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## 12th International Material Handling Research Colloquium – 2012

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In this paper, we address a one-to-many distribution network inventory routing problem over an infinite planning horizon. Each retailer has an independent, random demand, and the distribution center uses capacitated vehicles for routing delivery. The demand at each retailer is relatively small compared to the vehicle capacity. A novel mathematical model is given to simultaneously decide the optimal routing tours to retailers and routing frequencies of each route. Several heuristics are developed to solve large scale instances of the problem.

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As part of the 2010 IMHRC, Montreuil, Meller and Ballot enumerated the type of facilities that would be necessary to operate a Physical Internet (PI,  $\pi$ ), which they termed, " $\pi$ -nodes." This paper is part of a three-paper series for the 2012 IMHRC where the authors provide functional designs of three PI facilities. This paper covers a PI road-rail hub. The purpose of a PI road-rail node is to enable the transfer of PI containers from their inbound to outbound destinations. Therefore, a road-rail  $\pi$ -hub provides a mechanism to transfer  $\pi$ -containers from a train to another one or a truck or from a truck to a train. The objective of the paper is to provide a design that is feasible to meet the objectives of this type of facility, identify ways to measure the performance of the design, and to identify research models that would assist in the design of such facilities. The functional design is presented in sufficient detail as to provide an engineer a proof of concept.

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The National Institute of Standards and Technology's Intelligent Systems Division has been researching several areas leading to safe control of manufacturing vehicles to improve automated guided vehicle (AGV) safety standards. The research areas include:

- AGV safety and control based on advanced two-dimensional (2D) sensors that detect moving standard test pieces representing humans;
- Ability of advanced 3D imaging sensors, when mounted to an AGV or forklift, to detect stationary or moving objects and test pieces on the ground or hanging over the work area; and
- Manned forklift safety based on advanced 3D imaging sensors that detect visible and non-visible regions for forklift operators.

Experiments and results in the above areas are presented in this paper. The experimental results will be used to develop and recommend standard test methods, some of which are proposed in this paper, and to improve the standard stopping distance exception language and operator blind spot language in AGV standards.

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*Yossi Bukchin and E. Wexler*

The effect of workers' learning curve on production rate in manual assembly lines is significant when producing relatively small batches of different products. This research analyzes this effect and suggests applying work-sharing among the workers in such an environment to improve the time to complete the batch, namely, the makespan. Work-sharing refers to a situation where adjacent workers help each other in order to reduce idle times caused by blockage and starvation. The effect of work-sharing and existence of buffers on the makespan is examined and compared to a baseline situation, with no work-sharing and buffers. We present mixed-integer linear-programing (MILP) formulations, which minimize the makespan and provides optimal work allocation. A numerical study is conducted and the results along with some operational insights are presented.

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*Héctor J. Carlo, Azaria Del Valle-Serrano, Fernando L. Martínez-Acevedo, Yaritza M. Santiago-Correa and Iris F.A. Vis*

A recent trend in container ports is to operate dual non-passing Automated Storage Cranes (ASCs) that collaborate to serve storage and retrieval requests from opposite ends of a storage block. Since the ASCs are unable to pass each other, there is an exchange zone that serves as a temporary storage location so that one crane can start a request and leave it to the other crane to complete it. In this study, twelve priority rules are introduced and evaluated to determine which rule minimizes the total makespan for serving all requests, given the sequence in which each ASC will serve the requests. Preliminary results from 12 randomly generated experiments indicate that the priority rules favoring the crane furthest away from the origin of the next request (LonOri) and the longest individual completion times (LonTot) outperformed all other rules in terms of the average percent difference with the best found solution and in terms of the percent of times the priority rule yield the best found solution. Also, combining priority rules AdvFun and LonRem yields the best makespan in 11 of the 12 (91.67%) problem instances tested. Results of this study transcend container ports as it is applicable to any material handling system composed of non-passing MHE and that has pickup/deposit points at the ends of the system.

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*Andres L. Carrano, Reyhan Erin and Moises Sudit*

One of the major challenges faced by manufacturing companies is to remain competitive in dynamic environments, where fluctuations in customer demand and production rates require systems capable of adapting in a practical and economical way. A U-shaped production cell is considered one of the most flexible designs for adapting the workforce level to varying conditions. However, re-balancing efforts are time consuming and often require a new work allocation and line design. In this paper, a two-stage MIP model to determine the best cell design under varying workforce levels is proposed. The model seeks to maintain proportionality between throughput and the number of workers. Computational experiments considering various line configurations (up to 19 stations) and workloads (up to 79 tasks) are performed. The results show the proposed algorithm provides excellent results for all small and medium size problems addressed in this study, as well as for certain configurations of large problems. This approach can be used to generate lookup tables of line designs to help with quick reallocation of worker assignments on the shop floor and with minimal disruption.

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*Kimberly P. Ellis, R. Steven Roesch and Russell D. Meller*

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*Bill Ferrell and Selina Begum*

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*Kai Furmans, Eda Özden, Judith Stoll, Martin Epp, Thorsten Schmidt, Ingolf Meinhardt and Frank Schulze*

In this paper, we present a method for the performance evaluation of material handling systems in an early planning stage. We are mapping typical material handling elements onto stochastic analytical models. Our intention is to build a toolbox of material handling modules that allows a fast analysis of typical continuous conveying systems. The tool should enable the identification of bottlenecks and the computation of lead time distributions for intra-logistic systems.

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*Amir Hossein Gharehgozli, Yugang Yu, René de Koster and Gilbert Laporte*

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*Marc Goetschalckx, Edward Huang and Pratik Mital*

The design and planning of major material handling systems belongs to the class of systems design problems under uncertainty. The overall structure of the system is decided during the current design stage, while the values of the future conditions and the future planning decisions are not known with certainty. Typically the future uncertainty is modeled through a number of scenarios and each scenario has an individual time-discounted total system cost. The overall performance of the material handling system is characterized by the distribution of these scenario costs. The central tendency of the cost distribution is almost always computed as the expected value of the distribution. Several alternatives can be used for the dispersion of the distribution such as the standard deviation and variance. In this study the standard deviation of the cost distribution is used as the measure of the risk of the system. The goal is to identify all configurations of the material handling system that are Pareto-optimal with respect to the tradeoff between the expected value and the standard deviation of the costs; such Pareto-optimal configurations are also called efficient. The final selection of the material handling system for implementation can

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*Yeming Gong and René de Koster*

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*Kevin R. Gue and Onur Uludağ*

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*Sunderesh S. Heragu, Banu Y. Ekren, Gerald W. Evans and John S. Usher*

Warehouses play a critical role in supply chains. They serve as a vital link between manufacturers and customers. In this study, we investigate performance of the largest warehouse (Eastern Distribution Center - EDC) of the Defense Logistics Agency (DLA) located in New Cumberland, PA and propose a near optimum design for the receiving area of the warehouse to improve its performance. First, we develop a simulation model of the system. Second, we interface an optimization model with the simulation in order to optimize the number of people working at the induction stations. In the optimization model, our goal is to minimize the average cycle time of a material type. Last, we re-design the existing system based on results from the optimization. The simulation and the optimization models are developed through the use of ARENA 13.9 and OptQuest.

**Knowledge-Based Methods For Efficient Material Handling Equipment Development ...**  
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*Dirk Jodin and Christian Landschützer*

This paper focuses on the Knowledge-based engineering (KBE) method and general Knowledge-based technologies for automated design of material handling products. As in vehicle and aerospace engineering this is a widespread technology, the authors try to introduce the main benefits of KBE for the material handling equipment design. The benefits of KBE, as faster and more accurate (safer) product development, customized products and knowledge of employees captured within a knowledge management system, let KBE hold many promising possibilities within, to deal with nowadays demands on engineering development, driven by cost reductions and time shortcuts.

The authors introduce the actual stage of KBE and its methodologies within engineering development complemented by some critical remarks. There will be shown three different examples of realized KBE projects for material handling equipment, focusing on different levels of automated system the fully automated design of wire rope drums, driven only by some few input parameters specified in a graphical user interface (GUI). Furthermore the automated basic assembly layout for drive components of an AS/RS is shown. The automated layouting and basic design work for shelves and AS/RS within a complete storage systems by a GUI driven input procedure shows the advantages of KBE, for here e.g. in a very fast basic layout design for early stage cost estimation.

The authors will give an outlook of forthcoming work and present ideas to develop an appropriate methodology or working environment for the use of knowledge technologies in material handling design. They focus on the necessary steps and sources to provide, capture and use engineering knowledge and will introduce ideas for software tools to support the use of captured knowledge in automated material handling design.

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*Eva Klenk, Stefan Galka and Willibald A. Günthner*

In-plant milk run systems are a transport concept for in-plant material delivery which is becoming more and more applicable especially in the automotive industry. This is due to the system characteristic of providing materials in small lot sizes and with high frequency. As there is a number of different milk run concepts applied and there are several parameters influencing the efficiency and stability of these systems, this paper aims at presenting an overview of common concepts and their properties together with key figures based on an empirical study. The concepts are further analyzed and evaluated with respect to resulting lead times and stability

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*Ananth Krishnamurthy, Sanket Bhat and Debjit Roy*

At a disaster affected region, relief centers distribute critical supplies and aid to the affected victims. Unlike traditional distribution centers, relief centers experience significant 'crowd effects' due to the sudden influx of victims in a confined space. Using knowledge from studies on pedestrian traffic flow, specialized state dependent queuing models are developed to model the flow of victims along the walkways setup at a relief center. The underlying queuing network model is analyzed to derive expressions for the average times that victims experience before they receive the service at the relief center. The research shows that crowd density effects lead to significant increase in congestion and queuing delays underscoring the importance of developing specialized queuing models that assess the impact of congestion effects on alternative layouts of relief centers.

## **A Multi-Objective Optimization Approach For Designing Automated Warehouses ...280**

*Tone Lerher, Matej Borovinšek, Iztok Potrč and Matjaž Šraml*

A multi objective optimization of automated warehouses is discussed and evaluated in present paper. Since most of researchers in material handling community had performed optimization of decision variables with single objective function only (usually named with minimum travel time, maximum throughput capacity, minimum cost, etc.), the multi objective optimization (travel time – cost – quality) will be presented. For the optimization of decision variables in objective functions, the method with genetic algorithms is used. To find the Pareto optimal solutions, the NSGA II genetic algorithm was used. The main objective of our contribution is to determine the performance of the system according to the multi objective optimization technique. The results of the proposed model could be useful tool for the warehouse designer in the early stage of warehouse design.

## **Refurbishing And Recycling Facilities Design Methodology.....303**

*Suzanne Marcotte and Benoit Montreuil*

To design a facility, expected flows between the resources is one of the most important input. Flows are usually calculated given some statistics of previous periods or from the expected demand and the process required. However, in a refurbishing and recycling facility, flows are very fluctuating and not trivial to predict. The quantity produced by such facility not only depends on the demand but also on the supplies which are returned products under guaranty or discarded products after their end-of-use. The uncertainty and the variability on these supplies are often higher than the one on the demand which makes it even more complex to calculate the expected flows. This article contributes a methodology for designing such recycling and refurbishing facilities that are concurrently efficient and robust. It provides an empirical illustration of the methodology through a computer refurbishing and recycling facility case study.

## **Impact Of Rotated Aisles On Travel Distance In Manufacturing Facilities.....319**

*Dale Masel and Samantha Hedges*

The primary metric to evaluate the quality of facility layout is the total distance traveled to move materials around the facility. This distance is dependent on the location of each department in the facility and also on the aisle design. However, most research has only examined the location of the departments in setting up the facility layout and not the location of the aisles. In addition, research on facility layout typically assumes that the aisles will follow the boundary of the facility and are always parallel to the exterior walls of the facility. This assumption reflects the typical practice in how facilities are actually designed, but does not necessarily produce the optimal layout, for minimizing the total distance traveled.

This paper presents a methodology for designing the layout of a facility when the restriction of keeping aisles parallel to walls is eliminated. The methodology allows the main aisles in the layout to be rotated so that they are not parallel to walls, to provide a more direct route between some departments and reduce overall travel distance.

**An Object Oriented And Axiomatic Theory Of Warehouse Design.....328**  
*Leon F. McGinnis*

Despite the conceptual simplicity of warehousing, the development of integrated computational tools for warehouse design has remained an elusive goal. In recent years, there has been some progress toward this goal, with a growing body of research addressing topics as diverse as the design process itself, decision support for specific design decisions, warehouse representation, integrating warehouse representation and analysis, and conceptual approaches for developing integrated warehouse design tool chains. Until now, however, there has not been a suitable warehouse design theory that would provide an integrating framework for all these disparate efforts.

This paper presents an object-oriented and axiomatic warehouse design theory. Key assumptions about the warehouse to be designed are stated as axioms, with appropriate formalisms. Using the axioms and the associated notation, a formal specification of warehouse requirements can be stated, a formal description for a warehouse design can be given, and methods can be developed for testing the warehouse design against the requirements. Moreover, the axioms provide the foundation for identifying essential warehouse design decisions, and formally stating both the criteria for evaluating those decisions and the constraints limiting those decisions.

The paper provides a conceptual and rigorous bridge between the process-oriented research on warehouse design process or workflow, and the mathematically oriented approach to warehouse design reflected in the vast literature on mathematical models and algorithms for specific warehouse design and/or operating decisions

**Functional Design Of Physical Internet Facilities: A Road-Based Transit Center .....347**  
*Russell D. Meller, Benoit Montreuil, Collin Thivierge and Zachary Montreuil*

In their 2010 IMHRC paper, Montreuil, Meller and Ballot proposed a set of facility types that would be necessary to operate a Physical Internet, which they termed “ $\pi$ -nodes.” This paper is part of a three-paper series for the 2012 IMHRC where the authors provide functional designs of three PI facilities. This paper covers a road-based transit center, or road-based  $\pi$ -transit. The mission of a  $\pi$ -transit node is to enable the transfer of  $\pi$ -carriers from their inbound to outbound destinations. Therefore, a roadbased  $\pi$ -transit provides a mechanism to transfer  $\pi$ -trailers from one truck to another. The objective of the paper is to provide a design that is feasible to meet the mission of this type of facility, identify ways to measure the performance of the design, and to identify research models that would assist in the design of such facilities. The functional design is presented in sufficient detail as to provide an engineer a proof of concept.

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*Benoit Montreuil, Russell D. Meller, Collin Thivierge and Zachary Montreuil*

As part of the 2010 IMHRC, Montreuil, Meller and Ballot proposed a set of facility types that would be necessary to operate a Physical Internet (PI,  $\pi$ ), which they termed  $\pi$ -

nodes. This paper is part of a three-paper series for the 2012 IMHRC where **the authors** provide functional designs of three PI facilities. This paper covers a unimodal road-based crossdocking hub designed specifically to exploit the characteristics of Physical Internet modular containers so as to enable the efficient and sustainable transshipment of each of them from its inbound truck to its outbound truck. The objective of the paper is to provide a design that is feasible to meet the objectives of this type of facility, identify ways to measure the performance of the design, and to identify research models that would assist in the design of such facilities. The functional design is presented in sufficient detail as to provide an engineer a proof of concept.

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*Jörg Oser and Thomas Drobir*

In multi-aisle AS/RS systems one or more S/R machines serve several aisles with storage racks on both sides of the aisle. An important feature of multi-aisle configurations are aisle changing devices with transfer cars, curve guided aisle switching mechanisms or closed loop rail tracks with curved sections for a two-aisle layout. These systems offer an economic solution, when the number of storage and retrieval transactions is low and storage volume is high. One or several S/R machines each serving a specified number of aisles can be arranged in various layouts to meet the required storage capacity and throughput.

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*Jennifer A. Pazour and Russell D. Meller*

Picking machines, also known as remote-order-picking systems, are an example of a stock-to-picker piece-level order-fulfillment technology that consists of two or more pick stations and a common storage area. An integrated closed-loop conveyor decouples the pick stations from the storage area by transporting the needed totes to and from the storage area and the pick stations. We develop a probabilistic model capable of quantifying the inventory differences between order-fulfillment technologies that pool inventory with technologies that do not pool inventory. To determine the throughput of a picking machine, we develop a methodology that incorporates existing analytical models for the picking machine's subsystems. We present a case study comparing a picking machine to a carousel-pod system to illustrate how a manager could use our methodology to answer system design questions. Finally, we present conclusions and future research.

**Understanding And Modeling Sustainability Issues In Facility Logistics** .....465

*Brett A. Peters and Astrid Garcia Ramos*

Environmental issues have been the focus of much discussion and debate. In light of environmental concerns, many companies have focused on creating sustainable products and systems. While there is still much disagreement about what is "sustainable," there is a lot of on-going activity cover a wide range of areas and topics. However, relatively speaking, there is much less attention and activity within a facility logistics context. In this paper, sustainability issues related to facility logistics are explored. An overview of existing related research across a range of areas is provided. Major issues of concern for facility logistics will be discussed and

appropriate decision tradeoffs will be characterized to develop potential research issues related to sustainability with the context of facility logistics and closely related topics.

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*Sarah Root and Hector A. Vergara*

Driver retention has been cited as one of the primary motivating factors for the implementation of relay networks for full truckload transportation. The strategic design of such networks considering important operational factors such as limitations on load circuitry and equipment balance has been previously studied in the literature, however driver scheduling has not been explicitly considered in routing decisions. We present a prescriptive modeling approach that uses mathematical programming in conjunction with a decomposition-based algorithm to select feasible duties that consider current hours-of-service regulations and assign them to drivers domiciled at relay points in the network to cover truckload demands during a given planning horizon. Computational results are presented for randomly generated problem instances along with areas for future research.

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*Debjit Roy and René de Koster*

Due to rapid growth in foreign trade using sea vessels, there is a growing focus in improving the infrastructure and operational efficiencies at the container terminals. Particularly, the operational responsiveness of loading and unloading of containers, affects the vessel idle times and profitability of the shipping liners. In this research, we determine optimal stack layout design, which minimizes the container unload times using Automated Guided Vehicles (AGVs). To analyze alternate stack layout designs, we develop integrated queuing network models that capture the stochastic interactions among the container terminal processes (quayside, vehicle transport, and stackside), and provides realistic estimates of expected container unload throughput times.

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*Zaki Sari and Nadir Hakim Bessnoui*

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**Process Analysis For Material Flow Systems .....538**  
*Thorsten Schmidt, David Wustmann and Robert Schmalzer*

This paper describes a generic approach for analysis of internal behavior of logistic systems based on event logs. The approach is demonstrated by an example of event data from the simulation model of an automated material handling system (MHS) in a

manufacturing company. The purpose of the analysis is the identification of design and operation problems and their causes, prospectively. As a result, the simulation model developer obtains the condensed and ranked information on events. These events describe the internal system behavior with anomalies pointing at either possible problems or capacity reserves.

**An Extended Double Row Layout Problem .....554**

*Alice E. Smith, Chase C. Murray and Xingquan Zuo*

The double row layout problem (DRLP) seeks to determine optimal machine locations on either side of an aisle, where the objective has been defined as the minimization of material flow cost among machines while meeting machine clearance constraints. In this paper, we extend existing DRLP formulations in two respects. First, we consider the minimization of layout area besides the usual material flow cost objective. Second, we present a mixed integer linear programming formulation that permits non-zero aisle widths. This new formulation also includes new constraints that eliminate layout "mirroring," thus reducing the solution space significantly and thus solution times. Although small-scale problems may be solved optimally by commercial integer programming solvers, solution times are highly sensitive to the number of machines in a layout. A tabu search heuristic is shown to work well for moderately-sized problems. Numerical examples demonstrating the impact of both flow and area objectives, as well as aisle widths, are included.

**How To Choose An Order-Picking System.....570**

*Detlef Spee, Marita Ellinger and Tim Geißen*

Order-Picking-Systems are the parts of material flow systems, which have the largest variance of deployment alternatives. Since a long time there have been many attempts to systematize the way of identification of the order-picking-system that the "correct" solution can be found.

The previous methods could not be enforced universally. Thus nearly all the material handling system suppliers have their own approach to find the right system, as it turned out at a market analysis of Fraunhofer IML.

With the presented concept of finding a solution, a structured, fast method for system identification shall be presented. A stepwise approach to the system definition reduces the solution space for the next level of detail and thus the processing effort. This procedure should be defined in that way, that it will become a module or component in the integrated approach of warehouse CAD (or the warehouse design workflow) in future. This principle is currently being developed by the GATech and the Fraunhofer IML.

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*Haldun Süral and Melih Çelik*

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time. We also propose simple heuristics for this problem inspired by those put forward for parallel-aisle warehouses. Our computational results reveal that under certain cases, fishbone design can perform as high as 30% worse than an equivalent parallel-aisle layout, and a modification of the aisle-by-aisle heuristic produces good results compared to other heuristics.

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*Ching-Jung Ting and Amanda G. Rodríguez López*

In this paper, we consider the integration of dock assignment and truck scheduling problem at cross-docking terminals. The problem is first formulated as a 0-1 integer programming model. Since both dock assignment and truck scheduling problems are NP-hard, its integration is more difficult to solve. Thus we propose reduced variable neighborhood search (RVNS) algorithms to solve the problem. Computational experiments are carried out on four set of instances. The results show that RVNS is capable of finding good solutions in a much shorter computation time when it is compared with optimization solver Gurobi's solutions.

**Estimating Travel Distances And Optimizing Product Placement For Dedicated Warehouses With Manual Picking .....622**

*Uday Venkatadri and Sachin Kubasad*

This paper looks at the problem of estimating travel distances for rectangular warehouse sections with manual picking. This study was motivated by a real-life case in the food and beverage industry where case picking occurred in a rectangular section of the warehouse. In particular, we are interested in estimating the distance travelled by an order picker whose picking route begins and ends at a single depot. One of the assumptions in many distance approximation papers is that any location is equally likely to be picked. However, this assumption is unrealistic in the case of dedicated warehouse layout, where products are located strategically in order to minimize total distance.

The frequency of accessing a pick location can be estimated from the order history table of a WMS. This in turn can be translated into the probability of accessing certain locations. Under the simplifying assumption that there is no backtracking in the aisles, we build a probability tree to estimate the distance travelled by the order picker.

From a placement point of view, we present three product assignment (or order slotting) heuristics in this paper, namely the North-North, North-South, and Nearest Neighbour heuristics. Our study shows that there is very little variation between the heuristics in terms of travel distance.

**Dynamic Slotting Optimization Based On SKUs Correlations In A Zone-Based Wave-Picking System.....636**

*LI Yingde and Jeffery S. Smith*

Many exiting slotting methods ignore the picking correlations between Stock Keeping Units (SKUs). In a previous paper, a mix integer program model for dynamic slotting to minimize the pick-wave makespan among all zones under some load balancing constraints was developed. In this paper, we develop an ant colony optimization with

slot-exchange policy (ACO-SE) based on SKU correlation to assign the correlated SKUs to the adjacent slots in the same zone. The ACO-SE deposits pheromones between SKUs, uses local and global pheromone trail updates, and controls pheromone accumulation using the Max-Min rule. The main heuristic information is set to the correlation strength and the pick-times are introduced as the assisted heuristic information. A hybrid search mechanism was adopted to improve to global search efficiency. A slot exchange policy was proposed to re-slot the correlated SKUs based on the picks to ignore the proximity of SKUs and to make the farthest SKU for one carton closer to the initial point as far as possible. The promising computational results show that the ACO-SE has perfect convergence and very good CPU time. The solution quality of ACO-SE is always better than the Cube-per-Order-Index (COI), simulated annealing correlation (SA-C) heuristic; it has considerably faster convergence speed than SA-C. The result shows that in zone-based wave-picking system with return touring policy, the exact proximity of SKUs is not critical and that the correlated SKUs can be allocated to any locations along the path from the initial point to the other SKU's location; the correlation strength has no obvious impact on the picking efficiency, but and correlation probability has significant impact on the picking efficiency.

**Open Location Management In Automated Warehousing Systems .....657**  
*Yugang Yu and René de Koster*

A warehouse needs to have sufficient open locations to be able to deal with the change of item inventory levels, but due to ongoing storage and retrieval processes, open locations usually spread over storage areas. Unfavorable positions of open locations negatively impact the average load retrieval times. This paper presents a new method to manage these open locations such that the average system travel time for processing a block of storage and retrieval jobs in an automated warehousing system is minimized. We introduce the effective storage area (ESA), a well-defined part of the locations closest to the depot; where only a part of the open locations –the effective open locations-, together with all the products, are stored. We determine the optimal number of effective open locations and the ESA boundary minimizing the average travel time. Using the ESA policy, the travel time of a pair of storage and retrieval jobs can be reduced by more than 10% on average. Its performance depends hardly on the number or the sequence of retrievals. In fact, in case of only one retrieval, applying the policy leads already to beneficial results. Application is also easy; the ESA size can be changed dynamically during storage and retrieval operations.

**A Study On Storage Allocation In An Automated Semiconductor Manufacturing Facility.....682**  
*Claude Yugma, Stéphane Dauzère-Péres, Ahmed Ben Chaabane, Lionel Rullière, and Gilles Lamiable*

This paper deals with the allocation of storage capacity in the automated material handling environment of a semiconductor wafer manufacturing facility. The impact of the allocation of stockers to machines in semiconductor fabrication facilities (fabs) is very little studied, although it significantly impacts the efficiency of the Automated Material Handling System (AMHS). After motivating and describing the problem of allocating unitary stockers to machines, a first local approach is discussed. We then

propose a Mixed Integer linear Programming model to solve the global problem with two objectives: Minimizing the total maximum travel distance of vehicles and balancing the utilization of unitary stockers. Based on real data, numerical experiments are performed on some small instances. The analysis shows the importance of some parameters and that the two objectives tend to conflict.

**Toward Sustainability, High Density And Short Response Time By Live-Cube Storage Systems .....693**

*Nima Zaerpour, Yugang Yu and René de Koster*

This paper studies random storage in a live-cube storage system where loads are stored multi-deep. Although such storage systems are still rare, they are increasingly used, for example in automated car parking systems. Each load is accessible individually and can be moved to a lift on every level of the system in x- and y-directions by a shuttle as long as an open slot is available next to it, comparable to Sam Loyd’s sliding puzzles. A lift moves the loads across different levels in z-direction. We derive the expected travel time of a random load from its storage location to the input/output point. We optimize system dimensions by minimizing the expected travel time.

**Column Generation For The Container Relocation Problem.....699**

*Elisabeth Zehendner and Dominique Feillet*

Container terminals offer transfer facilities to move containers from vessels to trucks, trains and barges and vice versa. Within the terminal the container yard serves as a temporary buffer where incoming containers are piled up in stacks. Only the topmost container of each stack can be accessed. If another container has to be retrieved, containers stored above it must be relocated first. Containers need to be transported to a ship or to trucks in a predefined sequence as fast as possible. Generally, this sequence does not match the stacking order within the yard. Therefore, a sequence of retrieval and relocation movements has to be determined that retrieves containers from the bay in the prescribed order with a minimum number of relocations. This problem is known as the container relocation problem. We apply an exact and a heuristic column generation approach to this problem. First results are very promising since both approaches provide very tight lower bounds on the minimum number of relocations.

**Evaluation Of Environmental Benefits Of CHE Emerging Technologies By Using LCA.. .....713**

*Nenad Zrnić and Andrija Vujičić*

In the era of climate change combat transport industry is recognized as a sector with one of the largest environmental footprints. A part of transport industry is container shipping and handling division, which is currently growing with the fastest rate. This massive growth of container sector is due to containers pouring from Asia, mainly from China.

Thus, container port operations are also experiencing significant increase in port emissions. This fact puts port authorities in position to find a way to reduce environmental impact of port operations and at the same time withhold increase in number containers being handled.

In response to the demanding task of reducing emissions and increasing TEU numbers Cargo Handling Equipment (CHE) industry offers variety of solutions. In this paper, state-of-the-art technology for Rubber Tired Gantry (RTG) cranes is being analyzed in order to find out the most eco-efficient solution. A conventional RTG crane is compared to hybrid Eco-RTG with super-cap energy storage system and electrified E-RTG crane. The last two solutions represent the latest trend in CHE industry.

The methodology used to carry out RTG cranes environmental impact comparison is Life Cycle Assessment (LCA) outlined in ISO 14040, as a tool which offers possibility to address entire product's life cycle in a consistent way. The obtained results of RTG cranes LCA are presented in accordance to ISO 14040 principles with the highlight on CML and TRACI impact assessment methods.

Based on the obtained results, the recommendations on reducing environmental footprint of ports are done by necessary improvements on RTG cranes. Since, the objective of this paper is twofold, use of LCA methodology as a tool in the early stage of design is promoted due to its possibility to offer preliminary information and details of processes and materials.