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ADAPTING PETRI NETS TO DES: STOCHASTIC MODELLING OF MANUFACTURING SYSTEMS

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Abstract
Discrete-Event Simulation (DES) is commonly used for the simulation of manufacturing systems. In many practical cases, DES practitioners have to make simplifications or to use the software in an unconventional or convoluted fashion to meet their needs. Petri nets enable the development of transparent models which allow increased flexibility and control for designers. Furthermore, Petri nets take advantage of a solid mathematical ground and constitute a simple language. However, Petri nets lack the software capabilities to realise their full potential. This study investigates the suitability and relevance of Discrete-Event Simulation (DES) software for Petri net modelling in the context of manufacturing systems. A framework is developed for the modelling of different classes of Petri nets on DES. Analytical models of asynchronous flow lines are developed. Initial results show that the analytical models are without closed-form solution and the explosion of the state space is observed, justifying the use of computational methods and simulation for the analysis of manufacturing systems. This study shows that the gain in flexibility provided by Petri nets provides a new insight into the effects of stochasticity on setup and failure times in manufacturing systems. 37 refs.
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Key Words: *Petri Net, Discrete-Event Simulation, Stochastic Modelling, Manufacturing Plant Layout*

Pages 18-29

MODELLING AND SIMULATION OF A NOVEL MODULAR FIXTURE FOR A FLEXIBLE MANUFACTURING SYSTEM

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Abstract
Wrong or inadequate design and manufacture of modular fixtures can lead to deformations and displacements of workpiece and fixture-workpiece assembly, as well. Deformations and displacements can significantly impact final workpiece accuracy, rendering the fixture less efficient. With that in mind, this paper reviews development of a novel multi-purpose solution for a modular fixture design with higher efficiency, higher accessibility and flexibility. The results of simulations and modelling indicate that the proposed modular fixture design has advantages over the existing, conventional modular fixtures. The proposed framed structure of modular fixtures exhibits versatility in that it allows reliable locating and clamping of workpieces featuring complex geometry and shape. The novel design solution for modular fixtures opens new directions for future investigation, regarding selection and optimization of materials, shape and geometry of fixture elements which can be used to extend and upgrade modular fixtures. All this contributes to higher workpiece quality and accuracy, as well as the higher productivity and lower production costs. 31 refs.
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Key Words: *Modular Fixture, Fixture Layout, Fixture Modelling, Fixture Simulation*

Pages 30-41

USING 4-LAYER ARCHITECTURE TO SIMULATE PRODUCT AND INFORMATION FLOWS IN MANUFACTURING SYSTEMS

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Abstract
This work illustrates the application of novel simulation architecture with two case studies where the proposed architecture, the so-called 4-layer, allowed us to address the complexity of the analysed systems. The fundamental objective of this work is to show the structure of layers, how layers interact with one another and with the user, and what benefits this separation proposes. The first case study deals with moving car bodies from the paint plant to the assembly line through a sequencing system that involves distributed decision-making processes in an ASRS. The second case study focuses on analysing a layout of a section used to assemble the engine and transmission set, where the quality of the material flow is evaluated. The work highlights some of the advantages of modelling with 4-layer architecture, and explains the key processes that connect different elements. 25 refs.
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Key Words: *Discrete Event Simulation (DES), Material Handling System (MHS), Manufacturing System, Automobile Assembly Plant, Simulation Approach*

Pages 42-54

OPTIMIZATION OF INVENTORY ROUTING PROBLEM TO MINIMIZE CARBON DIOXIDE EMISSION

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Abstract
This study proposes a modification in the considered two-stage inventory routing problem (IRP) to minimize the total amount of carbon dioxide (CO_2) emission in the network by reducing the total distance travelled by all the vehicles to meet the demand. Multiple suppliers (S) and multiple production units (PU's) are representing the two-stages of the IRP network. Each PU demand is fulfilled directly (single stage transportation) from the suppliers using homogeneous vehicles. This approach gives a long travel distance for every vehicle during each trip. The CO_2 emission mainly depends on the distance travelled by the vehicle and vehicle characteristics. The proposed modification is the induction of Centralized collection and distribution centre (CCDC) between the suppliers and the PU's. It modifies the single stage transportation approach into a two-stage approach where CO_2 emission is reduced due to less travel distance which is claimed as novelty in this study. An evolutionary algorithm of an artificial immune system (AIS) is used for studying both the network models with numerical data and their results are compared. 26 refs.
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Key Words: *Inventory Routing, Homogeneous Vehicles, Carbon Dioxide Emission, Artificial Immune System*

Pages 55-68

MAPPING SPEM PROCESS SPECIFICATIONS TO ACTIVITY CYCLE DIAGRAMS

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Abstract
The development of discrete event simulation models to simulate engineering processes is a complex endeavour because it requires a great deal of effort, time and expertise in different areas, in addition to knowledge of techniques of modelling and implementation. We aim to provide a model-driven approach to automate the generation of simulation models from process models. The approach consists of algorithms that map elements of SPEM (*Software & Systems Process Engineering Metamodel*) to XACDML (*eXtensible Activity Cycle Diagrams Markup Language*). SPEM is a notation used to model engineering processes. XACDML is a textual specification of ACD. ACD is graphical notation to represent discrete event simulation models. We extended XACDML to cope with SPEM hierarchical elements enabling the mappings between the models. We developed a tool and use it in an example in order to demonstrate the feasibility of our approach. The results indicate that the approach is feasible and reduces the burden associated with building simulation models of engineering processes. 14 refs.
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Key Words: *Software & Systems Process Engineering Metamodel (SPEM), Activity Cycle Diagrams (ACD), Automatic Model Generation, Discrete Event Simulation*

Pages 69-80

ANALYSIS ON THE POSE AND DYNAMIC RESPONSE OF HYDRAULIC SUPPORT UNDER DUAL IMPACT LOADS

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Abstract
Hydraulic support is significant in the mining process because it serves as the primary supporting equipment in a coal mine. The roof beam and shield beam of hydraulic support are easily damaged because of the dynamic impact loads it has to bear. To improve its working performance, this study investigated the movement trend, pose, and mechanical response of hydraulic support when its roof beam and shield beam were subjected to impact loads. First, the roof beam, shield beam, and bars were made flexible using Hypermesh software. Then, a numerical simulation model of the hydraulic support was constructed using Adams software. The working resistance of the support was provided by two active external load signals applied vertically to the roof beam and located above the upper column. The impact load was applied along the normal direction of the top beam and the shield beam toward the symmetrical centre. The pose and stress state variations of the support were obtained under different impact conditions through measuring the variations of the rotation angles of the roof beam, deflection angles of the columns, length of the columns and balanced jack, and force of the hinge points. Results indicate that various trends of the hydraulic support under different impact effects are different, and in general, the support is more easily damaged when the impact load acts both on the roof beam and the shield beam compared with the single impact condition. This study is helpful for the stability control and structural design of the hydraulic support. 24 refs.
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Key Words: *Hydraulic Support, Dynamic Response, Impact Load, Pose Analysis*

Pages 81-91

CONTACT ANALYSIS OF CHAIN DRIVE IN SCRAPER CONVEYOR BASED ON DYNAMIC MESHING PROPERTIES

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Abstract
The chain drive system is the most important subsystem in a mining scraper conveyor. Compared with the general chain drive system, that in a scraper conveyor is highly coupled. The rings on a chain come in contact not only with the sprocket wheels but also with the central chutes and scrapers. In order to improve the reliability of the scraper conveyor, a contact analysis of the chain drive system based on its meshing properties was performed. Vogit model-based translational and rotating models of the chain drive system were first introduced. A finite element model of the chain drive system was then established. Contact simulations were conducted using the software LS-DYNA. Von Mises stress and contact pressure curves on various dangerous areas of the horizontal ring, vertical ring, and sprocket wheel were obtained. The von Mises stress and the contact pressure of the rings and the sprocket wheel were compared, and their differences were analysed. Results indicate that the maximum contact pressure for the horizontal and vertical rings is considerably larger than the maximum von Mises stress. The maximum contact pressure for the horizontal ring exceeds 2000 MPa, which is 90 % larger than the von Mises stress (1100 MPa). Meanwhile, the contact pressure for the sprocket wheel is considerably less than the von Mises stress. Therefore, the failure mode of the rings and the sprocket wheels differs. Contact analysis based on meshing properties is useful in describing the dynamic properties of the chain drive system in detail. This study provides guidance for overcoming chain break and jam problems in scraper conveyors. 22 refs.
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Key Words: *Scraper Conveyor, Contact Analysis, Dynamic Properties, Chain Drive*

Pages 92-104

TOPOLOGY OPTIMIZATION BASED DESIGN OF LIGHTWEIGHT AND LOW VIBRATION GEAR BODIES

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Abstract
This article presents a new approach aiming to reduce gear vibration and weight by modifying its body structure. The primary objective was to reduce vibration and noise emission of spur gears. For this purpose, a solid gear body was replaced by a lattice structure, which was expected to raise the torsional compliance of the body. The lattice structure was configured and optimized by a FE-based topology optimization software. For experimental purposes, the optimized gear was produced from Titanium alloy Ti-6Al-4V ELI using Selective Laser Melting technique. In the tests, the sound pressure of various running gear pairs was measured in order to estimate and compare the properties of a solid gear, of a lattice gear, and of a lattice gear, filled with polymer to increase the structural damping. It was experimentally confirmed that the cellular lattice structure of a gear body and addition of a polymer matrix may significantly reduce the vibration. 23 refs.
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Key Words: *Gear Body, Lightweight Lattice Structure, Topology Optimization, Stress Reduction, Vibration Reduction*

Pages 105-118

DESIGN OF LARGE-SCALE LOGISTICS SYSTEMS USING COMPUTER SIMULATION HIERARCHIC STRUCTURE

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Abstract
When designing simulation models of large-scale logistics systems in manufacturing, such as automotive industry or engineering and petrochemical production, creators of these models consider how to properly render the whole system in one simulation model as accurately as possible. One possible approach to designing such models is the application of a hierarchic structure. The structure groups and combines the essential elements of simulation models into larger units. The aim of the paper is to analyse and identify the potential of the computer simulation using a hierarchic structure for increasing the effectiveness of designing large-scale logistics systems in manufacturing. A case study from the automotive industry using EXTENDSIM software environment is used for that purpose. 31 refs.
(Received in August 2017, accepted in January 2018. This paper was with the authors 2 weeks for 1 revision.)

Key Words: *Discrete Event Simulation, Hierarchic Structure, Large-Scale Logistics System, Manufacturing*

Pages 119-132

RAPID EVALUATION OF MAINTENANCE PROCESS USING STATISTICAL PROCESS CONTROL AND SIMULATION

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Abstract
There are successful and less successful maintenance systems (MS). As a dynamic category, the success of the maintenance function must be taken into consideration both for the present day and the future. This is the reason why it is necessary to continuously evaluate, improve and redesign MS. Business process modelling is a good methodology for this purpose. A business process model basically encompasses a formal description of the concept of the system, evaluation methods and process improvement techniques. This paper presents a concept of MS evaluation by using statistical process control in connection with performance indicators and MS improvement by modelling and simulation system. The maintenance model is used for simulation and experimentation. The simulation helps to visualise, understand, analyse and improve processes. The proposed concept is extendable and could be applied in different MS. 33 refs.
(Received in August 2017, accepted in October 2017. This paper was with the author's 1 month for 2 revisions.)

Key Words: *Maintenance, Evaluation, Process Model, Simulation*

Pages 133-146

MODELLING AND OPTIMIZATION FOR A SELECTIVE ASSEMBLY PROCESS OF PARTS WITH NON-NORMAL DISTRIBUTION

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Abstract
Selective assembly method has progressed significantly for the past few years to become a valuable tool for improving quality in product assembly process where the required assembly precision is very high. In traditional selective assembly process, if the mating parts with non-normal distribution are grouped and assembled, many assembled products fail to meet the assembly precision requirement and thereby being identified as unacceptable to be scrapped. This paper proposes an approach by applying improved grouping selective assembly scheme to a ball-bearing assembly, to reduce the surplus parts and hence to improve acceptance rate of assembled products. A solving algorithm is presented based on genetic algorithm (GA), where the elitist strategy is integrated to improve the convergence of the algorithm, and the simulation is utilized to give better insight into the optimization process. Finally, some numerical experiments in different cases are conducted, which demonstrate that the proposed approach outperforms traditional selective assembly method in generating solutions with maximum assembly acceptance rate. 24 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Selective Assembly Process, Grouping Scheme, Modelling, Optimization*

Pages 147-158

OPTIMIZATION ALGORITHM SIMULATION FOR DUAL-RESOURCE CONSTRAINED JOB-SHOP SCHEDULING

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Abstract
This research aims to optimize the job-shop scheduling constrained by manpower and machine under complex manufacturing conditions. To this end, a branch population genetic algorithm was presented based on compressed time-window scheduling strategy, and optimized with elite evolution and fan-shaped roulette operator. Specifically, the compressed time-window scheduling strategy was proposed to meet the two optimization targets: the maximum makespan and the total processing cost. Then, the elite evolution and fan-shaped roulette operator were introduced to simplify the global and local search, enhance the capacity of branch population genetic algorithm, and suppress the early elimination of inferior solutions, thus preventing the algorithm from falling into the local optimal solution. Finally, the rationality and feasibility of the proposed algorithm were verified through a simulation test. The simulation results show that the proposed algorithm lowered the maximum makespan and total processing cost by 7.4 % and 4.7 %, respectively, from the level of the original branch population genetic algorithm. This means the compressed time-window scheduling strategy can significantly optimize the makespan and the cost, as well as the robustness and global search ability. 26 refs.
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Key Words: *Job-Shop Scheduling, Dual-Resource Constraints (DRCs), Compressed Time-Window Scheduling Strategy, Improved Branch Population Genetic Algorithm, Elite Evolution*

Pages 159-169

APPLICATION AND DYNAMIC SIMULATION OF IMPROVED GENETIC ALGORITHM IN PRODUCTION WORKSHOP SCHEDULING

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Abstract
From the point of view of combining theories with practice, in order to better realize the effective management of production workshop scheduling and thus improve the competitiveness of manufacturing enterprises in the market, this study focuses on the simulation of production workshop scheduling based on genetic algorithm. Firstly, the study analyses the concept and characteristics of production workshop scheduling, and then proposes the objective function and scheduling rules of production workshop scheduling; the study also introduces the genetic algorithm to combine the scheduling rules, which are regarded as the genetic gene to realize the optimization of the production scheduling through the simulation calculation; in addition, in order to satisfy the dynamic production environment of manufacturing enterprises, the study put forward a dynamic scheduling model; finally, the dynamic simulation of the production workshop scheduling system is realized through the mixed programming of Matlab and VC. The simulation results show that the dynamic model can reduce the scheduling times and improve the stability of dynamic scheduling, and has a positive guiding significance for the production workshop scheduling of manufacturing enterprises. 19 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Production Workshop Scheduling, Genetic Algorithm, Dynamic Model, Dynamic Simulation*

Pages 170-179

PARAMETER ANALYSIS AND OPTIMIZATION OF THE ROTATING ARC NG-GMAW WELDING PROCESS

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Abstract
Parameters of the narrow gap gas metal arc welding (NG-GMAW) method are complex and strongly coupled, which can easily cause welding defects, such as poor sidewall fusion, overlap, gas pore and slag inclusion. So parameter optimization of NG-GMAW is very difficult. The common experimental analysis method is complex, especially take a long time and cost. In this paper, the simulation analysis method is used to analyse NG-GMAW welding process. After the analysis of the NG-GMAW welding mechanism, the dynamic simulation model of the rotating arc NG-GMAW welding process is established firstly. Then, the influence of key process parameters on the welding quality is analysed in detail, which include the rotation angular velocity, rotation angular amplitude, wire feed speed, welding speed, sidewall stay time and so on. The simulation and analysis results illustrate the role and influence of the above parameters. In short, this paper provides a flexible and efficient method for the analysis and optimization of NG-GMAW welding process parameters to discover new phenomena, improve efficiency and save cost. 15 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *NG-GMAW, Rotating Arc, Simulation Model, Parameters Optimization*

Pages 180-189

OPTIMAL CONFIGURATION FOR WORKSHOP MANUFACTURING SYSTEM UNDER DUAL RESOURCE CONSTRAINTS

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Abstract
In view of the defects of simulation modelling and resource optimization algorithm for small-batch multi-variety job-shops, this paper presents a mathematical model and simulation model which considers the dual resources optimization of both manpower and equipment to minimize the investment in the overall job-shop under the condition of satisfying the requirement of average productivity and average production cycle. The mathematical model established simplifies the solving process of traditional optimization algorithm and replaces the optimal solution of the original problem with the obtained approximate solution. The job-shop dual resource optimization simulation system model is constructed to verify the mathematical model proposed. The simulation results verify the effectiveness of the results of the mathematical model. This paper also designs the multi-agent system and the dual resources optimization-based job-shop entity flow. The simulation results show that when the job-shop workers and processing equipment are within a certain range, the appropriate increase of the buffer zone in the equipment room can effectively enlarge the system's capacity. With the further rise of the buffer zone number, the system's capacity will no longer increase. Under the ideal scheduling strategy, the utilization ratio of equipment and labour efficiency can reach the maximum value. 32 refs.
(Received, processed and accepted by the Chinese Representative Office.)

Key Words: *Job-Shop, Production Cycle, Capacity Restriction, Dual Resource, Optimization, Simulation*