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LAYOUT EVALUATION WITH THE INDUSTRY 4.0 APPROACH FOR A MANUFACTURING LABORATORY

Rodriguez, L.; Loyo, J. & Silva, U.
Department of Systems, Division of Basic Sciences and Engineering, Autonomous Metropolitan University Azcapotzalco, Av. San Pablo 180, Col. Reynosa Tamaulipas, Mexico City (CDMX), Mexico
E-Mail: lwra@azc.uam.mx

Abstract
In this study, the Systematic Layout Planning methodology was adapted with an Industry 4.0 approach (SLP-Ind. 4.0) to optimize the design of a Production Design Area in a Manufacturing Laboratory. To validate the proposed SLP-Ind. 4.0, a "representative" product assembly process involving a ladder-shaped structure made of five Lego® bricks was evaluated. Four layout alternatives were evaluated, one considering the process manually and another three incorporating automated equipment such as a cobot (Collaborative Robot), a vision system, and at least one conveyor belt. Experiments and simulations of the process were obtained indicators through simulation such as cycle time, the line efficiency and production capacity. The results demonstrate that the optimal alternative improves the efficiency of the manufactured parts by 16.84 % compared to the manual process. In addition, the selected option has desirable characteristics such as modularity, flexibility, and adequate human-machine interaction. Therefore, with the use of SLP-Ind. 4.0 it is easier to obtain adaptable layouts to the variations of the production processes, ensuring a versatile manufacturing environment. 29 refs.
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Key Words: *SLP, Layout Planning, Design, Industry 4.0, Cycle Time, Simulation*

Pages 562-573

A NEW MODEL OF HUMAN RESOURCE MANAGEMENT FOR WORK IN AN INTENSIVE ENVIRONMENT

Nestorov, A.; Djordjevic, A.; Stefanovic, M.; Sladojevic, S. & Lalic, B.
Nidec Electric Motor Serbia LLC, Ratno ostrvo 8A, 21000 Novi Sad, Serbia
E-Mail: sladojevic@uns.ac.rs

Abstract
Managing operators is an important issue, especially in work-intensive environments and companies with hundreds or thousands of employees. The challenge of optimizing skilled labour selection on the production line, using measurable indicators and supported by highly sophisticated models and software solutions, is a significant global research topic. In this manuscript, authors present a novel model for managing human operators based on a matrix of selected indicators. This model aims to enhance the planning, selection, and deployment of human resources. By optimizing the allocation of human resources to different workstations while utilizing available resources, the model facilitates monitoring and supervision of employee qualifications. To implement this model, a software solution designed for advanced labour optimization has been introduced. This software utilizes simulation and testing of various scenarios, which is increasingly crucial in intensive working environments. 25 refs.
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Key Words: *Human Resource Management, Intensive Environment, Simulation Model, Business Indicator*

Pages 574-585

THE NASA-TLX APPROACH TO UNDERSTAND WORKERS WORKLOAD IN HUMAN-ROBOT COLLABORATION

Javernik, A.; Buchmeister, B. & Ojstersek, R.
University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia
E-Mail: aljaz.javernik@um.si

Abstract
Human-robot collaboration (HRC) is becoming increasingly widespread in today's production systems, as it can contribute to achieving more efficient and flexible production systems. Given the growing importance of HRC, this paper addresses the significance of human workload in HRC. To study workers workload an experiment was conducted using NASA-TLX questionnaire. The experiment featured two scenarios involving the same operation but varying robot motion parameters. Recognizing that individual differences contribute to success of collaboration, the experiment considered worker utilization in relation to robot motion parameters. To ensure the credibility of the experimental results, the robot motion parameters were adjusted to each individual in order to achieve the same conditions and utilization at all participants. Results revealed that worker utilization, in conjunction with robot motion parameters significantly influenced worker workload. The results highlight the need for personalized guidelines in collaborative workplaces that emphasize individual differences in abilities, skills and personalities to increase overall well-being and robot and worker productivity. 23 refs.
(Received in May 2023, accepted in September 2023. This paper was with the authors 2 months for 2 revisions.)

Key Words: *Human-Robot Collaboration, Industry 5.0, NASA-TLX, Safety Awareness, Worker Well-Being, Worker Workload*

Pages 586-597

DESIGN OF MICROGRIDS AS A COST ECONOMY ENERGY SAVINGS SIMULATION MODEL: MONTE CARLO METHOD

Straka, M.
Institute of Logistics and Transport, BERG Faculty, Technical University of Kosice, Park Komenskeho 14, 042 00 Kosice, Slovak Republic
E-Mail: martin.straka@tuke.sk

Abstract
The article examines the creation of a Cost Economy Energy Savings Simulation Model (CEESS Model) as an economic scenario generator for energy-independent structures using the Monte Carlo method. The CEESS model is a continuous simulation model created on the ExtendSim simulation system platform. The problem is related to the constantly changing environmental parameters for the purpose of energy security for buildings as modern, energy-independent and self-sufficient systems. In terms of the implementation of the defined part of the research, a logistical approach was applied: system analysis, coordination, algorithm work, planning, efficiency. We define logistics as a system, principle, philosophy of management of flows. The numerous simulation experiments carried out show that the return on investment of the option with an initial investment of 5000 euros is in the range of 2422 to 4978 days, the return on investment of the option with an initial investment of 10000 euros is in the range of 4233 to 7902 days and the return on investment of the option with an initial investment of 15000 euros is in the range of 5691 to 10073 days. 32 refs.
(Received in May 2023, accepted in August 2023. This paper was with the author 1 month for 2 revisions.)

Key Words: *Energy Savings Simulation Model, Monte Carlo Method, Local Energy Systems, Microgrids, Simulation, ExtendSim*

Pages 598-609

HOW DISCRETIZATION AFFECTS INTERMITTENT DEMAND STOCK MANAGEMENT BASED ON SIMULATION

Huskova, K.; Andar, J. & Dyntar, J.
Technical University of Liberec, Faculty of Economics, Voronezska 13, 460 01 Liberec 1, Czech Republic
E-Mail: katerina.huskova@tul.cz

Abstract
This paper is aimed at the development of an alternative combinatorial strategy of reducing searched solution space in intermittent demand stock management based on the past stock movement simulation. The combinatorial strategy involves an adjustable level of the discretization of control variables that are used within a selected inventory control policy. We combine this new strategy with the local search employing linear regression and bootstrapping to bound the reorder point and simulate (*Q*, *R*) inventory control policy using randomly generated data. The data is characteristic with an increasing intermittency and a non-zero demand variability. The outputs from simulation experiments show that combining two different strategies of reducing searched solution space brings a significant improvement in the trade-off among the minimal holding and ordering costs, required service level and the consumption of the computational time making the past stock movement simulation to be more applicable in extensive real life tasks. 35 refs.
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Key Words: *Logistics, Intermittent Demand, Stock Management, Simulation, Optimization*

Pages 610-618

STUDY OF ENVIRONMENTAL IMPACTS ON OVERHEAD TRANSMISSION LINES USING GENETIC ALGORITHMS

Sket, K.; Ficko, M.; Gubeljak, N. & Brezocnik, M.
University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, SI-2000 Maribor, Slovenia
E-Mail: miran.brezocnik@um.si

Abstract
In our study, we explored the complexities of overhead transmission line (OTL) engineering, specifically focusing on their responses to varying atmospheric conditions (ambient temperature, ambient humidity, solar irradiance, ambient pressure, wind speed, wind direction), and electric current usage. Our goal was to comprehend how these independent variables impact critical responses (dependent variables) such as conductor temperature, conductor sag, tower leg stress, and vibrations – parameters crucial for electric distribution. We modelled the target output variable as a polynomial of a certain degree of the input variables. The precise forms of the polynomial were determined using the genetic algorithms (GA). Developed models are essential for quantifying the influence of each input parameter, enriching our understanding of essential system elements. They provide long-term predictions for assessing transmission line lifespan and structural stability, with particularly high precision in forecasting temperature and sag angle. It is important to note that certain engineering parameters, such as material properties and load considerations, were not included in our research, potentially influencing accuracy. 29 refs.
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Key Words: *Overhead Transmission Lines (OTL), Machine Learning, Modelling, Optimization, Genetic Algorithms (GA)*

Pages 619-630

DESIGN AND MOTION SIMULATION OF CONVEYOR PRODUCTION LINE FOR SALTED KELP TURNOVER BOX

Zhang, W.; Zhang, C. T. & Deng, C. H.
Rongcheng College, Harbin University of Science and Technology, Weihai, 264300, China
E-Mail: zhangwei8171@hrbust.edu.cn

Abstract
To improve the automation degree of kelp turnover box conveying, a conveyor production line of salted kelp turnover boxes was developed, and a motion simulation model of the production line was designed. The conveyor production line was composed of a colour recognition system, an online weighing system, and a sorting and conveying system. After parametric design and model assembly, a motion simulation model of the conveyor production line was established. Based on the ADAMS solver built in UG software, the sorting action simulation, motion characteristic analysis, and working process simulation of differently coloured turnover boxes were performed using the STEP motion function, and the accuracy of the system structure and model was verified by simulation. Results showed the STEP motion function can control the time period driven by the model and obtain the motion change law of the turnover box in different time periods. The motion displacement and speed of the cylinder push rod changed smoothly with time, which is consistent with the actual situation real-world problems and advance the knowledge and practice of simulation. 24 refs.
(Received in June 2023, accepted in October 2023. This paper was with the authors 1 month for 2 revisions.)

Key Words: *Turnover box, Motion simulation, Motion function, ADAMS*

Pages 631-642

MONITORING SURFACE STATE OF AA7075-T6 DURING DYNAMIC LOADING WITH FBG SENSOR

Milkovic, M.; Njegovec, M.; Predan, J.; Javornik, J.; Djonlagic, D. & Gubeljak, N.
Faculty of Mechanical Engineering, University of Maribor, Smetanova 17, 2000 Maribor, Slovenia
E-Mail: nenad.gubeljak@um.si

Abstract
The AA7075-T6 material is widely used in aerospace applications due to its favourable strength-to-weight ratio and cost-effectiveness. The material undergoes a process of cold rolling and subsequent stretching to form metal sheets. This process generates residual compressive stresses on the surface of the material. Surface changes in the material are observed at low stress levels, resulting in variations in residual stresses and surface roughness. This article presents an approach to monitor the surface state changes of AA7075-T6 material during dynamic loading using Fiber Bragg Grating (FBG) sensor. Numerical Finite Element Method (FEM) simulations analyse the transfer of deformations from the damaged surface through the adhesive layer to FBG with different cladding thicknesses. Loading induces microcrack-related intensity changes in the FBG optical spectrum and deformation response. The magnitude of the response is greater, when the cladding thickness of the optical fibre is thinner. Experimental results show that the FBG optical spectrum response varies with cumulative number of dynamic cycles. 29 refs.
(Received in June 2023, accepted in July 2023. This paper was with the authors 1 month for 3 revisions.)

Key Words: *AA7075-T6, Dynamic Loading, Fiber Bragg Grating (FBG) Sensor, Surface Condition*

Pages 643-654

SIMULATION METHOD FOR STITCH WIRE VIBRATION LOAD AND FATIGUE LIFE

Liu, J. D.; Chen, J. Q.; Wu, J. Q.; Han, F. & Guan, J. F.
School of Electrical Engineering, Southwest Jiaotong University, Chengdu 611756, China
E-Mail: kwanjinfa@163.com

Abstract
Stitch wire is the key component in high-speed railway catenary. During the construction and operation of the catenary, tension changes can lead to fracture of the stitch wire. This study proposed a simulation method considering the structure and stress distribution of stitch wire to reveal the effect of tension changes on the fatigue life. Dynamic simulation model at a speed of 300 km/h was constructed to obtain the vibration load. A refined model of stitch wire was used to simulate the contact between the structures. Finally, the fatigue life of stitch wire was calculated when the tension changes by analysing the stress distribution under vibration. Results demonstrate that the lifting effect of the pantograph during operation causes vertical vibrations of stitch wire, and the stress concentration position is located at the connection with its clamp. As the tension increases form 2.0 kN to 5.0 kN, the range of vibration angle at the clamp decreases from 2.73° to 1.33°, and fatigue life increases from 1.36×10^6 to 8.76×10^6. The proposed method provides an accurate approach to simulate the load and fatigue life of stitch wire under real working conditions. 22 refs.
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Key Words: *High-Speed Railway, Stitch Wire, Vibration, Fatigue Life, Simulation Model*

Pages 655-666

MODELLING AND SIMULATION OF A DECISION-MAKING PROCESS SUPPORTING BUSINESS SYSTEM LOGISTICS

Suchanek, P.; Bucki, R. & Postrozny, J.
Silesian University in Opava, School of Business Administration in Karvina, Univerzitni namesti 1934/3, 733 40 Karvina, Czech Republic
E-Mail: suchanek@opf.slu.cz

Abstract
The article highlights the issue of accelerating the decision-making process in an exemplary business system that is designed to fulfil orders for customers. The information flow model with its mathematical representation is introduced. A pseudocode indicating the course of action in which simulations of the computational process is performed is shown. The simulation study illustrates the simulation procedure in order to extract data minimising the costs of making decisions in the discussed system. It is assumed that the most important goal when searching for a solution for the given input data is the need to find the satisfactory solution which allows to complete the business process. The thorough analysis of the obtained results made it possible to draw consistent conclusions for the business process taking into account the use of randomised input data. A lot of attention was paid to the problem of escalating the decision-making process. 28 refs.
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Key Words: *Decision-Making, Business System, Mathematical Modelling, Simulation*

Pages 667-678

SIMULATION OF CROWD EVACUATION BEHAVIOURS AT SUBWAY STATIONS UNDER PANIC EMOTION

Chen, Y. X.; Song, Y. H. & Huo, F. Z.
School of Safety Science and Emergency Management, Wuhan University of Technology, Wuhan, 430000, China
E-Mail: charlychen@whut.edu.cn

Abstract
To explore companion movement laws of different age groups and transfer rules of panic emotion during evacuation at subway stations, evacuation groups of different ages were distinguished in this study through differences in movement rate. Moreover, a double-exit subway cellular automaton evacuation model considering companion behaviours was constructed. A case study of evacuation of dense crowds at the Hukou Subway in Wuhan City of China was simulated, and effects of personnel structure, companion behaviours, and panic emotion on evacuation efficiency were analysed. Results show that, (1) the overall crowd evacuation time present a linear growth trend with the increase of pedestrian density. (2) The evacuation time initially decreases and then increases with the increase of companion ratio. The shortest evacuation time is achieved when the companion cells account for 10 %. (3) People are more reasonable and the general evacuation efficiency is higher if they can control emotions better during evacuation. The obtained conclusions provide great references to analyse companion behaviours of different age groups during evacuation. 26 refs.
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Key Words: *Evacuation, Companion Behaviour, Movement Rate, Panic Emotion, Cellular Automaton*

Pages 679-689

SIMULATION MODEL OF VEHICLE EMISSION REDUCTION EXHAUST SYSTEM

Tarbajovsky, P.; Puskar, M. & Sabadka, D.
Technical University in Kosice, Letná 9, 040 01 Kosice, Slovak Republic
E-Mail: michal.puskar@tuke.sk

Abstract
Constantly tightening vehicle emission standards leads to the creation of new technologies for reducing the content of toxic substances in exhaust gases while maintaining the highest possible engine performance. At the moment, however, it is clear that with regard to future emission standards, despite the technologically highly refined system of catalytic converters, the reduction of emissions with the help of catalytic converters alone will be insufficient. That is why a variable exhaust manifold/system was developed and patented, which has a significant impact on the reduction of vehicle emissions. This innovation enables three working modes of the engine, depending on the demand and output power requirements. The presented article presents the complex architecture of the proposed system, including the description and simulation of individual operating modes. The first working mode is the most ecological and economical mode, but it has a relatively lower performance. The second working mode is characterized by the production of higher power, and the third mode can be used at high engine loads. 17 refs.
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Key Words: *Simulation Model, Variable Exhaust System, Emission Reduction, Vehicle*

Pages 690-700

GREEN SUPPLY CHAIN OPTIMIZATION WITH FUZZY MCDM FOR ECONOMIC GROWTH

Li, Q.
Shijiazhuang College of Applied Technology, Shijiazhuang 050081, China
E-Mail: 2016010775@sjzpt.edu.cn

Abstract
An in-depth investigation into Green Supply Chain Management (GSCM) practices is presented, delineating their economic impact. The research applies fuzzy logic within a Multi-Criteria Decision-Making (MCDM) framework to systematize the evaluation and advancement of green practices in supply chains. The integration of fuzzy logic with MCDM is posited to refine the precision of evaluations. The approach centres on the assessment of green suppliers using a linear programming-based fuzzy Multi-Attributive Border Approximation area Comparison (MABAC) method. The study advances the discourse on GSCM by quantifying the economic merits, namely cost efficiency, market productivity enhancement, and brand image improvement. Evidence from practical applications substantiates the dual benefits of GSCM in bolstering environmental sustainability and generating significant economic gains. 32 refs.
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Key Words: *GSCM, Economic Benefits, MCDM, MABAC, Fuzzy Logic, Linear Programming*

Pages 701-711

HIGH-SPEED BEARING DYNAMICS AND APPLICATIONS IN PRODUCTION LINES

Zhang, L. J.; Yang, S. J.; Wang, S. J.; Zeng, Y. M.; Hua, W. C. & Li, G. L.
School of Mechanical and Electronic Engineering, Northwest A & F University; Yangling 712100, China
E-Mail: yangshanju@nwafu.edu.cn

Abstract
This study presents a novel approach to simulating and monitoring the dynamic performance of high-speed bearings, a critical component in automated industrial production for system efficiency and safety. The newly developed theoretical framework allows for detailed analysis of dynamic responses in these bearings, especially under high-speed conditions. The Short-Time Fourier Transform (STFT) is used to capture time-frequency domain characteristics, while real-time condition monitoring is achieved through a deep learning-based Convolutional Neural Network, enhanced by a multi-head attention mechanism. This method enables managing large datasets, real-time surveillance, and accurate prediction of bearing conditions. Ultimately, this approach provides an innovative perspective for fault diagnosis and performance assessment of high-speed bearings in complex production environments. 21 refs.
(Received in June 2023, accepted in September 2023. This paper was with the authors 6 weeks for 2 revisions.)

Key Words: *High-Speed Bearings, Dynamic Performance Simulation, Equilibrium Equations, Time-Frequency Domain Feature Extraction, Deep Learning, Real-Time Condition Monitoring*

Pages 712-722

BALANCING MATERIAL SUPPLY-DEMAND WITH ARIMA AND NEURAL NETWORKS

Han, L. N.; Ma, X. Z.; Tan, J. D.; Li, J. H. & Dong, Y. Q.
School of Public Finance & Taxation, Guangdong University of Finance and Economics, Guangzhou 510320, China
E-Mail: 202221031038@mail.bnu.edu.cn

Abstract
This study introduces a hybrid Autoregressive Integrated Moving Average Model-Back Propagation (ARIMA-BP) neural network model to improve the accuracy of production material demand forecasting amid growing market competition and diverse customer requirements. By integrating both linear and nonlinear elements, the model enhances efficiency in production planning, inventory optimization, and operational cost reduction. It explores novel methods to align supply and demand, optimizing the interplay of material procurement, product output, and inventory management. The study's key contribution is a forecasting approach that informs balanced production strategies, with significant implications for operational effectiveness and competitive advantage in manufacturing. 16 refs.
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Key Words: *Production Material Demand Forecasting, Supply Balance Strategies, ARIMA-BP*

Pages 723-733

OPTIMIZING SUPPLY CHAIN EFFICIENCY WITH FUZZY CRITIC-EDAS

Zhang, Y. M.; Song, Y. F.; Meng, X. & Liu, Z. G.
Department of Media Arts, Shijiazhuang Information Engineering Vocational College, Shijiazhuang 052161, China
E-Mail: songyufei0311@163.com

Abstract
In today's dynamic and complex global business landscape, effective supply chain network (SCN) management is critical for achieving competitive advantage and sustainability. This study presents an innovative methodology that leverages the fuzzy CRITIC (CRiteria Importance Through Intercriteria Correlation) and EDAS (Evaluation based on Distance from Average Solution) techniques to enhance the efficiency of SCNs. By integrating both quantitative and qualitative factors, the approach effectively navigates uncertainties and imprecise data in supply chain operations. The fuzzy CRITIC-EDAS method's application in a case study showcases its utility in optimizing SCN configurations for improved efficiency, cost savings, and risk reduction. The results offer a valuable decision support tool for supply chain management, promising to boost competitiveness and sustainability in an unpredictable market. 15 refs.
(Received in July 2023, accepted in October 2023. This paper was with the authors 2 months for 2 revisions.)

Key Words: *Production Supply Chain Networks, Fuzzy CRITIC-EDAS Method, Efficiency Optimization, Decision Support Tool, Risk Mitigation*

Pages 734-745

ADAPTIVE FAULT PREDICTION AND MAINTENANCE IN PRODUCTION LINES USING DEEP LEARNING

Pang, J. L.
College of Electronic Information, Huanghuai University, Zhumadian 463000, China
E-Mail: pangjianli@huanghuai.edu.cn

Abstract
In the era of Industry 4.0 and intelligent manufacturing, accurately predicting and maintaining production line faults is crucial in manufacturing. This study introduces a novel deep learning-based adaptive fault prediction and maintenance strategy, overcoming limitations of traditional statistical and machine learning methods in prediction accuracy and adaptability in complex environments. A new prediction model is developed, incorporating a wide convolutional feature extraction module, a customized gating module, and a multi-layered progressive extraction module. The model's process and parameters, including fault stage division using Wasserstein distance and optimization with L2 regularization and neuron dropout, are detailed. An adaptive maintenance strategy for predictive fault detection is established, enhancing precision in fault prediction and developing more effective maintenance approaches, ultimately boosting production efficiency and reducing operational costs. 21 refs.
(Received in August 2023, accepted in October 2023. This paper was with the author 5 weeks for 1 revision.)

Key Words: *Deep Learning, Adaptive Production Lines, Fault Prediction, Maintenance Strategies, Wasserstein Distance, L2 Regularization, Neuron Dropout*