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## TWO-STAGE HYBRID FLOWSHOP SCHEDULING PROBLEM WITH INDEPENDENT SETUP TIMES

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**Abstract**
In this paper, a two-stage hybrid flowshop scheduling problem with independent setup times is examined. The complexity of the studied problem is NP-Hard in the strong sense since it generalized the two-stage hybrid flowshop scheduling problem. Several real-life problems in different areas are modelled using the addressed problem, as in parallel computing and manufacturing processes. Solving the current scheduling problem necessitates the construction of adequate algorithms, providing near-optimal solutions within a satisfactory computing time. In this study, a genetic algorithm with specific features and three other heuristics are developed. These three heuristics are based on the optimal solution of the parallel machine scheduling problem with release dates and delivery times. In order to assess the performance of the meta-heuristic and the heuristics, a family of three lower bounds is proposed. An exhaustive numerical study is performed over a total of 1920 test problems. The obtained results provide strong evidence of the efficiency and the performance of the proposed procedures. 22 refs.
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**Key Words:** *Two-Stage Hybrid Flowshop, Independent Setup Times, Genetic Algorithm, Heuristics, Lower Bounds*

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Pages 17-28

## HYPOTHESIS-DRIVEN SIMULATION EXPERIMENTS WITH AN EXTENSION TO SED-ML

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**Abstract**
Most of the frameworks or assistance systems for experiment specification do not provide a process explicitly based on formally specified hypotheses. This deficiency leads to inaccurate or insufficient record of an experiment, decreasing the trustworthiness and reproducibility of the experiment. Moreover, the wide variety of models, metamodels, tools, and data for experimentation requires Global Model Management (GMM) that is utilizing Model-Driven Engineering techniques, facilitates documentation, sharing, reusability, and replicability of simulation experiments. In this study, we strive to illustrate how to support simulation experimentation with hypotheses as a scientific workflow through GMM with an extension to the Simulation Experiment Description Mark-up Language (SED-ML). In particular, we present a megamodel built to serve as a repository to manage the artefacts employed in a simulation experiment. Based on the SED-ML, and enriched with hypothesis handling, our megamodel attempts to address all the phases of a simulation experiment, including specification, input data generation, execution, and output data analysis. 35 refs.
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**Key Words:** *Design of Experiments, Simulation Experiment Description Markup Language, Global Model Management, Signal Temporal Logic*

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Pages 29-40

## COMBINING SIMULATION AND DATA ANALYTICS FOR OEE IMPROVEMENT

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**Abstract**
Overall Equipment Effectiveness (*OEE*) is a productivity performance metric widely used in industry to support production control decisions. However, there is still a gap in organisational procedures to systematically identify and address the most promising opportunities to improve the production setup. In this study, we propose and demonstrate a data-driven approach for increasing *OEE* by combining the strengths of discrete-event simulation with data analytics tools and methods, which provides a risk-free test environment that forms the basis for data-driven decisions and supports revealing production interdependencies. Therefore, this approach eases the process for practitioners to proactively identify production losses and forecast the outcome of the most promising selected improvement measures. A case study is performed to illustrate the potentialities of the proposed approach, demonstrating the interdependence between the processes and the improvement measures, and the knock-on effect both upstream and downstream. The results yield substantial insights and facilitate operational decision-making for managers. 26 refs.
(Received in August 2021, accepted in January 2022. This paper was with the authors 1 month for 1 revision.)

**Key Words:** *Discrete Event Simulation, Data Analytics, OEE, Improvement, Industry 4.0*

Pages 41-52

## COUPLING OF ODE AND DES MODELS FOR SIMULATION OF AIR DEFENCE IN WAR-GAMING EXPERIMENT

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**Abstract**
The planning stage of any procedure is critical to its successful and efficient execution. Even in the military, over the last few decades, mission planning support has evolved rapidly using modern Modelling and Simulation (M&S) tools. The article focuses on the M&S of Surface Based Air Defence (SBAD) and the design of the complex hybrid simulator coupling Ordinary Differential Equation (ODE) and Discrete-Event Simulation (DES) models. The simulator includes all entities and procedures that participate in SBAD missions, specifically the ODE models of a target, missile, radar, and the models of Command and Control (C2) system procedures. The design of the simulator also includes the possibilities of automated generation of flight routes, fire control and target distribution for multiple targets and Fire Units (FU) using queuing theory algorithms. As a main platform for the development and scenario design, the Jupyter notebook environment with the Python programming language was used. The primary objectives are to design, validate, and implement the proposed simulator in SBAD mission planning, military cadets' education, and experimental tasks. 24 refs.
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**Key Words:** *Modelling and Simulation, Flight Route, War-Gaming, Optimal Track, Air Defence, Command and Control*

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Pages 53-64

## DESIGN AND IMPLEMENTATION OF A DEVS-BASED CYBER-ATTACK SIMULATOR FOR CYBER SECURITY

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**Abstract**
The necessity of conducting business processes of institutions and individuals with information technologies has brought risks and threats. Cyber-attacks may lead to hard-to-recover results. Although many security systems have been developed against to these attacks, attacks and security breaches of information systems are increasing rapidly. In this study, it is aimed to understand the security weaknesses and vulnerabilities, which is one of the most important issues at the point of providing cyber security, and to detect cyber-attacks. Using physical networks to test cyber-attack methods is a very costly and time consuming process. In this paper, as a different method, a cyber-attack simulation model has been developed using the DEVS modelling approach to simulate and test cyber-attack scenarios and evaluate the results. An application has been developed that simulates an attack scenario in a virtual network and evaluates detector alerts by generating appropriate intrusion detection system signals. The DEVS-Suite simulation environment was used as a development environment. Comparisons were made with different cyber-attack simulation applications and their differences were revealed. 29 refs.
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**Key Words:** *Modelling and Simulation, Discrete Event Simulation, Cyber Security, Cyber-Attack Experiments, Network Testing Environments*

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Pages 65-76

## MODELLING AND SIMULATION ON CAVITY COLD PLATE FOR LI-ION BATTERY THERMAL MANAGEMENT

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**Abstract**
Recently, the safety of electric vehicles using lithium-ion batteries has received increased attention due to overheating. Cold plates can effectively enhance heat dissipation. However, given the defects of existing cold plates, such as complex structure and heavy weight, a simple cavity cold plate is designed. The effects of cold plate inlet and outlet sizes ($d_2$ and $\Delta d$), mass flow rate of coolant ($W$), and the inlet and outlet position on cell's maximum temperature and temperature difference are analysed using computational fluid dynamics (CFD) to enhance the heat dissipation capacity of the cold plate. Results show that the inlet and outlet sizes are positively correlated with the cell's maximum temperature. In addition, the cavity cold plate can satisfy the requirements of battery temperature difference by optimizing the inlet and outlet sizes and $W$. The cooling system of Model Z has better heat dissipation capacity than that of Model N. Conclusions obtained in the study have important reference for optimization of cavity cold plates. 23 refs.
(Received in November 2021, accepted in January 2022. This paper was with the authors 1 month for 1 revision.)

**Key Words:** *Cold Plate Modelling, Thermal Simulation, Battery Thermal Management, CFD*

Pages 77-88

## IMPLEMENTATION OF THE LEAN CONCEPT AND SIMULATIONS IN SMEs – A CASE STUDY

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**Abstract**
Increasing competition and globalization that encompasses all dealings in the world of business compel SMEs to seek more successful organizational and management modes and approaches. This paper presents a simulation model for the application of Lean methods and tools in SMEs and their impact on the improvement of production processes and product sustainability. The Lean concept can be used to achieve more efficient production whilst manufacturing lower-cost products including shorter manufacturing cycle, high quality, and added value. Research results show the usefulness of the application of dynamic simulations in the detection of critical places in processes and the usefulness of the application of relevant Lean methods and Lean tools for process improvement. Simulation results underline better performance of product manufacturing through the use of Lean tools with the aim to eliminate any waste. Reengineering the assembly line focuses on the following aspects, namely reducing waste, internal logistics, redesigning workplaces, and changing the workplace layout. 35 refs.
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**Key Words:** *Lean Concept, Lean Methods and Tools, SMEs, VSM, Simulation, Wastes of Assembly Line*

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Pages 89-100

## NUMERICAL SIMULATION OF MIGRATION LAWS OF DENSE PARTICLE FLOW IN PIPELINES

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**Abstract**
To explore the migration distribution laws of the cleaning agent of solid powder in industrial ventilation pipelines, a gas-solid flow migration model based on dense discrete phase model (DDPM) was built. Influences of various material injection methods (injection and jetting methods), positions, and directions in the narrowing zone of pipelines based on the migration laws of particulate cleaning agents in the pipelines were analysed. Results demonstrate that under the top injection method in the narrowing zone, the particulate cleaning agent presents obvious flow characteristics along the pipeline walls and cleaning agent concentration distributes unevenly in the pipelines. After the injection method is changed to top jetting, particle concentration remains high at one end near the wall and low at the other end. After changing the mouth from the top of the narrowing zone to the middle section and changing the spraying direction from perpendicular to the mainstream direction to the horizontal, the particle concentration of the cleaning agent reaches uniform distribution near the mouth and at the pipeline ends. Particle concentration in the pipelines is improved significantly. 26 refs.
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**Key Words:** *Dense Discrete Phase Model, Pipelines, Dense Particle Flow, Numerical Simulation*

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Pages 101-112

## MILK RUN TESTING THROUGH TECNOMATIX PLANT SIMULATION SOFTWARE

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**Abstract**
The article focuses on the testing of Lean tools on a created simulation model in the TX Plant Simulation software environment. Lean manufacturing tools and techniques are a progressive means of increasing the efficiency of production and logistics processes in an economically optimal way. It involves eliminating various types of waste, which requires good analysis and knowledge in the field. The article deals with the selected Lean production tools such as Value Stream Mapping, Milk run and Kanban to improve logistics flows processed in a case study. The output of the implemented case study was the optimization of logistics flows related to the supply of workplaces in the reduction of work in progress. 28 refs.
(Received in November 2021, accepted in February 2022. This paper was with the authors 2 weeks for 1 revision.)

**Key Words:** *Milk Run, Logistics, Model, Simulation, Lean Production*

Pages 113-123

## SYNCHRONISATION OF CONTACTLESS VIBRATION MONITORING METHODS

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**Abstract**
Today, the analysis of the behaviour of structures represents an important area of engineering, where we are mainly interested in the response of the structure to certain influences.

The article and research are based on the theoretical foundations of structural monitoring using contactless methods and discuss the practical analysis and simulation of synchronization of structural response to various artificially induced load cases. The responses of the structure were recorded through various parameters, such as displacement, speed and acceleration, with the help of geodetic (Robotic Total Station – RTS and Global Navigation Satellite System – GNSS) and physical equipment (triaxial geophone). When using geodetic equipment, in addition to the possibility of final synchronization of results, we were also interested in the actual influence of the frequency of data acquisition on the accuracy of measured values. Special attention was paid to spectral analysis, to which we added practical value through data processing using Fourier transform algorithms. 28 refs.
(Received in November 2021, accepted in January 2022. This paper was with the authors 2 weeks for 2 revisions.)

**Key Words:** *Model Synchronisation, Displacement Simulation, Geodetic Measurements, Physical Measurements*

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Pages 124-135

## A HYBRID CODE GENETIC ALGORITHM FOR VRP IN PUBLIC-PRIVATE EMERGENCY COLLABORATIONS

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**Abstract**
To minimize the total time for the distribution of relief commodities participated by both private companies and the government, a vehicle routing problem (VRP) model in emergencies was proposed. Considering the differences in the starting points of vehicles, the VRP of general logistics, and departments of vehicles, constraints, such as vehicle capacity limitation and time windows, were introduced into the model, which was close to meeting the practical demands of emergency relief. A hybrid code genetic algorithm (HCGA) was proposed, and it used dynamic mutations to avoid early traps in local optimization and to accelerate convergence. This algorithm was programmed by MATLAB. Furthermore, the vehicle routing optimization plans in an emergency was calculated by a simple genetic algorithm (SGA) and the HCGA, respectively. Results demonstrate that the total time for relief distribution in the HCGA is 11.62 % lower and the calculation time is 14.24 % shorter than that of the SGA. The HCGA is not only convenient in processing the constraints of the model and the natural description of problem solutions, but it is also effective in improving the complexity. 24 refs.
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**Key Words:** *Emergency Logistics, Vehicle Routing Problem, Genetic Algorithm, Health Emergencies*

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Pages 136-147

## A NEW MODEL FOR OPTIMIZATION OF CELL SCHEDULING CONSIDERING INTER-CELL MOVEMENT

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**Abstract**
Focusing on a cellular manufacturing system with inter-cell operations, a new scheduling framework is proposed in which a novel mathematical model is provided considering the cell scheduling sequence and an extended disjunctive graph model is established with multi-cell. In addition, an improved harmony search algorithm is proposed, comparison experiments show that the proposed solution can obtain the best results in most cases. To enhance further the generalizability of our strategy, an adaptive neuro-fuzzy inference system (ANFIS) structure is generated. ANFIS is based on the improved harmony search algorithm and takes the cell scheduling properties as input and the results of our proposed solution as output. Then, the optimal ANFIS structure is obtained by comparing different ANFIS structures. Finally, the ANFIS-predicted values are compared with those of the proposed solution and get a high fitting degree, which verifies the validity of the ANFIS structure. 19 refs.
(Received in August 2021, accepted in January 2022. This paper was with the authors 1 month for 1 revision.)

***Key Words:*** *Inter-Cell Scheduling, Harmony Search, Cell Scheduling Sequence, Adaptive Neuro-Fuzzy Inference System, Extended Disjunctive Graph Model*

Pages 148-159

## SIMULATION-BASED MODELLING OF THE IMPACT OF RIDESHARING ON URBAN SYSTEM

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**Abstract**
This paper follows the basic principles of taxi dynamics and uses an agent-based modelling approach (ABM) to simulate the underlying road network, vehicles and passenger situations in an urban environment and to carry out evaluations. First, based on two evaluation metrics: passenger travel time and total number of passengers transported, a comparison is made between the ride-hailing system (RH) and the system with ridesharing under different supply and demand rates, revealing the impact of ridesharing on system efficiency at urban scale. Then, in the ridesharing system (RS), four levels of supply are taken as examples, and passenger travel time is disaggregated to quantify how the definition of vicinity in the matching process affects the passenger travel time, passenger waiting time and vehicle detour time in a given city. Finally, a summary of the level of supply and the range of vicinity where ridesharing can be effective is presented in terms of the total distance travelled by the system. From a city management perspective, these results can help in the analysis and planning of efficient transport services. 26 refs.
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**Key Words:** *Ride-Hailing, Ridesharing, Agent-Based Model, Simulation*

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Pages 160-171

## OPTIMIZATION OF MULTI-STAGE PRODUCTION SCHEDULING OF AUTOMATED PRODUCTION

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**Abstract**
With the continuous growth of the automation level, the production process is featured by multiple stages and process parameters. There is a huge sum of diverse data on automated production. With a low value density, these data come from heterogenous sources, and respond to lots of concurrent processing demands. It is necessary to simulate and optimize the production scheduling of the automated production system. Drawing on the existing research, this paper illustrates the process of multi-stage production scheduling of automated production, and simulates the automated production line on Plant Simulation. The flow of the simulation model was illustrated, the simulation objectives were specified, and the model hypotheses were detailed. From the angle of deterministic simulation modelling, a joint optimization model was established for the multi-stage production scheduling of automated production, and the production task assignment was improved for traditional pull scheduling model to meet the demand of dynamic collaborative demand for machines. The proposed model was proved effective through simulations. 22 refs.
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**Key Words:** *Automated Production, Multi-Stage Production, Production Scheduling*

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Pages 172-183

## MECHANISM OF ROAD CAPACITY UNDER DIFFERENT PENETRATION SCENARIOS OF AUTONOMOUS VEHICLES

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**Abstract**
This paper takes L0 (ordinary vehicles), L2 and L4 (autonomous vehicles) as the research objects, adopts different car-following rules and improves them respectively based on driver's personality factors and variable time headway (VTH) strategy, introduces a benefit parameters to distinguish lane changing ability of them, and evaluates road capacity under mixed traffic flow with a basic diagram model and average travel time. Use SUMO to build a simulation platform and conduct a real-time systematic research based on Python. The results prove that: (1) After the penetration rate of autonomous exceeds 60 %, road capacity can be effectively improved, and the maximum increase of 32.52 % occurs in 100 % penetration scenario. (2) When traffic density is less than 27 vehicles/km, the average speed continues to be the maximum in 100 % scenario, and when it is greater than 27 vehicles/km, the critical penetration scenario is 80 %. (3) The average travel time begins to decrease after the penetration rate exceeds 20 %, and can be reduced by 23.38 % in 100 % scenario. It shows that traffic efficiency is closely associated with penetration rates of autonomous vehicles. 29 refs.
(Received in October 2021, accepted in February 2022. This paper was with the authors 1 month for 1 revision.)

**Key Words:** *Autonomous Vehicles; Road Capacity, Mixed Traffic Flow, SUMO, Penetration Rate*

Pages 184-195

# OPTIMIZATION OF FLEXIBLE PRODUCTION LOGISTICS UNDER LOW CARBON CONSTRAINT

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**Abstract**
Flexible production centring on machines or job-shops is necessary to meet the current trend of production and sales. By studying the energy consumption of production logistics, it is possible to minimize energy consumption and carbon emissions of the production process, without sacrificing production efficiency. The existing studies all try to optimize the logistics distribution. None of them attempt to optimize both production and logistics distribution parameters, and low carbon emission indices. Therefore, this paper explores the multi-objective optimization and carbon efficiency evaluation of flexible production logistics under low carbon constraint. Specifically, the constraint order between production logistics time, logistics quality, logistics cost, and low-carbon degree was determined, and the expressions of four linear programming models were given. Moreover, the carbon efficiency optimization of flexible production logistics was redefined, and a mathematical model was developed for the carbon efficiency optimization problem, which simultaneously optimizes carbon emissions and production indices. The proposed model was proved scientific through experiments. 26 refs.
(Received in November 2021, accepted in February 2022. This paper was with the authors 2 weeks for 1 revision.)

**Key Words:** *Carbon Efficiency, Flexible Production Logistics, Low Carbon Constraint, Linear Programming*