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Progress in Material Handling Research: 2014

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CICMHE
COLLEGE-INDUSTRY COUNCIL
ON MATERIAL HANDLING EDUCATION

MHI

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Institutional Co-Sponsor

MHI (www.MHI.org) sponsors and supports all of CICMHE's activities. The backing and assistance for the Colloquium by MHI was critical for both its planning and execution phases.

Local Industrial Host

Great thanks go to our wonderful industrial host, Intelligrated, Inc., at its headquarters in the Cincinnati, Ohio suburb of Mason. Intelligrated not only provided the meeting facilities for most of the events, but also additional funding for the event. Many thanks to Jerry Koch, Director of Corporate Marketing and Product Management, plus many others at Intelligrated for all the planning, coordination, and execution that made the event possible.

Preface

The College Industry Council on Material Handling Education (CICMHE) prepares and provides information, material, and activities in support of material handling education and research. Founded in 1952, the Council is composed of college and university educators, material handling equipment manufacturers, distributors, users, and consultants, representatives of the business press, and professional staff members of organizations concerned with material handling education.

CICMHE's mission is to increase awareness, understanding, exploration, and development of material handling and logistics through fostering and nurturing high value projects and events. CICMHE's goals are to:

- Focus on high-impact events and projects aiming for high-value teaching and learning and high-value research and innovation

- Transform and modernize educational offerings to enable high-impact teaching and learning in material handling and related domains

- Identify, foster, facilitate, nurture, and incubate research in material handling and related domains to advance (elevate) the state of art and practice

- Leverage connections between CICMHE members and industry organizations in order to provide value for both MHI membership and CICMHE community

CICMHE receives its financial support from MHI.

CICMHE cooperates on projects with the Material Handling Education Foundation, Inc. Its support manifests itself in financial aid for student scholarships, instructional aids, and travel grant programs for faculty and students at institutions providing education in the material handling field.

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Information about previous colloquia may be found at:

www.mhi.org/CICMHE/colloquium

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I. Comparing Industry And Academic Perspectives On Cross-Docking Operations
Paul Buijs and Iris F.A. Vis

This paper performs a comparative analysis on the industry and academic perspectives on cross-docking operations. Detailed descriptions are provided for three typical cross-dock settings by means of case illustrations. The purpose of these descriptions is to inspire break-through innovations in future cross-docking research by identifying constraints, decision problems, and performance indicators that are thoroughly anchored in current practice.

II. Real-Time Dock Door Monitoring System Using A Kinect Sensor
Héctor J. Carlo, Yeiram Martínez and Cristina Pomales-García

This study presents a proof of concept where a single Microsoft Kinect sensor is used for automated monitoring of a dock door in real-time. The proposed system will automatically and in real-time: (1) detect when an object breaches the dock door perimeter, and its corresponding speed and direction, (2) count the number of pallets loaded/unloaded to/from a trailer, (3) record the loading/unloading time of each load, and (4) reconstruct an image of every loading/unloading trip at a dock door, irrespectively of the material handling travel speed and direction. Particular emphasis is given to discussing how to extend the proposed concept by using multiple Kinect sensors, the technological challenges for implementation, and the expected benefits of a real-time dock door monitoring system.

III. Experimentally Investigating The Performance Of Various Order Picking Methods In Different Behavioral Contexts
Jelle De Vries, René De Koster and Daan Stam

Three manual picker-to-parts order picking methods (parallel picking, zone picking, and dynamic zone picking) are employed in an experimental warehouse setup and compared in terms of productivity, quality, and job satisfaction. Participants worked in teams and were subject to either an individual-based, or a team-based incentive scheme. Furthermore, the influence of individual participants' dominant regulatory focus (promotion or prevention) was taken into account. The outcomes show that in parallel picking an incentive system focused on individual performance is beneficial for productivity and quality compared to an incentive system focused on team performance, whereas team-based incentives are more productive in zone picking. These results were more explicitly present for participants with a dominant promotion focus. Participants with a dominant prevention focus picked more productively with team-based incentives in all picking methods. In addition to this, team-based incentives led to a relatively high quality in zone-picking, but a relatively low quality in dynamic zone picking. Our study shows that assigning the right people to the right picking task with a fitting incentive system can substantially cut wage costs without simultaneously harming productivity, quality, or job satisfaction.

IV. An Empirical Study About The Effectiveness Of Lean Empowerment In Warehouses
Kai Furmans and Payam Dehdari

Lean Management is well established in production environments. Some empirical evidences are available which suggest that in production systems lean management achieves positive results. For warehousing, some works have already been done, which deal with the application and adaption of lean tools for usage in warehousing. In order to answer the question, whether the application of lean tools leads to a better performance however, no study is available today. Therefore, an empirical study has been conducted, where the effectiveness of lean empowerment has been tested and compared to the performance of warehouse, who continued to work as before.

V. A Framework For The Robust Design Of Unit Load Storage Systems
Marc Goetschalckx, Pratik Mital and Edward Huang

The unit load storage assignment problem determines the assignment of a set of unit loads with known arrival and departure times to a set of unit storage locations in a warehouse. The material handling device(s) can carry at most one unit load at the time. In this research it is assumed that each of the storage locations can be accessed directly without load relocations or rearrangements and that the travel times between the storage locations and from and to the warehousing docks can be computed in advance. The objective is to minimize the total travel time of the material handling device for performing a number of storage and retrieval operations. This type of storage system is in widespread use and implemented in both mechanized and automated systems. It is by far one of the most common storage system architectures for unit loads.

The formulation of this problem belongs to the class of Assignment Problems (AP) but finding the optimal solution for the most general variant is provably hard for large problem instances. A classification of the different variants of the APs for unit loads will be presented. The size of the instance problem is proportional to the product of the number of loads and the number of locations and the number of periods in the planning horizon and is typically very large for real world problem instances. Efficient solutions algorithms only exist for product-based storage policies or for the very special case of a perfectly balanced warehouse for load-based storage policies. However, for load-based storage policies the integrality property is not satisfied in general. This results in very large binary programming problems that to date cannot be solved to optimality. However, the formulations have special structure that can be exploited to design efficient solution algorithms. Properties and the special structure of the formulation will be presented. A specialized compound solution algorithm combines primal and dual approaches and heuristics to reduce the optimality gap. Initial computational experience will be shared. It is anticipated that the solution algorithm can either be directly implemented in commercial warehouse management systems or that it becomes a tool to evaluate the performance of commercially implemented storage policies.

The above formulation is the sub problem in a decomposition algorithm for the design of unit load storage systems that identifies the tradeoffs between efficiency and risk of the performance of the storage system. Different risk measures such as the standard deviation and the downside risk can be used. An example based on realistic data values shows that in this case operator-controlled systems are less expensive and more risky than automated systems. However, if the same level of risk is mandated then the automated system is less expensive.

VI. Clickstream Big Data and "Delivery Before Order Making" Mode For Online Retailers
Yemig (Yale) Gong, Houxuan Xu and Jinlong Zhang

Our research is inspired by a leading online retailer using clickstream big data to estimate customer demand and then ship items to customers or hubs near customers by a mode of "delivery before order making" (DBOM) mode. Using clickstream data to obtain advance demand information in order quantities, we integrate the forecasting with a single item uncapacitated dynamic lot sizing problem in a rolling-horizon environment. Using the simulated clickstream data, we evaluate the performance of DBOM mode.

VII. Setting Cutoff Times for Picking Systems With Capacity Degradation

Kevin R. Gue

In the new landscape of e-commerce distribution, firms must offer increasingly aggressive delivery promises and then make good on them. These promises often take the form of a cutoff time, such that orders placed before the cutoff time receive premium service (next-day, same-day, etc.) and those placed afterward do not. Later cutoff times are stronger, of course, but the fulfillment system might not be able to process the order before the deadline. How late is too late? We develop a deterministic model to answer this and related questions when the order fulfillment system batches orders for efficient picking operations and therefore exhibits a phenomenon we call capacity degradation.

VIII. An Analysis Of Single-Command Operations In A Mobile Rack (AS/RS) Served By A Single Order Picker

Amine Hakim Guezzen and Zaki Sari

A Mobile rack Automated Storage and Retrieval Systems (MAS/RS) are picker-to-stock retrieval model which are a variation of the multi aisles AS/RS. This mobile storage system is composed of racks moving laterally on rails so that one can open an aisle between any two adjacent racks, the input/output system, the storage and retrieval (S/R) machine and the computer management system or the control system.

Evaluating an AS/RS could be done using several performance indicators, the two most important ones are: The utilization rate of the S/R machine and the average time necessary to serve storage or retrieval requests (the travel time).

The S/R machine could operate either in single command or in dual command. In a single command, the S/R machine executes either a storage or retrieval operation by cycle. The time necessary to execute a single command is said single cycle time. While in a dual command, the S/R machine executes a storage operation followed by a retrieval operation in the same cycle. The time needed to execute a dual command is said dual cycle time.

In this paper our interest is concerned with the mathematical modeling of single-command operations in a Mobile rack (AS/RS) system. We developed a closed form analytical expression allowing an approximate calculation of the travel time of Mobile Racks-AS/RS.

This expression was compared with an exact discrete expression developed earlier by one of the authors. The models developed in this work are used by Kouloughli et al to determine optimal dimensions of the mobile rack AS/RS that minimize expected travel times.

IX. Order Batching With Time Constraints In A Parallel-Aisle Warehouse: A Multiple-Policy Approach

Soondo Hong, Andrew L. Johnson and Brett A. Peters

A commitment of delivery time is critical in some online businesses (De Koster, 2003). An important challenge to meeting customers' needs is timely order picking which is also relevant to worker safety, item freshness, overall operational synchronization, and reduced overtime. We analyze an order batch picking situation where a trip is constrained by vehicle capacity and must be completed within a specified time. We develop a model which partitions orders to batches to minimize the total travel time such that each trip meets the orders' time constraints and capacity limit, and also determines a suitable operational policy for each batch. Each policy is characterized by routing method, travel speed, capacity, and pick time. The proposed batching model can simultaneously group orders and can select a best policy among possible policy choices for each batch. To solve the proposed batching procedure, an exact algorithm is implemented based on a branch-and-price method. Our multiple-policy approach experiences 2.1~7.0% reductions in retrieval time compared to a best single-policy approach. The experimental results emphasize that when time constraints are enforced in order batching, a multiple-policy is preferable to a single-policy approach, because allows additional flexibility.

X. Throughput Analysis Of S/R Shuttle Systems

Georg Kartnig and Jörg Oser

Shuttle systems are used in high performance automated storage/retrieval unit load systems. Each storage level is serviced by one transfer car travelling in dual command operation. One buffer slot is located at both ends of each level. This decouples horizontal travel from vertical input/output moves, which in this case requires two independent vertical reciprocating lifts at each end of the aisle. Other systems work with only one lift used in lower throughput applications. The content of this paper is treated in the following sections starting with a problem definition and a literature survey. This is followed by a detailed functional description of the system investigated here. A predictive model with analytical equations is derived for simplified calculations and a comparison with simulation results. A summary, conclusions and an outlook finalize the paper.

XI. Grid Facilities Design: Dynamic Modular Deployment Of Production, Handling And Storage Resources

Suzanne Marcotte and Benoit Montreuil

To survive and thrive in a fast-moving environment, facilities must be designed to show adaptability, flexibility and robustness. As some facilities are depicted by heavy and sophisticated equipment costly and hard to displace, others are composed of moveable workstations with highly flexible workers. In most cases, the trade-off is between the cost of redeploying the resources and the excessive cost of material handling and storage incurred by an inefficient deployment of the resources. We propose a design strategy based on (1) conceiving and designing the facility as a stable grid of modules, (2) dynamically deploying production, storage and handling resources to these modules, and (3) dynamically assigning process-product combinations to the modules so as to meet stochastic and dynamically evolving product demand on a rolling planning horizon. We illustrate the strategy as applied to a computer refurbishing and recycling facility.

XII. Integrating Analysis Into A Warehouse Design Workflow

Leon F. McGinnis and Timothy Sprock

Supply chain analyses, including those related to material handling systems, are typically purpose-built to answer specific questions and therefore have many different implementations depending on the question, the instance data, and the solver. The purpose-built nature of these models makes it difficult to integrate them into an iterative design workflow. Despite the myriad analysis implementations, the fundamental structure of these systems and their problem domain remains unchanged, suggesting that perhaps analyses could be automatically generated on demand, given an appropriate specification of the particular system to be analyzed. We apply model-based systems engineering (MBSE) methodologies to explore this possibility in the context of functional warehouse design.

XIII. Variation In Lifting Behavior During A Highly Repetitive Manual Material Task

Jay P. Mehta and Steven A. Lavender

Epidemiological studies have shown an association between manual material handling tasks and low back pain (LBP) (Macfarlane et al. 1997; Hughes et al. 1997; Vandergrift et al. 2012; Lavender et al. 2012). More specifically, manual handling tasks that involve repetitive bending, twisting, carrying or lifting movements have been associated with LBP (Marras et al. 1993; Hoogendoorn et al. 2002; Lotters et al. 2003; Heneweer et al. 2011; Mikkonen et al. 2012; Lavender et al. 2012). In addition, repetitive lifting during manual handling tasks has been associated with muscle fatigue (Dempsey 1998). However, the biomechanical mechanism linking muscle fatigue and back injury development has not been fully investigated. One theory is that muscle fatigue brings about altered behavioral strategies that changes an individual's exposure to biomechanical risk factors (National Academy Press 2001). Another theory is that momentary muscle substitution patterns result in more variable and less coordinated movements, while still maintaining the same overall behavioral strategy (National Academy Press 2001). With either of these

theoretical views, there should be increased variability in biomechanical measures typically used to characterize lifting behavior Larger movement variability may also impose greater loads on the underlying structure.

The aim of the current research was to quantify the biomechanical variation experienced during repetitive asymmetric lifting as often observed in occupational lifting tasks (Marras et al. 1993). Specifically, over the course of a 60-minute repetitive asymmetric lifting task, the behavioral response measures (three-dimensional postural deviations, movement speeds, and spine moments) were hypothesized to exhibit larger peak values, suggestive of a mechanism for injury, as time progressed.

XIV. An Experimental Study Of The Impact Of Warehouse Parameters On The Design Of A Case-Picking Warehouse

Russell D. Meller and Lisa M. Thomas

The best design for a warehouse is based on its ability to meet the demands placed on the warehouse, which are typically characterized by warehouse parameters like the order profile, inventory requirements, etc. Consequently, these parameters should be considered in the design process. In this paper we characterize the design of a case-picking warehouse with five design variables and identify the warehouse parameters that have the greatest impact in setting the values of these variables. With our analysis, the search for the optimal design can be reduced by limiting the design space considered.

XV. Positioning Automated Guided Vehicles In A General Guide-Path Layout

Abraham Mendoza, José A. Ventura and Subramanian Pazhani

The locations of dwell points for idle vehicles in an automated guided vehicle (AGV) system determine the response times for pick-up requests and thus affect the performance of automated manufacturing systems. In this study, we address the problem of optimally locating dwell points for multiple AGVs in general guide-path layouts with the objective of minimizing the maximum response time in the system. We propose a mixed integer linear programming (MILP) formulation for the problem. We also develop a generic genetic algorithm (GA) to find near optimal solutions. The MILP model and GA procedure are illustrated using a two-dimensional grid layout problem. Our computational study shows that the proposed GA procedure can yield near optimal solutions for these test problems in reasonable time.

XVI. Modular Design Of Physical Internet Transport, Handling And Packaging Containers

Benoit Montreuil, Eric Ballot and William Tremblay

This paper proposes a three-tier characterization of Physical Internet containers into transport, handling and packaging containers. It first provides an overview of goods encapsulation in the Physical Internet and of the generic characteristics of Physical Internet containers. Then it proceeds with an analysis of the current goods encapsulation practices. This leads to the introduction of the three tiers, with explicit description and analysis of containers of each tier. The paper provides a synthesis of the proposed transformation of goods encapsulation and highlights key research and innovation opportunities and challenges for both industry and academia.

XVII. A New Approach For Generating Facility Layouts Using An Algorithmic Approach

Christian Mosblech and Volker Sadowsky

In this paper a new approach is described to automatically create layouts for material flow systems. The current research in progress aiming at adopting the methods and algorithms of the Electronic Design Automation to be used in logistics planning is presented. These methods are already applied to create microchips being multiple times more complex than material flow systems while following the same goal: Functional units have to be placed on a predefined area and are linked by connections weighted differently. This basic requirement can be applied to microchip designs as well as material flow systems. The common condition is to create the setup with the smallest connection length possible.

The results are compared to a currently applied computerized method to calculate facility layouts. The overall result of the introduced method is nearly equal to the traditional reference method to create a computerized material flow layout. However, while the new algorithm does all calculations automatically, the traditional method requires manual finishing to achieve a comparable result.

This article thereby shows the potential of the research in progress toward the goal to support logistics planning with a new generation of automated software tools.

XVIII. Analysis Of Class-Based Storage Strategies For The Mobile Shelf-Based Order Pick System
Shobhit Nigam, Debjit Roy, René De Koster and Ivo Adan

Mobile Shelf-based Order Pick (MSOP) systems are gaining significant interest for e-commerce fulfillment due to their rapid deployment capability and dynamic organization of storage pods based on item demand profiles. In this research, we model the MSOP system with class-based storage strategies and alternate pod storage policies using multi-class closed queuing networks. We observe that though closest-open location pod storage policy do not allow to efficiently use the storage spaces in comparison to random location pod storage policy in an aisle, it increases the system throughput for all item classes.

XIX. Designing Retail Facilities To Improve Product Exposure
Pratik J. Parikh and Corinne Mowrey

A retail facility should effectively engage consumers during their shopping trips if they want to convert demand into purchases. Unfortunately, the complexity of the retailing environment and lack of scientific tools often results in gut-feel approaches experimented in practice. A key factor to retail design often alluded to, but rarely analyzed, is product exposure to the travelling shopper. We define the extent of the shopper's field of vision in order to determine the actual exposure of products experienced by a traveling shopper. In so doing, we can explore the effect rack orientation has on product exposure. Our main contributions include defining product exposure and an approach to estimate it at any point along the travel path. Our results indicate that certain rack orientations result in product exposures as high as 2.5 times that of the traditional 90° orientation.

XX. A Framework And Analysis To Inform The Selection Of Piece-Level Order-Fulfillment Technologies
Jennifer A. Pazour and Russell D. Meller

The piece-level order-fulfillment technology selection problem is an important strategic problem that significantly impacts distribution center costs and operations, and is typically solved based on empirical experiences. Given a demand curve and a suite of available piece-level order-fulfillment technologies, we analyze where in the demand curve different order-fulfillment technologies should be applied. To do so, we develop a framework that jointly determines the best combination of piece-level order-fulfillment technologies and the assignment of SKUs to these technologies, which relaxes the sequential-modeling approach of previous research. We validate our methodology with industry data and show that our model provides technology recommendations and SKU assignments that are consistent with successful implementations. Through a set of numerical experiments and statistical analysis, we identify key factors in implementing manual versus automated order-fulfillment technologies and provide observations into the application of different order-fulfillment technology strategies. Finally, we present conclusions and future research directions.

XXI. A Two-Level Stochastic Model To Estimate Vessel Throughput Time
Debjit Roy, Vibhuti Dhingra and René De Koster

A good estimate of the vessel sojourn time is essential for better planning and scheduling of container terminal resources, such as berth scheduling, quay crane (QC) assignment and scheduling, and fleet size planning. However, estimating the expected vessel sojourn time is a complex exercise because the time is dependent on several terminal operating parameters such as the size of the vessel, the number of containers

to be loaded and unloaded, and the throughput of the QCs. The throughput of the QCs in turn depends on the type and number of transport vehicles, number of stack blocks, the topology of the vehicle travel path, the layout of the terminal, and several event uncertainties. To address the modelling complexity, we propose a two-level stochastic model to estimate the expected vessel sojourn time. The higher level model consists of a continuous-time Markov chain (CTMC) that captures the effect of QC assignment and scheduling on vessel sojourn time. The lower level model is a multi-class closed queuing network (CQN) that models the dynamic interactions among the terminal resources and provides an estimate of the transition rate input parameters to the higher level CTMC model. We estimate the expected vessel sojourn times for several container load and unload profiles and discuss the effect of terminal layout parameters on vessel sojourn times.

XXII. Experimental Validation Of Travel Time Models For Shuttle-Based Automated Storage And Retrieval System

Zaki Sari, Latéfa Ghomri, Banu Y. Ekren and Tone Lerher

In this paper, we aim to validate travel time models for single and dual command cycle displacements of lifts and shuttles in a shuttle-based automated storage and retrieval system (SBS/RS) by using experimental computer simulation. The models under consideration take into account acceleration and deceleration delays. We use ARENA 12 software for the simulation modeling. By simulation, we emulate the real functioning of the system. Therefore, we assume that the results from the ARENA simulation are equivalent to the onsite experimentation. Simulation results are very close to those obtained by analytical travel time models. This shows the high precision of these models to predict operations of SBS/RS.These models can be used at design or operation phases to calculate throughput of the system, to compare between different topologies of SBS/RS or with other types of AS/RS to help decision makers to choose among different alternatives of automated storage systems.

XXIII. Model And Algorithm For Supply Chain Analysis In Energy-Wood Industry

Thorsten Schmidt and Hannes Hahne

Short rotation coppices are a renewable energy concept based on renewable raw material. This paper proposes a model and calculation method which generates valid supply chains using quantified technological and infrastructural constraints.

XXIV. The Cube Per Order Index Slotting Strategy, How Bad Can It Be?

Peter C. Schuur

A well-known and frequently applied policy to assign stock keeping units (SKUs) to (dedicated) storage locations in a warehouse is the Cube per Order Index (COI) slotting strategy. Basically, COI stores an SKU based on how frequently it is picked per unit of stock space required. Fast movers are located close to the Input-Output points. For single command order picking, COI slotting is well-known to minimize order picking travel time. For multi command this is no longer true. An interesting question is: how bad can it be? In this paper we show that there is no limit to this badness. Worst-case behavior of COI is infinitely bad. We construct a worst-case example that proves the following. Given an arbitrary positive integer p, there is (i) a warehouse configuration (ii) a set of SKUs (iii) a set of orders for these SKUs such that slotting these SKUs in the warehouse according to COI leads to an order picking travel time which is p times larger than the order picking travel time produced by an optimal slotting strategy.

XXV. Data Model And Software Tools For Modeling Picking Operations

Jeffrey S. Smith

When developing simulation models of picking warehouses, it would be helpful to find a way to generate some random pick lists based on a given warehouse layout/configuration. The academic community appeared to be lacking any usable form of “starter code” to perform this function. The best answer was essentially, “we modeled the pick locations as a graph and the picker/vehicle travel using paths

through the graph." The preferred answer would be if the community could provide the data structures, the file read/write code, and any shortest path code based on the data structures that are applied to an order picking model. Unfortunately, it became clear that the code and corresponding data structure specifications were not readily available in any usable format. Yet, the data models and code should be fairly standard and widely available. The request was not focused on proprietary picker-routing, order batching, or WMS code.

With no standards or even de facto standards available, this research began to develop the specifications, data structures, and code. This has been an arduous task that has very little relationship to the actual modeling and research that the code would support. Further, this exact same task has likely been performed hundreds of times by researchers over the years as a precursor to their research/testing. Yet there are no standard data models and associated software tools to represent warehouse configurations and operations. Why?

XXVI. Optimization Of SKUs' Locations In Warehouse

David Sourek and Vaclav Cempirek

Many companies, which deal with warehousing, optimize their warehouses. The main business of these companies is to offer to customers the warehousing services. It is possible to note that these companies are specialized in warehousing. On the other hand, we can find companies, which have as the main business the selling of goods to customers. These companies use the warehouses too but in a little bit different way. The arrangement of their warehouses can be very unsuitable and convenient for optimization. Our paper is focused on optimization of stored goods' locations based on market basket analysis. The solution of this task is known as well but not so many authors deal with it. A common problem for many companies is to find sets of products that are sold together. As the source of these information the history of sales transactions is used. The process of the data preparation is mentioned in this paper. The steps described in this paper are applied on real retail store.

XXVII. Development Of A Heuristics For A Criteria Based Planning Of Pallet Storage Systems

Detlef Spee, Michael Schmidt and Steffen Schieweck

Reproducible and quantitative reasoning as the foundation for high-quality planning processes evolves to be key to achieve high quality of speed for logistical processes. This article strives to fulfill this demand by developing a coherent heuristics for the planning of pallet storage systems.

The heuristics uses quantitative approaches provided by the available literature. In case of nonexistent sources, the missing components are developed and integrated. To be applicable in an industrial environment, the comparison and assessment of the created implementation alternatives is mainly monetary based. The heuristics follows a modular structure to achieve adaptability and extensibility. It explicitly does not intend to replace a human designer but to support him during the creation and assessment of high-quality design alternatives.

A concluding case study evaluates the practical applicability of the heuristics and its created solutions. The review of the heuristics turns out to be positive. As a consequence, extension and improvement tasks are proposed.

XXVIII. Modeling And Optimization Of Radio Frequency Identification Networks For Inventory Management

Atipong Suriya and J. David Porter

Stock loss and out-of-stocks are outcomes of poorly designed inventory management systems and can lead to significant revenue losses. Inventory management systems (IMSs) based on radio frequency identification (RFID) have the potential to minimize these losses if they are properly designed and deployed. However, the placement of RFID readers to support IMSs is often done on a trial and error basis which is time consuming and results in less than optimal coverage. A methodology to find the optimal location and number of RFID readers in a warehouse facility to ensure a desired level of radio frequency signal coverage was developed in this research. The results show that the proposed methodology works

very well when applied to small rectangular facilities and small inverted-T facilities. However, some limitations exist when the method is applied to large facilities.

XXIX. Comparison Of Alternative Configurations For Dense Warehousing Systems
G. Don Taylor and Kevin Gue

In heavily constrained environments requiring very high density storage, traditional aisle-based warehousing may not provide viable options. One feasible manifestation of high density storage systems is the 'puzzle-based' system, in which unit loads are moved through the system via manipulation of empty (escort) locations to retrieve desired items. Another option would be the use of movable concentric rings, with escorts being utilized to enable lateral movements of unit loads between the rings. In this paper, the authors present analytical results to compare retrieval time performance for these two types of high density storage systems for randomly demanded items under various assumptions regarding the initial placement of escorts. The paper concludes that the use of movable concentric rings results in significant improvement to retrieval time performance in comparison to rectangular, puzzle-based systems, and further concludes that additional research is warranted.

XXX. Integrate Vehicle Routing And Truck Sequencing In Cross-Docking Operations
Ching-Jung Ting and Ting-Dong Cheng

Cross-docking is a an important logistics strategy in which freight is unloaded from inbound vehicles and directly loaded into outbound vehicles, with little or no storage in between. This study considers a crossdocking system which combines the vehicle routing problem with crossdocking (VRPCD) for both inbound and outbound operations and truck sequencing problem at docks. The objective is to minimize the logistics center operation costs and transportation costs. We first formulated the integrated problem with a mixed integer programming model. Since VRPCD and sequencing problems are NP-hard, the integrated problem is also an NP-hard problem. We propose an ant colony optimization (ACO) algorithm to solve the VRPCD and sequencing problem by two independent ant colonies sequentially. The proposed ACO is tested with 15 randomly generated instances. The results show that ACO can obtain the optimal solutions in small size instances. We believe the proposed ACO algorithms can be used for practical use for the cross-docking system.

XXXI. Modeling Conveyor Merges In Zone Picking Systems
Jelmer Van Der Gaast, René De Koster and Ivo Adan

In many order picking and sorting systems conveyors are used to transport products through the system and to merge multiple flows of products into one single flow. In practice, conveyor merges are potential points of congestion, and consequently can lead to a reduced throughput. In this paper, we study merges in a zone picking system. The performance of a zone picking system is, for a large part, determined by the performance of the merge locations. We model the system as a closed queueing network that describes the conveyor, the pick zones, and the merge locations. The resulting model does not have a product-form stationary queue-length distribution. This makes exact analysis practically infeasible. Therefore, we approximate the behavior of the model using the aggregation technique, where the resulting subnetworks are solved using matrix-geometric methods. We show that the approximation model allows us to determine very accurate estimates of the throughput when compared with simulation. Furthermore, our model is in particular well suited to evaluate many design alternatives, in terms of number of zones, zone buffer lengths, and maximum number of totes in the systems. It also can be used to determine the maximum throughput capability of the system and, if needed, modify the system in order to meet target performance levels.

XXXII. Robust Truckload Relay Network Design Under Demand Uncertainty

Hector A. Vergara and Zahra Mokhtari

This research addresses the issue of incorporating demand uncertainty in the strategic design of relay networks for truckload transportation. An existing composite variable mathematical model for the design of hybrid relay networks is extended by developing its robust counterpart. The proposed approach considers uncertainty in the number of truckloads to be dispatched between a pair of nodes in the network which is characterized by a symmetric interval around the expected demand value. A two-step heuristic approach is used to solve the robust model. Several numerical experiments are carried out to study the differences between the solutions obtained with the robust approach and those generated by the existing deterministic model. In particular, we were interested in understating how different levels of uncertainty affect total cost of the system and the configuration of the resulting networks. At the end, numerical results are discussed and directions for future research are presented.

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