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SETTING AN INDUSTRY 4.0 RESEARCH AND DEVELOPMENT AGENDA FOR SIMULATION – A LITERATURE REVIEW

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Abstract
The fourth industrial revolution, or Industry 4.0 (I4.0), originated in German, englobes many innovative features, in order to bring the concept of "smart factories". Moreover, discrete-event simulation (DES) is one of the most important areas involved in this goal. With this in mind, the purpose of this paper is to propose a research and development agenda (R&D) for DES researchers and practitioners, in order to comply with the I4.0 agenda. To achieve this, a literature review (LR) was conducted, in which 45 papers were considered relevant for this research. From their analysis, it was found that: the ability to automatically generate simulation models; the automation of data exchange between manufacturing applications and simulation tools; and visualization features, are the most essential DES features for I4.0. Thereafter, the LR focused on analysing the most recent papers in these areas of simulation, in order to propose a list of R&D items for DES researchers and practitioners. 45 refs.
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Key Words: *Discrete-Event Simulation, Industry 4.0, Visualization, Data Exchange Automation, Automatic Generation, Research and Development, Literature Review*

Pages 391-404

THE MATRIX OF FUNCTION AND FUNCTIONALITY IN PRODUCT DEVELOPMENT PROCESS

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Abstract
This work presents a developed mathematical model that transforms functions and functionalities as sets from the functional domain and design elements domain. The sets are interconnected by a matrix model which we called the matrix of function and functionality (MFF). By the MFF model we are searching cross-sections of function and functionality sets. The cross-sections we called submatrices. Submatrices contain design parameters that designers need for development of new product conceptual variants. MFF is conceived as a tool used in conceptual design phase. MFF collects and binds data from the requirement list and transforms them into functional requirements. Compared to the morphological matrix, MFF is structured as multidimensional matrix, which according to the mathematical model presented in this work, generates a functional structure as multilayer functional structure. MFF simulates the iterativity of the design process in conceptual phase, generating new conceptual variants. According to the mathematical model of MFF, a computer application was made and also presented in this work. 25 refs.
(Received in November 2017, accepted in May 2018. This paper was with the authors 2 months for 2 revisions.)

Key Words: *Product Development, Conceptual Design, Design Process, Function, Functionality, MFF (Matrix of Function and Functionality)*

Pages 405-418

ANALYSIS OF PATENT #US2014/0319274A1: A CASE STUDY OF SIMULATIONS FOR NEW DESIGNS REVIEW

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Abstract
The technical information needed to replicate a prototype is usually concealed when aircraft manufacturers patent new designs. Competitors must face this problem by developing inverse engineering processes that are validated by simulations and design thinking processes to find any patent weaknesses.

This paper focuses on a case study for patent analysis, applied to a revolutionary new concept in aircraft design: Patent #US2014/0319274A1 "Aircraft including a passenger cabin extending around a space defined outside the cabin and inside the aircraft". The computer simulations were performed first by a low computational software, "*FlowDesign*" (Autodesk), and afterwards, by a professional tool "*3DWind tunnel*" (MicroCFD). Results revealed that the drag coefficient and the drag force decreased 5.8 % and 3.8 % respectively at climbing, while the lift force increased up to 47 % for a pitch angle of 6^{0}. The patent weaknesses reside in a wrong seat arrangement and not taking into account the possibility of a "hole" variable to adapt aircraft shape to different flying operations. 22 refs.
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Key Words: *Patent Analysis, Aircraft Design, Improvement Characterization*

Pages 419-430

MODELLING AND SIMULATING THE DYNAMICS OF THE EUROPEAN DEMAND FOR BIO-BASED PLASTICS

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Abstract
Bio-based plastics are currently hardly competitive on the European market mainly due to their high production costs compared to fossil-based alternatives. A major issue in this context is the interplay between decreasing production costs and changing framework conditions and its effect on the competitiveness of bio-based plastics. In order to examine this, we developed a System Dynamics model that we use for simulations based on various assumptions defined in a high-level expert workshop. Our results show a positive influence on the market price and hence on the demand for bio-based plastics of establishing new capacities and adopting new production technologies. Despite this, bio-based plastics will not achieve cost competitiveness in the next 15-year period if framework conditions with regard to the oil price remain unchanged and if no new policy incentives are introduced such as tax exemptions and subsidies for new technologies. This negative trend is further enhanced later on by rising feedstock prices on the biomass market. 32 refs.
(Received in December 2017, accepted in June 2018. This paper was with the authors 2 months for 2 revisions.)

Key Words: *System Dynamics, Bio-Based Plastics, Scaling and Learning Effects, Feedstock Price, Price Competition*

Pages 431-443

SIMULATION ANALYSIS OF ORDER PICKING EFFICIENCY WITH CONGESTION SITUATIONS

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Abstract
Paper presents analysis of the order picking system efficiency under congestion situations. Analysed picking system is manual and organized as picker-to-part system with very narrow aisles. About 150 different variants of the system was taken into consideration. Each of them is characterized by different storage policies (random, class-based and volume-based), number of order pickers and picking strategies (single picking and batch picking). Main attention was paid to picker blocking phenomenon and its impact on order picking efficiency. Authors explain where, when and why such situations may happen. Additionally, they point out how the number of pickers, storage policy and picking strategy impact pickers blocking and picking process efficiency. Due to complexity of presented issue, dynamics and volatility of picking processes, simulation method was implemented. 26 refs.
(Received in January 2018, accepted in June 2018. This paper was with the authors 2 months for 1 revision.)

Key Words: *Warehousing, Order Picking, Congestion, Simulation, Performance Analysis*

Pages 444-457

THE APPLICATION OF SIMULATION MODEL OF A MILK RUN TO IDENTIFY THE OCCURRENCE OF FAILURES

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Abstract
At present, AGV systems are an important part of numerous companies and their internal logistics systems. They are used to efficiently secure different types of transport processes in order to minimize operating costs. However, their reliable operation requires adequate setting and maintenance. Computer simulation is probably the most suitable option from a wide range of engineering methods with which to meet these requirements. This paper describes the development of a simulation model in the Tecnomatix Plant Simulation program to identify critical points of failure within a specific delivery process on the basis of a Milk Run system. Based on the results obtained, an appropriate solution was determined with which to make the whole process function more efficiently and reliably. 27 refs.
(Received in February 2018, accepted in June 2018. This paper was with the authors 1 month for 4 revisions.)

Key Words: *AGV Simulation, Milk Run, Performance Efficiency, Delivery, Failures*

Pages 458-471

FULLY AUTOMATED POINT-BASED ROBOTIC NEUROSURGICAL PATIENT REGISTRATION PROCEDURE

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Abstract
In this study, we have introduced a framework for an automatic patient registration procedure using freely distributed fiducial markers within a robot application in neurosurgery. The localization procedures in the image space and in the physical space are fully automated. We have developed a novel algorithm for finding the point pair correspondence between freely distributed fiducial markers in the image and in the physical space. The algorithm introduces a similarity matrix to maximize the possibility of successful point pairing and to remove the potential outlier points. The correspondence algorithm has been tested in 900,000 computer simulations and also on the real data from five laboratory phantom CT scans and twelve clinical patient CT scans, which were paired with 1415 readings captured with an optical tracking system. Testing of simulated point scenarios showed that the correspondence algorithm has a higher percentage of success when a larger number of fiducial markers and a lower number of outlier points were present. In the 24055 tests on the clinical data, there has been a 100 % success rate. 26 refs.
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Key Words: *Biomedical Imaging, Medical Robotics, Iterative Algorithms, Iterative Closest Point Algorithm, RONNA*

Pages 472-484

PERFORMANCE OPTIMIZATION OF ENERGY RECOVERY DEVICE BASED ON PAT WITH GUIDE VANE

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Abstract
Among the technologies for middle-pressure and low-pressure energy recovery, the influence of guide vane is generally neglected in pump as turbine (PAT) based on centrifugal pumps. For high-pressure energy recovery technology, only few studies have been conducted on PAT with guide vane, and the dynamic and static flow laws between the inverse impeller and guide vanes remain unclear. In this study, by optimizing the key geometric parameters of the impeller with forward-curved blades, the influence of different parameters on its performance was investigated. Results show that when the number of blades is 10 at the same flow rate, the highest efficiency is achieved and the internal flow becomes stable. With the same number of blades, the total head increases gradually with the increase of flow rate, whereas the efficiency increases initially and then decreases. Under the same head, the PAT model with blade outlet angle achieves the highest efficiency, power and the best hydraulic performance. Conclusions obtained in this study have important value for implications to optimize the cavitation of multi-stage PAT. 25 refs.
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Key Words: *Pump as Turbine (PAT), Impeller with Forward-Curved Blades, Numerical Simulation, Parameter Optimization*

Pages 485-497

A SIMULATION STUDY FOR THE SUSTAINABILITY AND REDUCTION OF WASTE IN WAREHOUSE LOGISTICS

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Abstract
In this study, the authors have investigated warehouse processes to identify critical ones that are wasteful. The aim of this research study was to improve the efficiency of warehouse processes by reducing travel time and cost in replenishment and order picking. To achieve this objective, the authors have proposed a mathematical model and discrete event simulation study. For the simulation model, the Dijkstra algorithm has been selected to schedule forklifts driving and picking vehicles routes in internal transport. According to the extensive simulation analysis approximately 67 % of waste could be reduced in warehouses. Of course, this number depends significantly on a warehouse layout, operations and material handling equipment used in warehouses. 25 refs.
(Received in March 2018, accepted in June 2018. This paper was with the authors 2 weeks for 1 revision.)

Key Words: *Logistics, Warehousing, Discrete Event Simulation, Sustainability, Performance Analysis*

Pages 498-511

MODELLING AND SIMULATION OF POUCH LITHIUM-ION BATTERY THERMAL MANAGEMENT USING COLD PLATE

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Abstract
The thermal management system is an integral part of a battery pack because of the temperature sensitivity of lithium-ion batteries. Cold plate cooling is a relatively mature liquid cooling method for lithium-ion batteries, but cold plate has a low cooling efficiency and poor economy. To improve the efficiency and economy of cold plate cooling, the effects of inlet mass flow rate and mini-channel cross-sectional width on the maximum temperature, temperature difference, and pressure drop at 4 C discharge rate were analysed. The finite element model of the cold plate cooling system was established by adopting the finite element method. FLUENT was utilized to calculate the cold plate cooling system model, and the cell temperature and mini-channel pressure drop data were obtained. Results show that increasing the mass flow rate of the coolant can reduce the maximum temperature and temperature difference of the cells, but the economy of the cooling system worsens when the mass flow rate exceeds 0.003 kg/s. In addition, the temperature trend over time presents a typical inverted U-shape with the change in the mini-channel cross-sectional width. Energy consumption and cooling system volume should be reduced by selecting a suitable mass flow rate and mini-channel cross-sectional width. This study provides guidance for the design of the pouch lithium-ion battery cold plate cooling system. 20 refs.
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Key Words: *Modelling and Simulation, Lithium-Ion Battery, Thermal Management, Cold Plate, Mass Flow Rate*

Pages 512-520

SIMULATION OF FLOW LINE SCHEDULING OF PRODUCTION ENTERPRISES BASED ON IMPROVED ARTIFICIAL FISH SWARM ALGORITHM

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Abstract
This paper aims to develop a desirable solution for non-blocking flow line problem under lean production mode. For this purpose, the artificial fish swarm algorithm (IAFSA) was improved by the probability coding of polar coordinates for solving the flow line scheduling under lean production mode. The improvement can prevent the algorithm from falling into the local optimum trap. The convergence of the proposed algorithm was verified by the popular test function Ackley. Finally, the IAFSA and another two popular swarm intelligence algorithms were applied to solve the test function of flow line scheduling. The comparison reveals the advantages of the IAFSA over the classic AFSA and the classic particle swarm algorithm in convergence speed and solution accuracy. The research findings lay a solid basis for the scheduling of actual hybrid flow lines and the preparation of scheduling plans in flow line production enterprises. 30 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Flow Line Scheduling, Improved Artificial Fish Swarm Algorithm (IAFSA), Lean Production Mode*

Pages 521-533

MODELLING OF STRAIGHT BEVEL GEAR TRANSMISSION AND SIMULATION OF ITS MESHING PERFORMANCE

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Abstract
This paper aims to accurately simulate straight bevel gear transmission, and analyse its exact meshing performance. To this end, the equations for tooth surface, tooth root surface and tooth root transition surface of straight bevel gear were derived based on the gear planning principle. Then, the parametric finite-element modelling of straight bevel gear transmission was realized in ANSYS using surface interpolation technique, and the gear pair meshing was simulated by transient analysis. The tooth surface contact stress and the bending stress were obtained throughout the meshing process. Later, the proposed model was contrasted with three traditional models to verify its feasibility. The results show that the modelling accuracy directly bears on the gear strength, and both the contact stress and the bending stress of the gear varied with the meshing position. The proposed method eliminates the huge errors of the traditional equivalent gear design, and pioneers in the analysis of the meshing features of gear pair. Suffice it to say that this research lays the basis for the accurate design and optimization of straight bevel gear transmission. 17 refs.
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Key Words: *Straight Bevel Gear, Gear Planning, Tooth Surface Equation, Parametric Modelling, Transient Meshing Analysis*

Pages 534-542

MODIFIED BINARY PARTICLE SWARM OPTIMIZATION ALGORITHM IN LOT-SPLITTING SCHEDULING INVOLVING MULTIPLE TECHNIQUES

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Abstract
This paper aims to strike a balance between cost, time and quality of multi-technique, multi-process flexible job-shop scheduling problem (FJSP) and thus improve the overall performance of the FJSP model. For this purpose, a bi-objective planning model was established for multi-technique, multi-process FJSP according to the multi-objective planning method in operational theory. Then, the structure of solution was designed for the established model, and the binary particle swarm optimization (BPSO) algorithm was modified to simulate the proposed method. Through the simulation, the following conclusions were put forward: (1) The established bi-objective planning model for multi-technique, multi-process FJSP meet the general requirements of manufacturing enterprises, laying the basis for further modification and derivation; (2) The modified BPSO (MBPSO) algorithm can solve the said model in a stable, fast and accurate manner. The research findings shed theoretical new light on the solution and application of real-world multi-technique, multi-process FJSP and provide practical guidance for the flow shop enterprises to improve their scheduling plans. 17 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Multi-Technique, Multi-Process Flexible Job-Shop Scheduling Problem, Modified Binary Particle Swarm Optimization Algorithm, Largescale Batch Production*

Pages 543-552

OPTIMIZATION OF MULTI-TASK JOB-SHOP SCHEDULING BASED ON UNCERTAINTY THEORY ALGORITHM

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Abstract
This paper aims to solve the difficulties in job-shop scheduling, a key determinant of production cost and economic effectiveness of manufacturing enterprises. For this purpose, the existing job-shop scheduling problems were introduced, the internal and external uncertainties that may influence the scheduling plan in actual production were enumerated, and the corresponding scheduling and rescheduling strategies were reviewed one by one. Then, the flexible job-shop model was established under uncertainties, the mathematical models were created considering such three uncertainties as the discrete makespan, rush order cut-in and machine failure, and the proactive-reactive scheduling strategy was proposed against emergencies or uncertainties. Finally, the proactive-reactive scheduling strategy, developed based on the uncertainty theory, was proved effective and feasible through the simulation experiments on scheduling optimization under machine failure and rush order cut-in. The research findings shed new light on the production planning and scheduling strategy of manufacturing enterprises. 16 refs.
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Key Words: *Uncertainty Theory, Multi-Task Job-Shop Scheduling, Scheduling Optimization, Economic Effectiveness*

Pages 553-561

INTEGRATED PRODUCTION SCHEDULING AND DISTRIBUTION PLANNING WITH A TWO-STAGE SEMI-CONTINUOUS FLOW SHOP ENVIRONMENT

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Abstract
In the past decades, a significant amount of attention has been attracted by operational production-distribution scheduling models. These models suggest that compared with hierarchical planning processes, the optimal plan can be achieved by considering the production and distribution decisions at the same time. For example, managers can schedule the production the delivery tasks consecutively. In a typical two-stage semi-continuous flow shop production plant, raw materials are converted into continuous resources in the first stage, and then, in the second stage, they are fed to the discrete-production processes of end products. Machines are employed to guarantee the continuous running of certain types of processes in each stage. Furthermore, the processing sequence at the first stage determines the readiness time and costs of resources. The product family is the basic scheduling element, and products sharing common materials and manufacturing procedures are categorised in the same product family. Taking these dependencies derived in practical manufacturing processes into consideration, various industrial cases can be fit in this model, including the food and drink industries or the metallurgical industry. This paper finally presented numerical-based tests on specific cases from an industrial application. 14 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Operational Integrated Production-Distribution Scheduling, Two-Stage Production Process, Semi-Flexible Flow Shop, Sequence Dependent Setup Times and Costs*