14th IMHRC Proceedings (Karlsruhe, Germany – 2016)

Progress in Material Handling Research

2016

Progress in Material Handling Research: 2016

Follow this and additional works at: https://digitalcommons.georgiasouthern.edu/pmhr_2016

Progress in Material Handling Research: 2016

Editors

Kimberly Ellis, Ph.D.
Andres Carrano, Ph.D.
René de Koster, Ph.D.
Gary Forger
J. David Porter, Ph.D.
Jeffrey Smith, Ph.D.

CICMHE
COLLEGE-INDUSTRY COUNCIL
ON MATERIAL HANDLING EDUCATION

MHI

IMHRC 2016 Planning Committee

Kimberly Ellis, Ph.D. (Chair)
Associate Professor
Grado Department of Industrial and Systems
Engineering
Virginia Tech
250 Durham Hall (0118)
Blacksburg, VA 24061
USA

Kai Furmans, Ph.D.
Professor, Head of Institute of Material Handling
and Logistics
Karlsruhe Institute of Technology
Kaiserstrasse 12
76131 Karlsruhe
Germany

Gary Forger
Managing Director of Professional Development
MHI
8720 Red Oak Boulevard, Suite 201
Charlotte, NC 28217
USA

IMHRC 2016 Scientific Committee

Kimberly Ellis, Ph.D. (Chair)
Associate Professor
Grado Department of Industrial and
    Systems Engineering
Virginia Tech
250 Durham Hall (0118)
Blacksburg, VA 24061
USA

Andres L. Carrano, Ph.D.
Professor
Department of Manufacturing Engineering
Georgia Southern University
P.O. Box 7990
Statesboro, Georgia 30450-7995
USA

René de Koster, Ph.D.
Professor
Erasmus University
Rotterdam School of Management
P.O. Box 1738
3000 DR, Rotterdam
Netherlands

Gary Forger
Managing Director of Professional Development
MHI
8720 Red Oak Boulevard, Suite 201
Charlotte, NC 28217
USA

J. David Porter, Ph.D.
Associate Professor
School of Mechanical, Industrial, and
    Manufacturing Engineering
Oregon State University
420 Rogers Hall
Corvallis, OR 97331-6001
USA

Jeffrey Smith, Ph.D.
Professor
Department of Industrial and Systems
    Engineering
Auburn University
3306 Shelby Engineering Center
Auburn, AL 36849-5346
USA

Acknowledgments

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, CICMHE is comprised 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.

The mission of CICMHE 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; and

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

CICMHE receives its financial support from MHI. CICMHE also collaborates on projects with the Material Handling Education Foundation, Inc. (MHEFI), which supports student scholarships, instructional aids, and travel grant programs for faculty and students at institutions providing education in the material handling field.

www.cicmhe.org

Information about previous colloquia may be found at:

www.mhi.org/CICMHE/colloquium

Table of Contents

14th International Material Handling Research Colloquium – 2016

I. Performance Comparison of Automated Warehouses Using Simulation
Nand Kishore Agrawal, Sunderesh S. Heragu and Chinnatat Methapatra

The purpose of this study is to compare the performance of two types of warehouses, both of which use autonomous vehicles (AVs). One warehouse uses movable racks (MR) for storing mini-loads, whereas the other uses fixed racks (FR). In general, warehouse automation not only increases the speed of the fulfillment process but also makes the picking process more accurate. We simulate three scenarios for the MR and FR systems using Simio. Four performance measures are considered for the comparison – the average order processing time (WR), the average utilization of AVs (U), the average order processing queue length (Nq) and the average distance travelled by AVs (d). We also estimate the capital costs of both systems and use it to compare the two systems. On the basis of our assumptions and simulation results, we find that the FR system not only requires an average 56 % less capital investment than the MR system, but it also provides a more efficient warehousing automation option with relatively lower utilization of AVs, lower order processing time and lower average number of orders waiting to be processed.

II. Job Sequencing in a Miniload System
Lennart Baardman, Kees Jan Roodbergen and Héctor J.Carlo

More and more warehouses shift towards the use of automated systems. One such system is a miniload system. In this system, a crane retrieves bins from their storage locations and brings the bins to the picking station, where a worker takes the requested products from the retrieved bins. After a product has been picked, the bin is put back by the crane in its original location. A buffer is present at the picking station to absorb fluctuations in speed between the picker and the crane. The problem of scheduling jobs in this system has received little attention in the literature. We describe system properties and give insight in the performance of a number of heuristics.

III. Transport Items and Physical Internet Handling Boxes: A Comparison Framework Across Supply Chains
Eric Ballot and Benoit Montreuil

Pallets, cardboard boxes, and plastic crates are widely used tools to operate supply chains. As such they have many impacts on handling effort, shipment protection, transport mean utilization as well as repositioning and recycling efforts and they represent billions of assets spread all over the world. The historical and local origins of the designs and the sharing among many stakeholders do not ensure at all any kind of global optimization. The purpose of this paper is to define and explain a research effort to better measure and evaluate the efficiencies and inefficiencies for supply chain stakeholders for themselves and globally. When validated the framework will be sued to evaluate new designs on a global scale especially for the design of the handling box related to the Physical Internet concept.

IV. Dual-Tray Vertical Lift Modules for Fast Order Picking
Daria Battini, Martina Calzavara, Alessandro Persona and Fabio Sgarbossa

In the last years, new solutions for order picking systems have been developed both from industry and academics, especially for small items. They include innovative flexible automatic parts-to-picker systems and optimized picker-to-parts ones. One of these solutions consists in the use of Vertical Lift Modules (VLMs), a storage column in which small items are stored in extractable trays. In this paper, we study a new system composed by dual-tray VLMs where the operators perform picking and sorting

activities. We propose several actions in order to improve the productivity of the entire system: 1) class based storage assignment of items inside the VLMs; 2) batch retrievals of items and 3) batch orders and batch retrievals with pick-and-sort activity. The impacts of these actions are evaluated with a simulation of the system using real data from an industrial case.

V. Continuous Approximation of Multi Cycle Time for Multi Aisles Automated Storage and Retrieval Systems
Yassine Boudghene Stambouli and Latefa Ghomri

Knowing that, in an automated storage and retrieval system, the travel time of the storage/retrieval machine is an important parameter which affects the whole system performances, several works were dedicated to its evaluation and its modeling, in single, dual and multi command. These models were proposed for different configurations of AS/RS; such as unit load, multi-aisles and Mobile Racks. These models are based mainly on a discrete approach and the analytical expressions represent the system functioning exactly. In this paper we present a general approach for analytical modeling of multi command cycle time by giving particularly the modeling of the Time Between that we will use to model the Dual Cycle time and the Multi Cycle time. This continuous approach with its simplified mathematical expressions aims to make the calculations more easy than the discrete approach and can be generalized for any one deep physical configuration of AS/RSs and later used to make an optimization of the dimensions of such systems.

VI. Throughput Rate of a Two-Worker Stochastic Bucket Brigade
Yossi Bukchin, Eran Hanany and Eugene Khmelnitsky

Work sharing in production systems is a modern approach that improves throughput rate. Work is shifted between cross-trained workers in order to better balance the material flow in the system. When a serial system is concerned, a common work-sharing approach is the Bucket-Brigade (BB), by which downstream workers sequentially take over items from adjacent upstream workers. When the workers are located from slowest-to-fastest and their speeds are deterministic, it is known that the line does not suffer from blockage or starvation, and achieves the maximal theoretical throughput rate (TR). Very little is known in the literature on stochastic self-balancing systems with work sharing, and on BB in particular. This paper studies the basic BB model of Bartholdi & Eisenstein (1996) under the assumption of stochastic worker speeds. We identify settings in which conclusions that emerge from deterministic analysis fail to hold when speeds are stochastic, in particular relating to worker order assignment as a function of the problem parameters.

VII. A Performance Measurement Framework and Solution Approach for the Integrated Facility Layout Problem with Uncertain Demand
Melih Çelik, Begün Efeoglu and Haldun Süral

The integrated facility layout problem (IFLP) focuses on the simultaneous determination of the relative locations of multiple copies of capacitated equipment or machinery in a facility, as well as the material flow between these units. In this paper, we consider the IFLP in the existence of uncertain demand for the products of the facility. Motivated by the framework for next generation facility layouts by Benjaafar et al. (2002), we extend the approaches in the literature for distributed facility layouts to the case of dynamic demand and the possibility of relay outs, and propose a heuristic solution approach to minimize the expected total material handling cost over the planning horizon. We also analyze the performance of the resulting solutions in terms of empty travel of the material handling equipment and waiting time. Our computational results reveal that when demand is dynamic and stochastic, the relationship between the level of uncertainty and relay out cost plays an important role in determining layout performance, and therefore a priori assumption of using a certain layout type may lead to detrimental results.

VIII. A Simulation Model to Evaluate the Layout for Block Stacking Warehouses
Shahab Derhami, Jeffrey S. Smith and Kevin R. Gue

Storing pallets of Stock Keeping Units (SKUs) on top of one another in lanes on a warehouse floor is known as block stacking. This storage system is widely used in manufacturing systems and distribution centers. The arrangement of lanes in the layout of this system significantly impacts utilization of the storage space and transportation costs. Existing research that studies the layout for this system focuses exclusively on determining the optimal lane depth with respect to space utilization and ignores transportation costs. In this study, we develop a simulation model that computes several performance metrics to evaluate both of these objectives for a warehouse layout. It aims to take the stochastic variations exist in the real world situation into account. Designing the layout based on the historical data distinguishes this model from the analytical models in the systems with high level of uncertainty, where determining the required parameters for analytical models are difficult due to the high variations. We verified the model using the existing analytical models and developed an experimental analysis to show the trade-off between the space utilization and transportation costs in the layout design problem.

IX. Determination of Cycle Times for Double Deep Storage Systems Using a Dual Capacity Handling Device
Katharina Dörr and Kai Furmans

Double deep storage is an efficient method to improve space utilization in warehouses. Contrary to intuition, it also can be efficient when considering retrieval times, since the aisles of a warehouse with double deep storage may be shorter than comparable warehouses with single deep storage. AS/RS-machines equipped with two load-handling units might further improve the situation, since two storage units (for instance pallets or cases) can be stored and retrieved, effectively allowing quadruple command cycles, bringing in total two storage units into the aisle and retrieving two storage units at the same time. In this paper, we present a method for the computation of cycle times and average cycle times with the assumption of equally distributed access probabilities for AS/RS-machines equipped with two load handling devices.

X. Energy and Cycle Time Efficient Warehouse Design for Autonomous Vehicle-Based Storage and Retrieval System
Banu Y. Ekren, Anil Akpunar and Tone Lerher

This study explores the best warehouse design for an autonomous vehicle based storage and retrieval system (AVS/RS) minimizing average energy consumption per transaction and average cycle time per transaction, simultaneously. In the design concept, we consider, rack design in terms of number of bays, number of tiers, number of aisles; number of resources, namely number of autonomous vehicles and lifts and; velocity profiles of lifts and autonomous vehicles in the AVS/RS. We completed 1,296 number of experiments in simulation to obtain Pareto solutions representing the "average energy consumption per transaction" and "average cycle time per transaction" trade-offs based on designs which is a very useful visual tool in decision making. Different from the existing studies, we approach to the warehouse design problem of AVS/RSs from a multi-objective view as well as energy efficient view minimizing both electricity consumption and cycle time per transaction in the system.

XI. A Scalable Algorithm for Locating Distribution Centers on Real Road Networks
Saeed Ghanbartehrani and J. David Porter

The median problem is a type of network location problem that aims at finding a node with the total minimum demand weighted distance to a set of demand nodes in a weighted graph. In this research, an algorithm for solving the median problem on real road networks is proposed. The proposed algorithm, referred to as the multi-threaded Dijkstra's (MTD) algorithm, is then used to optimally locate Wal-Mart distribution centers on the 28-million node road network of the United States with the objective of

minimizing the total demand weighted transportation cost. The resulting optimal location configuration of Wal-Mart distribution centers improves the total transportation cost by 40%.

XII. A High-Density, Puzzle-Based System for Rail-Rail Container Transfers
Kevin R. Gue and Gang Hao

We describe a high-density, puzzle-based storage and transfer system for containers in a rail-to-rail hub for the Physical Internet. The system uses a new algorithm called GridHub, which is able to transfer items in all four cardinal directions simultaneously within a grid. We show how the GridHub system might be used in a rail-rail transfer hub to transfer containers between one side of the grid and a train.

XIII. A Novel Approach to Analyze Inventory Allocation Decisions in Robotic Mobile Fulfillment Systems
T. Lamballais, D. Roy and M.B.M. de Koster

The Robotic Mobile Fulfillment System is a newly developed automated, parts-to-picker material handling system. Storage shelves, also known as inventory pods, are moved by robots between the storage area and the workstations, which means that they can be continually repositioned during operations. This paper develops a queueing model for optimizing three key decision variables: (1) the number of pods per product (2) the ratio of the number of pick to the number of replenishment stations, and (3) the replenishment level per pod. We show that too few or too many pods per product leads to unnecessarily long order throughput times, that the ratio of the number of pick to the number of replenishment stations can be optimized for order throughput time, and that waiting to replenish until a pod is completely empty can severely decrease throughput performance.

XIV. Simulation-Based Energy and Cycle Time Analysis of Shuttle-Based Storage and Retrieval System
Tone Lerher, Banu Y. Ekren and Anil Akpunar

This study explores the best warehouse design for shuttle-based storage and retrieval system (SBS/RS) minimizing average energy consumption per transaction and average cycle time per transaction, simultaneously. For that we provided average energy consumption per transaction versus average cycle time per transaction graphs, for different design scenarios of the studied SBS/RS warehouse. In the design concept, we considered, rack design in terms of number of bays, number of tiers, number of aisles, as well as velocity profiles of lifts in the system. We completed 144 experiments by simulation to see the trade-offs based on the design scenarios and provided them by two separate graphs. The results show that while the SBS/RS warehouse has low number of tiers, it has low energy consumption per transaction as well as low average cycle time per transaction in the two lift velocity scenarios.

XV. Introducing the Concept of Hyperconnected Mobile Production
Suzanne Marcotte and Benoit Montreuil

Many globalized businesses are trying to cope with growing competition by strategically expanding their dedicated network of production facilities so as to be able to offer and to deliver time and price competitive offers to their clients across the world. In this paper, exploiting Physical Internet principles, we introduce the concept of hyperconnected mobile production that can alternatively enable businesses to dynamically expand and contract as necessary their production capacity in regions worldwide. First, hyperconnected mobile production exploits open fabs from multiple parties readily available in those regions. Second, these fabs are to rely on plug-and-play production modules. These modules are to be flowed in and out of open fabs worldwide by the fab operators or their business clients so as to absorb dynamic production requirements from customers. Third, the production modules are to be dynamically re-configurable through adding and removing plug-and-play modular resources. We first show that hyperconnected mobile production builds on eight innovation threads: distributed, outsourced, on-demand,

modular, additive, mobile, containerized and hyperconnected production. We then provide an overall description of key facets of the hyperconnected mobile production concept and finally elicit a number of promising research avenues.

XVI. Operational-Level Optimization of Inbound Intralogistics
Yeiram Martínez and Héctor J. Carlo

This study is concerned with optimizing inbound operations at distribution centers (DCs), warehouses, and cross-docks with staging areas. The objective of the problem is to minimize the makespan required to move all unit loads from the trailers to the flow racks, and from the flow racks to their respective storage locations. It is assumed that a set of inbound trailers with known composition have been assigned and sequenced to inbound dock doors. The following three inbound logistics decisions are simultaneously considered: i) unloaders' assignment and scheduling, ii) loads-to-flow rack assignment, and iii) assignment and haulers' scheduling. In this study we describe the relationship between the problem of minimizing makespan and an unloader-hauler balancing problem. Three rule-based heuristics are proposed and evaluated in an instance of the problem.

XVII. Non-Traditional Aisle Design for a Manufacturing Facility Layout
Dale Masel and Dean Marinchek

Methods for designing a facility layout typically assume that the aisles for interdepartmental travel will be parallel to the exterior walls of the facility. However, by putting aisles at an angle to the exterior walls, more direct routes between departments can be created, reducing travel distance. This paper describes a method to create a facility layout that does not have orthogonal aisles and testing of the resulting layouts shows that travel distance is reduced.

XVIII. Toward an Engineering Discipline of Warehouse Design
Leon McGinnis and Timothy Sprock

Warehouses today are complex dynamic engineered systems, incorporating automation, mechanization, equipment, fixtures, computers, networks, products and people, and they can support the flow of tens or hundreds of thousands of different items to enable fulfilling thousands or tens of thousands of orders daily. In that sense, they represent a design challenge that is not terribly different from the design of other complex dynamic engineered systems, such as a modern passenger airplane, an automobile, or a unique building. What is different is that the design of these other complex dynamic engineered systems typically follows some engineering design discipline. Here, we argue for the development of a corresponding engineering discipline of warehouse design.

XIX. Understanding Worker Blocking and the Design Process
Russell D. Meller and Lisa M. Thomas

Designing a distribution center (DC) is a complex process that consists of answering dozens of interrelated questions. From our perspective, the penultimate question is one of which picking methodology is optimal. To answer this question requires a full evaluation of picking methodologies in terms of their ability to meet the expected throughput requirements of the system. In manual picking systems, as throughput requirements increase, worker interaction and blocking increase as well. This implies that being able to estimate the amount of worker blocking in a system is critical to a design effort. Most of the prior research in this area addresses this point from an analysis perspective. In this paper we provide a design perspective based on the results from a structured simulation modeling study we conducted. We present our main result — a design rule ratio — as well as how this design rule ratio is used within a design process.

XX. Omnichannel Business-to-Consumer Logistics and Supply Chains: Towards Hyperconnected Networks and Facilities
Benoit Montreuil

This paper deals with omnichannel business-to-consumer logistics and supply chains. Its key contribution is the conceptualization of hyperconnected network and facility design options for enabling to meet the challenges toward achieving omnichannel logistics efficiently and sustainably while meeting the timely expectations of clients. These design options exploit key Physical Internet concepts. They encompass the transportation, pickup and delivery of ordered goods, the deployment of products across territories to enable fast response to orders, as well as on-demand production of products across networks of facilities while engaging multiple parties. The options range from current practice to prospective ones that are associated to a more mature level of implementation of the Physical Internet. The paper identifies key relative advantages and disadvantages of alternative options, synthesizes strategic insights for industry, and provides research challenges and opportunities.

XXI. Outsourced Storage and Fulfillment Facilities to Enhance the Service Capabilities of Shopping Mall Tennants
Zachary Montreuil and Mike Ogle

This paper proposes development of an Inventory and Fulfillment Center (IFC) that will provide a new range of outsourced, centralized storage and services for shopping mall tenants. The paper describes the competitive issues faced by shopping mall tenants, the requirements and features of a centralized, outsourced storage and fulfillment facility, and development of an agent-based model in AnyLogic® to demonstrate the concept. The range of research and business challenges introduced by this new concept are also presented.

XXII. Logistics Models to Support Order-Fulfillment from the Sea
Jennifer A. Pazour and Ian Shin

Sea based logistics use maritime platforms to transfer cargo stored on vessels and delivers them ashore. This chapter describes the motivations and logistical requirements of seabasing. The sea base's organizational structure, its material handling environment, and the internal cargo flow processes of the T-AKE vessel are described. Three seabasing distribution network scenarios — Iron Mountain, Skin-to-Skin Replenishment, and Tailored Resupply Packages — are described and mapped to warehousing and distribution networks, characteristics, and decision problems. Finally, related literature is reviewed and open areas for logistics research to support order fulfillment from the sea are identified.

XXIII. Integrated Versus Sequential Scheduling and Assignment at a Unit Load Cross-Dock
Arpan Rijal, Marco Bijvank and René de Koster

Within a cross-dock, the assignment of trucks to dock-doors and the scheduling of trucks to be processed are two major operational decisions. Conventionally, assignment and scheduling decisions are made sequentially. However, solving the two problems sequentially can lead to sub-optimal solutions because the objectives of the two problems are in conflict with each other. To gain further insights, we create an integrated model which is capable of simultaneously scheduling and assigning trucks at cross-docks. We contrast the integrated model with a sequential model which first schedules trucks for processing and then assigns them to dock-doors. Experiments demonstrate that the integrated model can produce superior solutions, despite that it is computationally more expensive.

XXIV. Evaluating Transaction Pairing Strategies for Vehicle-Based High-Density Storage Systems
Debjit Roy and Harit Joshi

Vehicle-based storage and retrieval systems present an attractive choice for distribution center automation because it provides the flexibility in managing demand fluctuations without affecting transaction throughput times. In this research, we contend that while dual-command cycles can reduce the

vehicle travel times for processing transactions, it may not be the best policy for reducing transaction throughput times when transactions arrive at random time instants. We develop stochastic models to test the transaction throughput time performance with multiple pairing strategies and present operational insights.

XXV. New Design Guidelines for In-Plant Milk-Run Systems
Thorsten Schmidt, Ingolf Meinhardt and Frank Schulze

Tugger trains became a popular means of supply in material handling intensive production systems. In contrast to forklift trucks they interlink a supermarket with multiple delivery locations along a transport route in a milk-run. But the efficiency gain (higher transport capacity, reduced labor costs) has its price: Compared to forklift trucks, planning and dimensioning of in-plant milk-run systems is more complicated. The paper discusses features and drawbacks of a recent standardization approach of the Association of German Engineers (VDI) and highlights the variety of technical restrictions which have to be considered when a milkrun system is designed. It shows, that algorithms can support the design and dimensioning process. It is, however, not feasible to formulate the design task as an ordinary optimization problem which can be handled by a solver without any further interaction.

XXVI. Maritime Location Decisions for LNG Bunkering Facilities
Reinier C. Schneider and Iris F.A. Vis

Liquefied natural gas (LNG) is one of the upcoming fuels to be used for more sustainable shipping activities in the maritime sector. For a widespread adoption by end-users, a refuelling network requiring capital intensive investments, needs to be in place. From a macro perspective of suppliers of LNG, it makes sense to develop the infrastructure at strategic locations that capture as many vessels and ships as possible. The goal of this research is to develop a facility location model that can contribute to the location selection of LNG facilities in a new fuelling network. The new model will fit the maritime sector and specifically the LNG transition. Experiments, with data obtained from expert interviews, have been performed to study facility location decisions in the North Sea areas.

XXVII. Methodology for Choosing Appropriate Inland Vessels as a Floating Distribution Centers
Andrea Seidlova and David Sourek

The primary goal of this paper is to propose a methodology for the choice of an appropriate vessel type under the specific condition of floating distribution center. The right choice of the appropriate type of vessel has a fundamental influence on the long-term success of city logistic projects with water transport. In this paper, we propose a methodology for vessel choice according to its inner layout and technology of handling. The possibility of an application in practice will be defined for each option.

XXVIII. A Heuristic Approach to Storage System Design with Simultaneous Assignment of Goods

In the paper at hand, we analyze the planning of manually operated storage systems consisting of different storage areas. When solving design problems like dimensioning or equipment selection, the assignment of goods to storage areas has to be considered. Based on a general model to describe the geometry and performance calculation of a warehouse, we present a heuristic approach to assign goods to storage areas while simultaneously determining the design of the storage areas in a way that generates the lowest running costs. Our approach aims to support planners during the rough planning stage by providing a quick overview of different solution alternatives. To evaluate our approach, we apply it to an example from industrial practice.

XXIX. The Storage Replenishment Problem in Rectangular Warehouses
Haldun Süral, Claudia Archetti and Melih Çelik

In warehouses, storage replenishment operations involve the transportation of items to capacitated item slots in forward storage area from reserve storage. These items are later picked from these slots as their demand arises. While order picking constitutes the majority of warehouse operating costs,

replenishment operations might be as costly in warehouses where pick lists generally consist of only a few lines (e.g., order fulfillment warehouses). In this study, we consider the storage replenishment problem in a parallel-aisle warehouse, where replenishment and order picking operations are carried out in successive waves with time limits. The aim is to determine the item slots that will be replenished and the route of the replenishment worker in each replenishment wave, so as to minimize the total labor and travel costs, and ensure the availability of items at the start of the wave they will be picked. The problem is analogous to the inventory routing problem due to the inherent trade-off between labor and travel costs. We present complexity results on different variants of the problem and show that the problem is NP-hard in general. Consequently, we use a heuristic approach inspired by those from the inventory routing literature. We use randomly generated warehouse instances to analyze the effect of different storage policies (random and turnover-based) and demand patterns (highly skewed or uniform) on replenishment performance, and to compare the proposed replenishment approach to those in practice.

XXX. A Lagrangian Relaxation for Capacitated Single Allocation P-Hub Media Problem with Medium Capacity Levels
Ching-Jung Ting and Kuo-Rui Lu

In this paper we consider a capacitated single allocation p-hub median problem with multiple capacity levels (CSApHMPMC) in which the decisions are to determine the location of p hubs and their capacity levels, the single allocation of non-hub nodes to hubs in the logistics network. This problem is formulated as an integer programming model with the objective of minimizing the sum of total transportation cost and fixed cost of the selected p hubs with established capacity levels. A Lagrangian relaxation (LR) approach is proposed to solve the CSApHMPMC. The Lagrangian function that we formulated decomposed the original problem into smaller subproblems that can be solved easier. We only solve the CSApHMPMC using Gurobi optimizer for the small sized problems. The experimental results show that the proposed LR heuristic can be an effective solution method for the capacitated p hub median location problem with multiple capacity levels.

XXXI. Monte Carlo Algorithm to Study Performance Parameters of Shuttle Systems
Wolfgang Trummer and Dirk Jodin

Shuttle systems provide alternative solutions in storage technology. Material flow analyses of these systems are extensive due to complex interaction of several shuttles and lift elements. Besides classic cycle time calculation, it also requires advanced analyzing methods. At the Institute of Logistics Engineering (ITL), Graz University of Technology, an innovative, software-based approach has been developed to investigate the performance of shuttle systems. This approach is based on the Monte Carlo method. The software tool takes into account a variety of different systems and operating parameters to reflect operative behavior of shuttle systems.

XXXII. Analyzing Order Throughput Times in a Milkrun Picking System
J.P. van der Gaast, M.B.M. de Koster and I.J.B.F. Adan

E-commerce fulfillment competition evolves around cheap, speedy, and time-definite delivery. Milkrun order picking systems have proven to be very successful in providing handling speed for a large, but highly variable, number of orders. In this system, an order picker picks orders that arrive in real time during the picking process; by dynamically changing the stops on the picker's current picking route. The advantage of milkrun picking is that it reduces order picking set-up time and worker travel time compared to conventional batch picking systems. This paper is the first in studying order throughput times of multi-line orders in a milkrun picking system. We model this system as a cyclic polling system with simultaneous batch arrivals and determine the mean order throughput time. These results allow us to study the effect of different product allocations. For a real world application we show that milkrun order picking reduces the order throughput time significantly compared to conventional batch picking.

XXXIII. Intermodal Hubs in the Physical Internet

Nadeepa Wickramage and Bill Ferrell

Distribution of finished goods is currently an effective but inefficient process that consumes significant quantities of fossil fuel to move empty assets. This results in increased costs that are passed to the consumer and unnecessarily increased carbon emissions. The Physical Internet (PI) is focused on shared logistics that could prove to be an important element of next-generation logistics systems. The idea is to store and transport goods in anonymous standard-sized containers so that transportation and warehousing can be efficiently shared by many companies including competitors. If implemented, this idea has the potential of dramatically increasing efficiency thereby reducing fuel consumption and decreasing costs as well as emissions. This paper focuses on one aspect of the PI, intermodal hubs. More importantly, the key difference between the PI hub as imagined in this research and a transhipment facility or breakbulk terminal is that the control is decentralized; hence, this research explores decentralized control of a PI hub through experiments using scenarios and heuristics in an effort to gain some understanding how design and operations impact performance.

MHI

CICMHE
COLLEGE-INDUSTRY COUNCIL
ON MATERIAL HANDLING EDUCATION