Academy (EAVA), and the second by UiT. The third course (Simulation Modeling Software, C3) was jointly developed by EAVA and UiT.

The first course (Airport Operations, EAVA) teaches students to build computer models for airport activities. It covers aspects such as airport operations fundamentals, customer service management, passenger and cargo handling, capacity building, safety, and more.

The second course (Airline Flight Operations, UiT) teaches students to build computer models for airline operations. It includes principles of operations (particularly in Arctic conditions), flight planning, managing cargo operations, and other relevant aspects.

The third course (Simulation Modeling Software, EAVA and UiT) provides students with practical skills on using the simulation software program. All course materials will be digital and freely available to students. The course content will be supported by teachers' manuals, prepared by the partners responsible for developing the course content. Additionally, manuals and workbooks for students will be developed, with those for the third course created jointly.

The software program SIMIO was used for generating and teaching simulation models. SIMIO is widely recognized and used by academic and business institutions. It is available for academic purposes (teaching) free of charge.

3.4 Implementation

The project focused on modeling begins with setting clear and achievable goals. This foundational step ensures that both educators and students have a shared understanding of the objectives and outcomes expected from the course. Tasks were shared between participating institutions, and teachers individually built models, which were later discussed jointly. Each model was analyzed and explained in detail during joint workshops.

Individual model development by the teachers allowed for a deeper understanding of the subject matter with students' needs in mind. Along with model design, the courses were rearranged and supplementary teaching materials, such as slides and teacher manuals, were developed. As the digital models are technically sophisticated, detailed explanations were added to each model.

Following the individual efforts, joint seminars were organized where participants introduced their models to their peers and partners. These seminars served as platforms for collaborative activities and deeper cooperation.

The final part of the project involved testing the models in the actual teaching process. This testing phase was crucial to evaluate the effectiveness of the models and ensure they met the educational goals. Feedback from students and instructors was collected to refine the models and teaching materials further, ensuring a robust and practical learning experience.

3.5 Testing

To ensure that students can effectively use and benefit from these models, teaching sessions are conducted. These sessions are designed to equip students with the necessary skills and techniques to utilize the models in various scenarios, making the learning process more practical and applicable.

Finally, the program includes a comprehensive evaluation of students' progress. This evaluation is essential to measure the effectiveness of the teaching methods and the students' understanding and application of the models. Regular assessments help in identifying areas of improvement and ensuring that the educational goals are being met efficiently.

To test the simulation-based learning (SBL), a course titled "Airport Operations" was conducted. The testing phase of SIMIO teaching included the integration of models specific to airport ground processes and passenger flow. The class chosen for the testing included students from the final year degree program at the Estonian Aviation Academy and Erasmus students from other parts of Europe. The teaching was conducted mostly face-to-face, with hybrid sessions as needed.

The first step of testing involved introductory teaching sessions, including discussions about the importance of simulations and basic information about the SIMIO software. The teaching continued by highlighting the successful application areas of SIMIO across many industries, including manufacturing, aerospace, defense, and industrial engineering. Considering the students' interest, extra materials were provided to cover the importance of SIMIO use in different fields.

The hands-on experience with SIMIO began in the second step of teaching. The basic Source-Server-Sink (SSS) model was built using general examples (Figure 2).

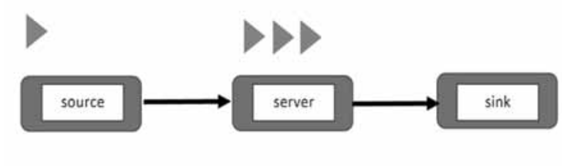

Figure 2: Principal model design,

Detailed instructions were provided for the arrival of entities, the processing properties, and the types of processing methods for each entity at the server. For advanced learning, the use of multiple server models and examples were also taught in the class.

During the practical training, students were grouped into teams of two or three people to achieve the following objectives:

1. Understand the sample problem statement by recognizing the given details of the sample model and identifying what needs to be found using Simio simulations.
2. Identify the elements and resources required to build the basic model.
3. Specify server capacity and processing properties.
4. Successfully execute the model.
5. Read and interpret the results table after executing the model.

The majority of the students showed great interest in learning the visual representation of the problem and attempting to find reasonable solutions. A significant percentage of students advanced their skills quickly, asked questions, and discussed model improvements. The feedback on the teaching and practical sessions was impressive. The teaching continued for a few weeks with introductory lectures and practical training.

As practice for students, solved modeling problems from the built-in SIMIO SimBits and examples provided by the instructor were regularly used. During practical sessions, students were encouraged to ask questions about the model-building and solution strategies and to participate in discussions. Advanced aviation models regarding optimizing ground-side processes, passenger flow in the terminal, and flight arrivals/departures were also presented to spark students' interest.

To conclude, SIMIO modeling is a valuable tool for studying and analyzing airport operations at any stage. From the airport management perspective, whether landside or airside, terminal operators could benefit from running simulations beforehand by inputting flight schedules and passenger quantity details into the model.

3.6 Evaluation

The attempt to teach SIMIO, a modern simulation tool, at the Estonian Aviation Academy was successful, driven by the strong interest of the students. The instructor's step-by-step instructions and detailed discussions about problems and their potential solutions significantly enriched the students' experience with simulation modeling, guiding them effectively through the learning process. Practical training sessions were identified as the most successful method for teaching SIMIO, allowing students to apply theoretical knowledge in practical scenarios. This hands-on approach not only facilitated better understanding but also enhanced their problem-solving skills.

Given the success of practical training, future SIMIO courses will prioritize practical sessions and one-to-one discussions. This approach will ensure that students receive personalized guidance and have ample opportunities to engage deeply with the material. At the end of the course, students' skills were assessed through group or individual projects and assignments. These assessments included practical demonstrations of the solved problems, accompanied by detailed reports analyzing the problems. This comprehensive evaluation process ensured that students could effectively demonstrate their understanding and application of SIMIO modeling, highlighting the effectiveness of the practical, discussion-based teaching approach.

4 Results and Conclusions

The integration of SIMIO software into aviation management education at the Estonian Aviation Academy has demonstrated significant benefits. It ensured students gained practical skills and a deeper understanding of complex aviation operations, effectively bridging the gap between theoretical knowledge and real-world application. The SIMIO modeling environment allowed students to visualize and interact with sophisticated aviation scenarios, making the learning process more engaging and relevant. Students responded positively, appreciating the hands-on experience and the relevance of the simulations to real-world situations.

The practical applications of SIMIO enabled students to see the direct consequences of their actions within simulated environments, fostering a deep understanding of aviation management principles and practices. This practical approach also helped students develop a wide range of essential skills, including technical, functional, problem-solving, decision-making, and communication competencies.

This experience suggests that other educational institutions could benefit from adopting similar SBL models. Future research could explore the long-term impacts of such educational approaches on students' career readiness in the aviation industry. Additionally, expanding the use of SBL to cover more aspects of aviation management and incorporating feedback from industry professionals could further enhance the curriculum.

In conclusion, the use of SIMIO software for simulation-based learning in aviation management represents a positive experience in Estonian Aviation Academy's educational practice. SIMIO provides a valuable model that other institutions can adapt to enhance their educational offerings and prepare students for the challenges of modern aviation management.

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On the Relationship between Model Complexity and Decision Support in Agent-based Modeling and Simulation

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Abstract. Agent-based models can simulate interactions of complex systems that lead to emergent events. This capability enables the exploration of potential outcomes of different assumptions and scenarios, which can support the decision-making process for complex systems. However, identifying the optimal level of detail and granularity of agent-based models is challenging and highly related to the decisions they are intended to support. Detailed and granular models can incorporate more information and potentially provide a more realistic representation of an actual system. However, the more complex models require more time and resources to run and analyze, and their complexity can make the in -terpretation of simulation challenging. Conversely, simpler and more aggregated models are often easier to interpret and more efficient to run, though they may offer a less accurate representation of the original system. In this paper, we discuss the trade-offs between detailed and aggregated models and review the factors that influence the optimal level of detail and granularity.

Introduction

Agent-based modeling and simulation (ABMS) is a modeling approach that is applied to understand and predict the behavior of complex systems, such as social, economic, and natural systems. Generally, an agent-based model represents the behavior of individual agents (which can represent people, companies, or other entities) and the interactions between them. The collective behavior of the system emerges from the interactions between these agents in the simulation.

ABMS enables the exploration of the potential outcome of different assumptions or scenarios to support the decision-making process in various fields [11, 14, 2, 6]. Schinckus [9] identifies four main approaches to employing agent-based modeling in economics: The deductive approach using perfectly rational agents, the abductive approach with adaptive agents, the metaphorical approach using concepts from physics, and the phenomenological approach that aims to reproduce observed statistical patterns. This diversity of approaches demonstrate the flexibility of ABMS in capturing different aspects of a complex system which make it a unique decision-support tool.

Intuitively, an agent-based model that incorporates more details and granularity of a real-world system will more accurately replicate the behavioral patterns of the original system. However, there are various benefits to employing simpler models, such as model interpretability and required resources. These advantages can outweigh the consequences of lower accuracy of simple models which motivates the modelers to create models with the highest possible level of detail and granularity. However, there are various benefits to employing simpler models, such as model interpretability and reduced resource requirements [13, 10]. These advantages can outweigh the consequences of lower accuracy. Therefore, balancing the incorporation of the highest possible level of detail and granularity in an agent-based model with considerations such as model interpretability and resource requirements is a complex and challenging task for modelers. Besides the trade-off between model complexity and accuracy, it is crucial to understand the complexity of an agent-based model in order to grasp its capabilities and limitations accurately.

Sun et al. [12] explain that a model can be structurally simple yet produce complex behaviors, or it can be very complicated in structure without necessarily generating complex dynamics. The authors emphasize that we must consider both the desired level of structural complicatedness and the intended complexity of model behaviors while designing agent-based models.

Decision support systems can benefit from the use of ABMS, which provides policy-makers and decision-makers with a controlled and transparent way to explore potential outcomes of different decision options. The relationship between the level of decisions and the complexity of a model is often proportional, with more complex models being better suited for supporting higher levels of decision-making.

For instance, simple models may suffice for operational-level decisions based on established rules and procedures, while strategic-level decisions requiring long-term planning and resource allocation may require more complex models to consider a wider range of factors and uncertainties.

The aim of this paper is to discuss the factors that influence the complexity of an agent-based model employed as a decision support tool, taking into account the desired level of decision support. These factors include agents' characteristics, the agent-based model's interaction rules, the user's specific context and decision-making requirements, the availability of resources and expertise, the nature and scope of the decisions being made, the desired level of interpretability of the model, the reliability of the model, and the available resources to run the simulations.

1 Model Complexity vs. Decision-Making

In this paper, the complexity of a model refers to its structural aspect. We consider the complexity of an agent-based model to be strongly dependent on the number of agents, the rules and behaviors attributed to the individual agents (including the degree of interdependence between agents), and the environmental factors affecting agents. A more complex agent-based model typically refers to a greater number of agents, each having a more extensive range of attributes and behaviors, as well as more complex rules governing their interactions with each other and their environment.

Several factors can affect the complexity of an agent-based model such as the multitude and diversity of agents, processes, and interactions, along with their respective attributes [12]. Following the ODD (Overview, Design concepts, and Details) protocol [4], the main factors that affect an agent-based model's complexity are:

Agents: The more agents and the more diverse the types of agents, the more complex the model is likely to be.

Interactions: The more interactions between agents and the more complex those interactions are, the more complex the model is likely to be.

Rules: The more rules for agents' decisions and the more complex those rules are, the more complex the model is likely to be.

The environment: The more features and interaction rules for the environment, the more complex the model is likely to be.

Scheduling: The longer the model's time horizon, the more complex the model is likely to be.

There are several methods to measure the complexity of an agent-based model. One of the most popular methods is Kolmogorov's definition of complexity [7], which is a measurement of the resources needed to specify the model. Moreover, Popovics and Monostori [8] proposed an approach to determine the complexity of discrete event simulation models by combining several parameters.

Agent-based models are used to support a variety of decisions. However, modeling decisions is challenging due to the importance of including the beliefs, desires, and intentions of decision-makers while considering physical, emotional, and social factors [3]. There are multiple studies that focused on modeling human decisions and behaviors in agent-based models [1, 5]. Focusing on business-related decisions, we can categorize the decisions into operational, tactical, and strategic level decisions. *Operational level decisions* are relatively simple decisions and involve the execution of well-defined rules and procedures.

As such, simple agent-based models may be sufficient to support these decisions. *Tactical level decisions* are medium-term decisions that involve the allocation of resources and the coordination of activities. These decisions may be more complex than operational level decisions and may require more sophisticated models to evaluate the potential consequences. Finally, *Strategic level decisions* are long-term decisions that involve the allocation of resources and the formulation of overall goals and objectives. These decisions may be more complex than operational or tactical level decisions and may require more sophisticated models to evaluate the potential consequences.

We propose a further classification of decisions based on their intended purpose into forecasting, demonstration of past decisions, and hypothesis testing. For forecasting decisions, the modeler designs the model as a prediction tool. It may be necessary to use highly detailed and complex models that consider a wide range of factors and processes to make accurate predictions.

However, it is also possible to use simpler models that capture the key processes in a system in order to make more qualitative, non-specific predictions. The complexity of the model needed for predictive purposes will depend on the level of certainty required. The second category is the demonstration of past decisions to understand their cause and effect. Simple models are often suited for this purpose since they are more explainable than complex models, and it is more convenient to understand them.

In hypothesis testing or what-if analysis, the goal is to confirm or challenge a theory. Modeling complex systems is often done by simplifying and generalizing in order to build theories. Simple models that focus on general questions are more effective at developing theories with general validity.

In another perspective, Sun et al. [12] argue that different principles apply depending on the type of agent-based model being developed.

The principle of parsimony should be followed for abstract theoretical models, keeping the model as simple as possible.

For empirically grounded models aimed at prediction or decision support, the 'Medawar zone' principle applies meaning models should be in an intermediate range of complicatedness, as complicated as necessary but no more so.

The authors also mention that in all cases, modelers should strive to match the level of model complicatedness to the specific research questions being investigated.

2 Summary and Conclusion

Increasing complexity of agent-based models can lead to a more accurate representation of the system being modeled and the behavior of individual agents. For example, if a model of a stock market includes a large number of variables that describe the behavior of individual investors, it is likely to provide more accurate predictions of stock prices.

However, more complex models require more computational resources for simulation and comprehensive datasets for accurate calibration of the model. These challenges potentially limit the practical implementation of large-scale models involving millions of agents with intricate interactions in time-sensitive or resource-constrained decision-making contexts.

Moreover, complex models are less interpretable for stakeholders who are not familiar with the underlying assumptions and relationships between variables. Consequently, this challenge constrains decision-makers ability to effectively employ models and make informed judgments using simulation results. Lastly, complex models are also more prone to errors and inaccuracies, especially if the underlying assumptions or relationships between variables are not well understood. This vulnerability can compromise the reliability and validity of the results and lead to incorrect or misleading predictions and insights.

In conclusion, the design of agent-based models requires an approach that addresses both the demands of the decision-making process and practical implementation. A model that is overly simplistic may not possess the necessary information to facilitate informed decision-making, whereas a model that is excessively complex may prove to be intricate to comprehend. For the future of agent-based modeling in decision support systems, modelers should focus on developing models at both ends of the complexity spectrum, investigating complexity indicators to address the crucial challenge of finding a balance between complexity and simplicity. The goal must be to create models that are simple, yet theory-driven and rich in dynamics to understand the key processes of the system.

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Exploring the Use of Urban Consolidation Centers for Efficient Last-Mile Delivery Using Agent Based Modelling and Simulation

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Abstract. With the rise of e-commerce and door-to-door sales, last-mile deliveries are gaining more and more importance. As a result, last-mile distribution has become one of the most sensitive logistics processes due to its uniqueness, difficulties in meeting schedules, and high costs. Therefore, this work explores the use of urban consolidation centers to ease these last-mile difficulties. Experiments are based in different hub-based fleets (traditional internal combustion vehicles or electric cargo bikes), demand patterns, and delivery frequency strategies by means of a biased randomization vehicle rooted in an agent-based simulation model. Results quantify the effect of having an urban consolidation center and highlight the use of electric cargo bikes for the last-mile distribution.

Introduction

Last-mile deliveries are a challenge all around the world because of the increment in the number of parcels delivered daily that leads to an even bigger number of vehicles, sometimes half-empty, driving for long distances. Additionally, this leads to a growth in urban freight vehicles, which congest city centers and produce such an amount of noise and air pollution. Therefore, urban consolidation centers or city freight hubs arise as an appropriate mitigator of those problems.

Urban hubs are warehousing centers located at key points in cities that speed up the entire process of delivering packages to retailers and online customers. Thanks to this type of solution, it is possible to meet ultra-fast delivery services at the time delivery operations gain efficiency as freight consolidation occurs. The use of urban hubs is, therefore, seen as a way of mitigating some of the aforementioned problems as described by Bukoye et al. [1].

Hence, this article explores the use of urban hubs in the city center of Vienna (Austria) [2] and the use of hub-based electric-powered vehicles for the final deliveries in the hub influence zone. Moreover, a simulation-optimization model is designed and implemented to run the computational experiments.

1 Problem Description

As stated before, large cities such as Vienna have a special interest in solving the problems generated by last-mile logistics. For that purpose, the idea of using urban hubs is quite attractive. That way, several companies such as DHL, DPD, UPS, and local Post can share a place to store, organize, and deliver parcels conjointly in order to save costs. Therefore, in this work, we consider an urban hub for distributing parcels to up to 150 customers in the city center of Vienna disseminated within the 2nd, 3rd, 10th, 11th, and 23rd districts, as shown in Figure 1.

However, given the space limitation, this work focuses on the delivery process from the hub to the final customers for a range of scenarios. Therefore, real orders to the companies and the routes from their depots to the hub are out of the scope of this article. Subsequent paragraphs, however, are indented.

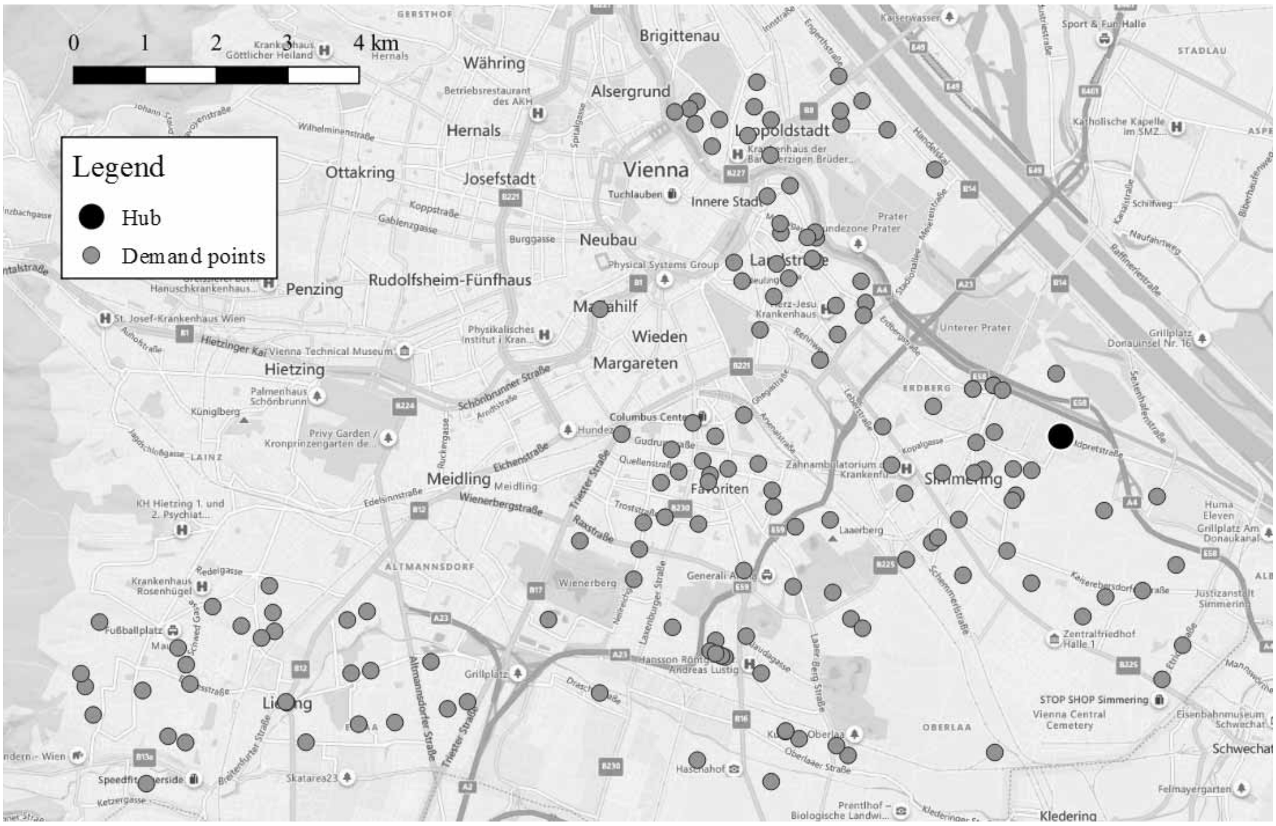

Figure 1: Map of Vienna with the clients (red dots) and hub (black dot).

2 Methods

The agent-based simulation model is based on customer, hub, and vehicle agents. Additionally, an order agent is considered, as well as the heuristic agent. Thus, customer agents are characterized by a demand and an ordering trigger probability. On the other hand, the hub agent considers a parcel capacity and a schedule for doing the deliveries. Similarly, vehicles fleet are hub-based with a given capacity. In this regard, we consider an homogeneous fleet with the same capacity.

Firstly, two different types of vehicles are tested, i.e. internal combustion traditional vans and electric-powered cargo bikes. With respective capacities of 50 and 30 parcels per vehicle. Secondly, two demand periods are considered: a regular valley demand and a peak demand characterized by different ordering probabilities. In our experiments, we fixed these probabilities to 0.30 and 0.70, respectively.

In order to solve our Vehicle Routing Problem (VRP), calculate delivery costs, and measure CO_2 emissions; a biased-randomized solution procedure [3] was implemented on the basis of the concepts presented by Juan et al. [4]. Our approach depends in its work on the implementation of a set of steps in order to reach an optimal solution.

The first step is calculating the cost of serving each customer individually with a vehicle; in our case, we named it pendulum tours. The cost in this step represents the total cost for each round trip from the depot to each customer separately.

The generated pendulum tours matrix represents the initial base routing solution, where we have assumed/assigned it at this phase as the "best solution" to compare it later with other solutions that will be found. The next step is to generate the saving list by performing Clarke and Wright Savings heuristic on the pendulum tours matrix.

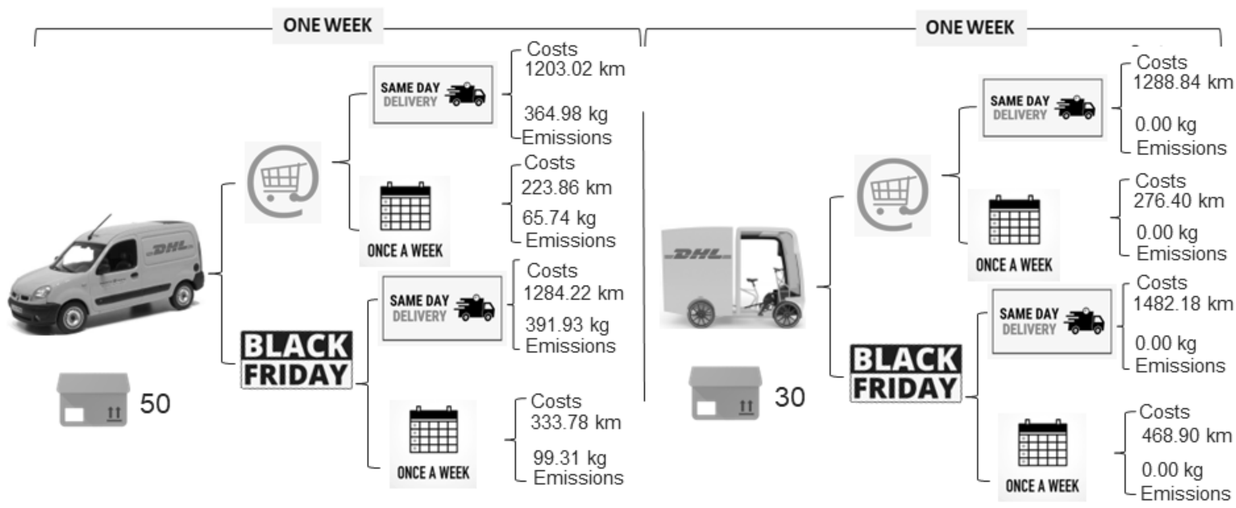

Figure 2: Description of simulation scenarios.

Scenario				Distances	Emissions
Vehicle	Demand	Setting selected		Average (km)	Average (km)
VAN	Valley	Ultra-fast	S1	1203.02	364.98
		End-of-week	S2	223.86	65.74
	Peak	Ultra-fast	S3	1284.22	391.93
		End-of-week	S4	333.78	99.31
Cargo bike	Valley	Ultra-fast	S5	1288.84	0.00
		End-of-week	S6	276.40	0.00
	Peak	Ultra-fast	S7	1482.18	0.00
		End-of-week	S8	468.90	0.00

Table 1: Description of simulation scenarios and results.

Both, the provisional best solution and saving list have stored in temporary variables, so we do not lose them and keep them as a reference to compare with generated solutions. After all, the required parameters have been set, we have assigned a number of iterations in order to perform an iterative biased-randomized saving heuristic procedure.

3 Results

Experiments are run for a simulation period of one week based on a number of scenarios that will determine the ruling simulation model parameters.

Firstly, the study examines two distinct vehicle types: traditional internal combustion vans and electric-powered cargo bikes, with parcel capacities of 50 and 30 per vehicle, respectively.

Secondly, two demand periods are analyzed: a regular valley demand and a peak demand, each defined by different ordering probabilities. In our experiments, these probabilities were set at 0.30 for the valley demand and 0.70 for the peak demand.

Thirdly, two delivery systems are studied, an ultra-fast delivery system in which orders are delivered the following day they were requested; and an end-of-week strategy in which orders are aggregated and consolidated to be delivered at the end of the experimental week.

Finally, ordering demands are based on a geometric random variable starting at 1 with a probability of 0.65. With respect to the VRP heuristic, we fixed the number of iterations to 300 and the skewed biased savings distribution parameter to 0.35.

The average distance for traditional van with ultra-fast delivery system in a standard day is about 1,200 km, whereas these distances are slightly higher for the same scenario when using cargo bikes, which in this case is 1,290 km. On the other hand, when focusing on a peak demand season, with a cargo bike delivering ultra-fast, the distance increases up to 1,500 km. While the end-of-week delivery system, varies from 220 up to 470 km for the different vehicles and periods. Detailed results can be found in Figure 2 and Table 1.

4 Conclusions

This work focused on exploring an urban hub as a potential solution for last-mile urban distribution challenges. Here we considered the use of traditional vans and cargo bikes as well as two delivery strategies (ultra-fast and end-of-week) for comparison purposes. Additionally, two different demand scenarios, peak days and valley days, were examined.

After the analysis of the results described in Table 1, a number of conclusions can be drawn.

Firstly, end-of-week delivery system is quite more efficient in terms of costs and emissions. Nonetheless, the ultra-fast one is more popular because of the high delivery companies competition. The cost of such a competition is estimated in 300-537 in comparison to the end-of-week delivery.

Secondly, in valley demand periods, it can be observed that the costs from a cargo bike and the ones of the van are not so different, up to 6.65 for ultra-fast delivery. Finally, from 65 up to 392 kg CO_2 emissions can be saved when moving to the electric delivery. Additionally, these emissions can be reduced by using the end-of-week delivery. Particularly, emissions savings up to 82.15 can be achieved compared to the ultra-fast deliveries when using the traditional vans.

Further studies are necessary to explore various possibilities and determine the trade-offs between them. Additionally, real data collection is required for validation purposes. These efforts will inform future research, which should focus on investigating horizontal cooperation strategies and examining new scenarios.

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LIOPHANT Simulation, c/o Agostino G. Bruzzone, DIME, University of Genoa, Savona Campus, via Molinero 1, 17100 Savona (SV), Italy

LSS – Latvian Simulation Society

The Latvian Simulation Society (LSS) has been founded in 1990 as the first professional simulation organisation in the field of Modelling and simulation in the post-Soviet area.

President	Artis Teilans, *Artis.Teilans@rta.lv*
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LSS, Dept. of Modelling and Simulation, Riga Technical University, Kalku street 1, Riga, LV-1658, Latvia

NSSM – National Society for Simulation Modelling (Russia)

NSSM – The National Society for Simulation Modelling (Национальное Общество Имитационного Моделирования – НОИМ) was officially registered in Russia in 2011.

President	R. M. Yusupov, *yusupov@iias.spb.su*
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PTSK – Polish Society for Computer Simulation

PTSK is a scientific, non-profit association of members from universities, research institutes and industry in Poland with common interests in variety of methods of computer simulations and its applications.

President	Tadeusz Nowicki, *Tadeusz.Nowicki@wat.edu.pl*
Vice President	Leon Bobrowski, *leon@ibib.waw.pl*

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PSCS, 00-908 Warszawa 49, ul. Gen. Witolda Urbanowicza 2, pok. 222

SIMS – Scandinavian Simulation Society

SIMS is the Scandinavian Simulation Society with members from the five Nordic countries Denmark, Finland, Norway, Sweden and Iceland. The **SIMS** history goes back to 1959.

President	Tiina Komulainen, *tiina.komulainen@oslomet.no*
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SLOSIM – Slovenian Society for Simulation and Modelling

The Slovenian Society for Simulation and Modelling was established in 1994. It promotes modelling and simulation approaches to problem solving in industrial and in academic environments by establishing communication and cooperation among corresponding teams.

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SLOSIM, Fakulteta za elektrotehniko, Tržaška 25,
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UKSIM - United Kingdom Simulation Society

The UK Modelling & Simulation Society (**UKSim**) is the national UK society for all aspects of modelling and simulation, including continuous, discrete event, software and hardware.

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Secretary	T. Bashford, *tim.bashford@uwtsd.ac.uk*

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UKSIM / Prof. David Al-Dabass, Computing & Informatics, Nottingham Trent University, Clifton lane, Nottingham, NG11 8NS, United Kingdom

Observer Members

ROMSIM – Romanian Modelling and Simulation Society

ROMSIM has been founded in 1990 as a non-profit society, devoted to theoretical and applied aspects of modelling and simulation of systems.

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ROMSIM / Florin Hartescu, National Institute for Research in Informatics, Averescu Av. 8 – 10, 011455 Bucharest, Romania

ALBSIM – Albanian Simulation Society

The Albanian Simulation Society has been initiated at the Department of Statistics and Applied Informatics, Faculty of Economy at the University of Tirana, by Prof. Dr. Kozeta Sevrani.

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Albanian Simulation Goup, attn. Kozeta Sevrani, University of Tirana, Faculty of Economy , rr. Elbasanit, Tirana 355, Albania

Former Societies / Societies in Re-organisation

- **CROSSIM** – *Croatian Society for Simulation Modelling*
  Contact: Tarzan Legović, *Tarzan.Legovic@irb.hr*
- **FrancoSim** – Société Francophone de Simulation
- **HSS** – Hungarian Simulation Society
  Contact: A. Gábor, *andrasi.gabor@uni-bge.hu*
- **ISCS** – Italian Society for Computer Simulation

The following societies have been formally terminated:

- **MIMOS** –Italian Modeling & Simulation Association; terminated end of 2020.

Association Simulation News

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- Publication of the series **ARGESIM Reports** for monographs in system simulation, and proceedings of simulation conferences and workshops
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