⊠ 연구논문

A Design Procedure of Material Handling and Storage Systems for Micro-load AS/RS
- 소형자동창고 물류시스템의 지능적 설계방법에 관한 연구 -

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ABSTRACT

이 논문은 전자 부품 조립산업에서의 통합 물류 시스템의 효율적인 선택과 최적의 설계를 위해 객체지향형 전문가 시스템과 해석적 모델을 결합한 방법론을 제시한다. 물류시스템의 선택과 설계 (마이크로로드 AS/RS 선정)를 위해 지능형 물류시스템 (IMHSS: Intelligent Material Handling and Storage System)을 개발하여, 그 결과를 시뮬레이션 결과와 비교함으로써 지능형 물류시스템 모델의 적합성을 나타내고자 한다.

1. Introduction

The selection and design of material handling systems are complex problems since manufacturing environments have increasingly utilized various highly advanced systems technologies such as computer integrated manufacturing (CIM), just-in-time (JIT), flexible manufacturing systems (FMS), and total quality assurance systems (TQAS). Material handling and storage systems (MHSS) design, which is a sub-category of facilities design, has been a popular topic of study. In the context of facilities design, the opportunity for improvements through automated material handling (NH) is so boundless that the market for automated MH systems exceeds billions of dollars today [13]. Automated material handling and storage systems are also identified as the highest capital expense item in modern factories. Yet it is surprising that large investments are made without carrying out a careful analysis of system operation and performance [16].

Today, the growing trend toward the use of CIM has increased the importance of MHS selection, design, and control. Furthermore, the introduction of JIT concepts and techniques has forced MHS vendors and designers to develop new material handling alternatives and new design approaches such as small lot sizes, mixed-model assembly, decentralized storage, standardized containers, deliveries to the points of use and pulling approaches.

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This paper describes a methodology for selection, design, and control of integrated MHSS. The methodology combines expert systems, analytical models, and object-oriented approaches to select feasible material handling and storage alternatives and generate the best design and control strategies. Although many researchers have been using artificial intelligence techniques in the design of MHS, no work has been performed in the application of object-oriented approaches, knowledge-based systems, and analytical models for selection, design, and control of integrated MHSS [9,10,14,15]. Object-oriented representation and knowledge-based system using the blackboard are built so as to incorporate both its open system and multiple knowledge sources. In contrast, in the procedural closed system, the facility designer has no control over objects at the programming level. The reason for utilizing an object and knowledge framework for MHSS is to find a suitable data structure which separates abstract behavior from implementation.

2. Solution Methodology

The methodology proposed in this paper includes an object-oriented model which provides a conceptual framework for knowledge representation. In addition, the blackboard system is used as a problem-solving framework for multiple expert systems. Using the blackboard system, problems can be accessed by different knowledge sources and are solved in a systematic fashion under the master controller. The solution methodologies used are both an algorithmic and AI approach. A hybrid AI problem-solving (object-oriented and knowledge-based) approach is used which incorporates hierarchical abstraction in the design process [17,18].

An Intelligent Material Handling and Storage System (IMHSS) has been developed from this methodology, which consists of three subsystems: the material handling (MH) selection expert system, the MH design expert system, and the MH control expert system. The first subsystem generates all feasible MHSS alternatives[8]. The second subsystem designs the selected alternatives(s) generated by the first stage. This module provides an initial design, and an analytical module is used to generate a detailed design. The last subsystem selects the best control strategy for the MHSS.

Selection, design, and control of integrated MHSS is a complex task necessary to conceptualize, design, and evaluate a total solution for the overall material handling problem. Many different types of knowledge, therefore, need to be represented for the IMHSS to deal with large-scale automated handling/storage systems.

The object-oriented paradigm is used for knowledge representation of the IMHSS model which supports modularity, multiple reasoning, inheritance, message-sending communication, and hierarchical structures. The object-orientation for knowledge representation can be considered as an advanced representation originated from a frame-based system. The concept of frames and slots very much resembles objects and instance variables in Smalltalk-80. Objects and frames are literally almost the same idea. The idea of frames is to group pieces of knowledge that characterize a certain concept such as a class of objects with a number of properties (instance variables in Smalltalk-80).

Although MHSS design can be achieved through a traditional approach, an integrated approach is a more effective method to combine selection, design, and control issues into a single organization. Material handling design expert system (MAHDES) is one of the IMHSS systems to ensure and integrate these design issues in a hierarchical mode. A macro level of design issues such as the preceding MH equipment, types of assembly flows, and number of systems are resolved while a micro level (detailed) of design issues is addressed in an analytical form, which will be discussed in the next section.

The functional diagram and a generic design scheme of IMHSS are shown in Figure 1 and 2 respectively. To show how the design procedure can be used to make the selection, design, and control of MHSS, the multiple design stages shown in Figure 2 have developed.

In this paper a micro-load AS/RS [5] has been chosen as an example of a feasible alternative to show both the feasibility and potential of the design methodology and procedure for integrated MHSS. A cost model for selecting the best design is also included. The design procedure for a micro-load AS/RS is described as follows:

1. determine assembly operation requirements
2. select feasible integrated MHSS for assembly
3. determine high level design issues such as preceding MH equipment, number of micro-load AS/RS, and type of layout
4. determine detailed design using analytical model, and
5. determine the best alternative based on the cost model.

3. IMPLEMENTATION

With the methodology discussed in the previous section, IMHSS has been developed for electronics assembly environment. In electronics assembly industries, new technological and design solutions are needed more urgently than others due mainly to short product life cycles, variability of demand, smaller order sizes, and lower product prices. Despite the growing use of automated MHSS that support JIT production in electronics assembly companies, only a few procedures for the integration of selection, design, and control decisions of these systems are currently available [3,7,11].

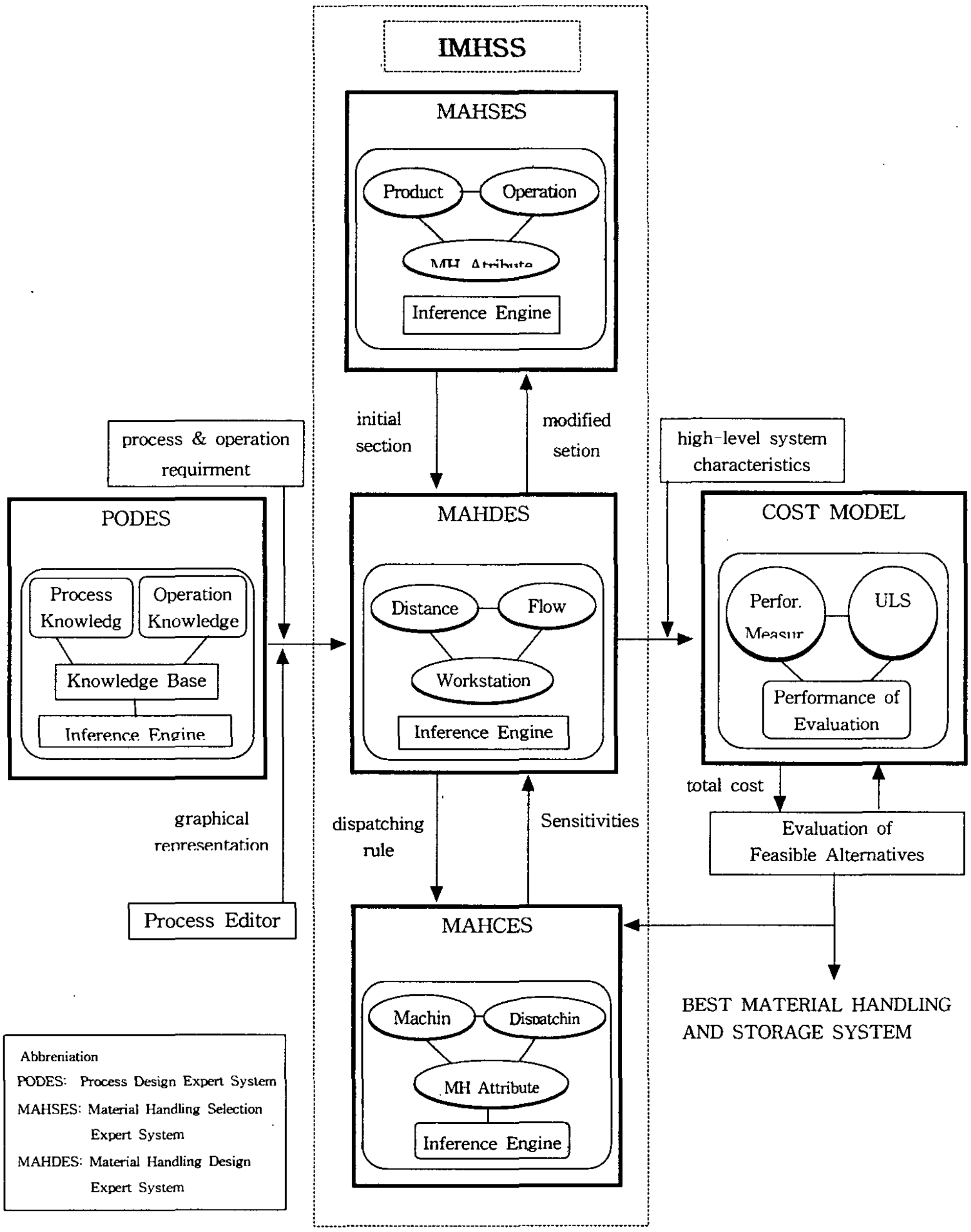


Figure 1. Functional Diagram of IMHSS

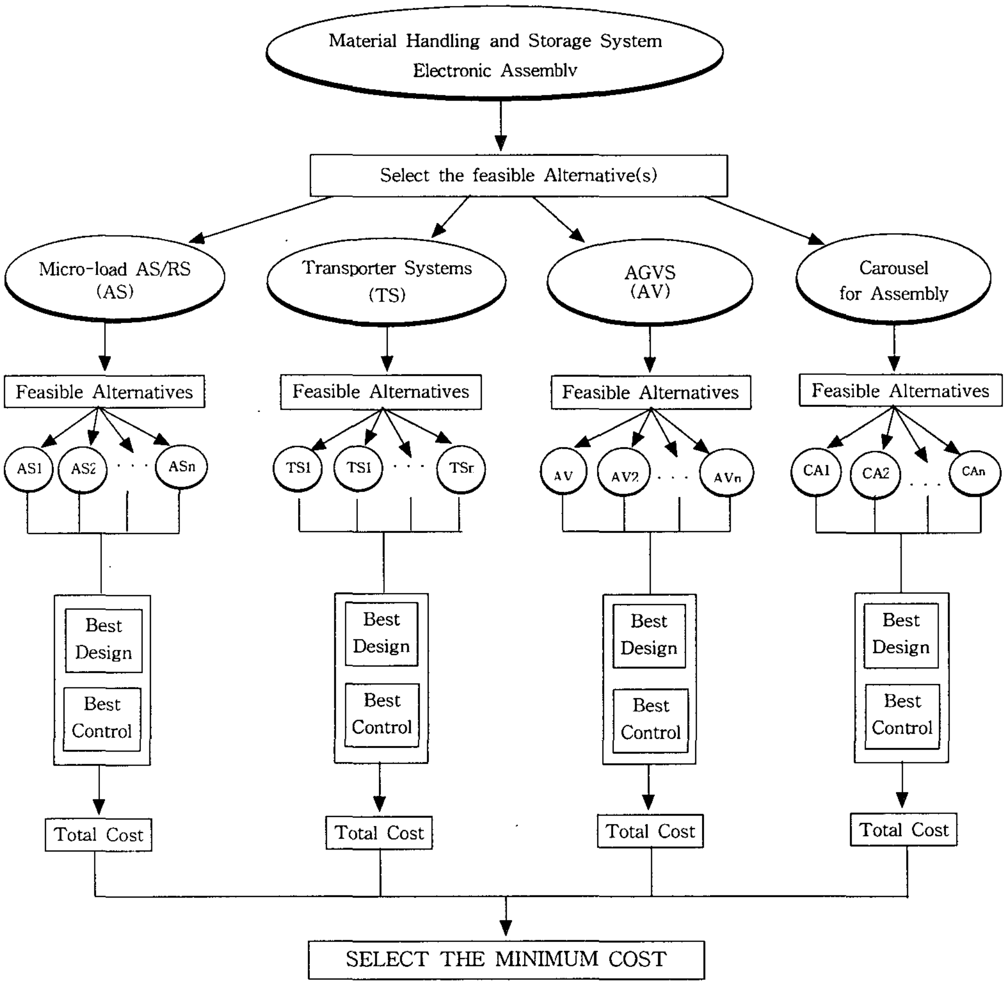
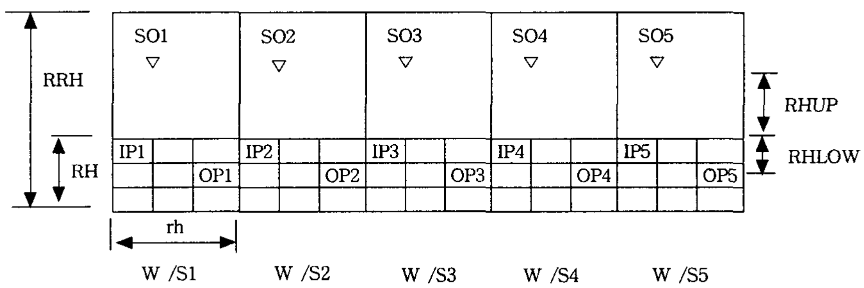


Figure 2. Generic Design Procedure of IMHSS



KEY:

RRH: Number of rows of racks

rh: Number of openings per W/S

RHUP: Height of Upper Rack

RHLOW: Height of Lower Rack

Figure 3. Side View of the Micro-load AS/RS

3.1 Selection of MHSS

The material handling selection expert system named MAHSES [4] helps the facility designer in the selection of the most appropriate MHSS for electronic assembly environments, so as to meet handling requirements and design constraints. (see [4] for details)

There are potentially a large number of types of MHSS that can be used for electronic assembly operations.

Following is a list of MHSS alternatives considered by the system.

1. micro-load AS/RS
2. carousel for assembly
3. transporter with flow rack (FR)
4. transporter with carousel (C)
5. transporter with mini-load AS/RS (ML)
6. light-load automated guided vehicle system (with FR, C, or ML)
7. roller conveyor with spur (with FR, C, or ML)
8. cart-on-track conveyor (with FR, C, or ML)
9. power-and-free conveyor (with FR, C, or ML)
10. bench assembly (with FR, C, or ML)

3.2 Design of MHSS

In MAHSES a micro-load AS/RS has been selected for analysis and design due to its popularity in the electronics industry. Material handling design expert system, named MAHDES, has been developed and shows that the hierarchical approach using hybrid techniques -- expert systems and analytical method -- is feasible and provides insight into design problems and solution. It is composed of two models. Model I (knowledge-based) includes the selection of assembly layout and configuration while model II (analytical) addresses unit load sizes and performance measures of each alternative.

3.2.1 Production Scenario

The procedure described in this paper is partially based on the design procedure developed by McGinnis and Trevino [12]. Changes have been made to the model to relax some of the assumptions using AI techniques. The objective of this procedure is to determine the unit load size and rack design that achieve daily assembly requirements within storage and retrieval (S/R) machine capacities, and that minimizes annual total cost of the system.

Production and withdrawal kanbans are used to control the production schedule. Production can be started only when a workstation receives a production kanban from another workstation according to the production routing. The production kanban is sent to a workstation or assembly line whenever a container of subassemblies is retrieved by the succeeding workstation in the system. When more parts are needed from one of the assembly stations supported by the system, a container of parts is retrieved from one of the input ports (IP) and a withdrawal kanban (electronic signal) is sent to the S/R machine. The S/R machine retrieves a full container of parts from the storage buffer of the preceding workstation as indicated (SO) in Figure 2. When a container of parts is completed, it is deposited in the output port (OP) and a signal is sent to the S/R machine to move the container to the storage area located in the upper part of the rack section (SO) in front of the workstation. Figure 3 represents the kanban/material movement between two workstations in the micro-load AS/RS.

3.2.2 Model I (Knowledge-based)

In MAHDES, model I serves as one module of IMHSS to generate only the macro level of design decisions among which are described the following:

1. number of systems,
2. type of layout,
3. type of flow, and
4. preceding material handling equipment.

The output of MAHDES provides input to the macro level of design issues, such as performance measurements. The knowledge embedded in MAHDES is facts and rules. Five types of material flows are identified to determine an assembly flow as shown in Figure 4: single-linear, parallel, multiple-parallel,
circular-U, and S-shape. There are four classes of rules in MAHDES as follows:

Class 1: rule for initially starting up the expert system,
Class 2: rules for determining the preceding MH equipment,
Class 3: rules for determining the type of assembly flows, and
Class 4: rules for determining the number of systems.

MAHDES starts its consultation session by typing "startUp" in the MAHDES interaction window. Then class 2 rules require the user to input the type of path and distance between the preceding department (process) and the target department. Based on this information, suitable preceding MH equipment can be suggested. Two sample rules in class 2 are shown below:

Rule distanceShort
IF: the distance between the preceding department (process) and target department is less than 30 feet.
THEN: the distance is considered to be short.

Rule cart1
IF: the type of path is variable
AND the distance between two points is short
THEN: use Light-load AGVs for the preceding MH equipment and apply Rule "straight-flow- AGVs" and "XT-flow-AGVs".

From the above rules, it is observed that if the type of path between two points is not fixed, and the distance between two points is considered to be short as suggested by the rule "distance-short", an AGV is recommended as the appropriate preceding MH equipment. The logic of this class of rules is similar to that of MAHSES to select the most appropriate MHSS in electronic assemblies. Class 3 rules are used to determine the type of assembly flows, which is a function of material flows. For example, if an AGV is used, the type of material flow is most likely linear, parallel, and multiple-parallel. In this class, five types of assembly flow are identified as shown in Figure 4 to aid further decisions in the analytical model, because it is hard to determine this decision at the analytical level. Class 4 rules are used for determining the number of systems (totestacker) based on three parameters: types of assemblies (progressive, testing, and burning), number of workstations, and size of workstations. Since these decision variables may not be obtained at an analytical level, a knowledge-based system can be used to represent the knowledge and experience of the designer. Class 4 consists of 10 rules. The decisions made by the rules in MAHDES are based on several critical criteria which are summarized as follows:

1. distance information,
2. type of paths,
3. type of assemblies,
4. number of workstations, and
5. size of workstations.

MAHDES is one of the IMHSS systems to ensure and integrate these design issues in a hierarchical mode. A macro-level of design issues as described above are resolved while a micro-level (detailed) of design issues is addressed in an analytical form, which will be discussed in the following section.

3.2.3 Model II (Analytical)

The objective of the procedure is to determine design combinations that satisfy S/R machine capacity, workstation capacity and throughput requirements, and select the design that minimizes a total annual cost (TC) function. The TC function includes storage, setup, handling, and inventory carrying costs. The minimum TC is determined by an interactive procedure, and a computer program has been developed to provide design issues. Specifically, the procedure is used to address the following decisions: [see Figure 8]

1. unit load size per product,
2. throughput requirements,
3. rack design, and
4. number of input ports and storage openings per workstation.

To address the above decisions, the following performance measures are estimated in the analytical procedure:

1. average WIP inventory carried,
2. S/R machine utilization,
3. S/R machine throughput,
4. number of production and withdrawal kanbans, average utilization per workstation, and total cost.

3.2.3.1 Assumptions

1. The main workpart of N products flows from workstation to workstation internally. Other parts and components are delivered to each workstation externally.
2. Completed product totes are stored in the storage opening (SO) located above the I/O ports unless they are needed by another workstation at the time of retrieval. In this case, the S/R machine sends the tote to the workstation input port (IP) that has requested the material immediately.
3. The products are stored in the workstation storage opening buffer using a randomized policy.
4. Routings are fixed, but routing sequence depends on the type of product requested.
5. Deterministic daily production requirements are assumed.
6. ON/OFF switches are used on workstation I/O ports and storage openings to communicate handling requests to the S/R machine or production requests to workstations, respectively.
7. The requests received by the S/R machine are served using a first-come-first-served (FCFS) discipline. The S/R machine receives two types of commands:

- requests from input ports asking for workparts from the storage opening buffer of the preceding workstation (the S/R machine picks up a tote containing the workparts requested random from the storage buffer), and
- requests from output ports asking to store workparts in the workstation storage buffer (the S/R machine stores the totes randomly within the dedicated workstation storage buffer).

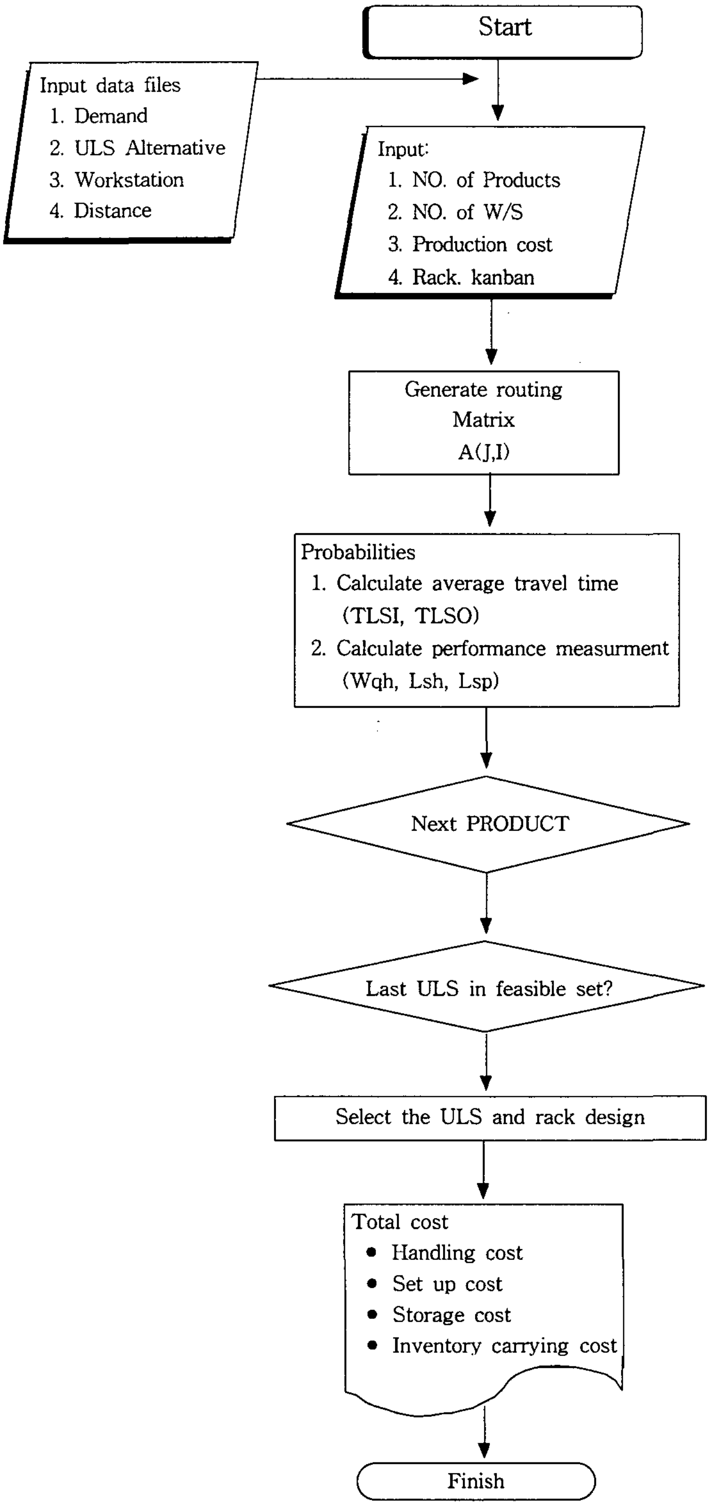


Figure 8. Design Procedure

3.2.3.2 Nomenclature

C_{ij} = Production cost for product i in W/S j
Cv_{ij} = Variable production cost for product i in W/S j
D_i = Demand for product i
F = Annual inventory carrying cost rate
$HCPH$ = Handling cost per hour
HC_{ij} = Handling cost for product i in W/S j per year
HR_{ij} = Handling requirements per product I per W/S j
$ICCij$ = Inventory carrying cost for product i in W/S j
$Lshi$ = Average number of requests in handling system of product i
Lsp_j = Average number of production requests of products in W/S j
N_i = Number of workstation that product i visits
NPK_{ij} = Number of production kanbans for product I in W/S j
NWK_{ij} = Number of withdrawal kanbans required for product i in W/S j
$NPPY$ = Number of periods per year
NUL = Number of unit load size
NWS = Number of workstations (M)
SC_{ij} = Storage cost per product i in W/S j per year
$SCPCPY$ = Storage cost per tote per year
$SETC_i$ = Setup cost per product i in W/S per year
$SETC_{ij}$ = Setup cost per product i in W/S j per year
$SETCPH$ = Setup cost per hour
t_{ij} = Setup time for product i in W/S j
ULS_i = Unit load size of product i

3.2.3.3 Cost model

The components of the total cost are described as follows:

1. The setup cost per product ($SETC_i$) is obtained as a function of the setup time for product *i* in *W/S j*.

Equation (1) summarizes the setup cost, in which the setup cost per hour is assumed given :

$$SETC_{ij} = t_{ij} \times \frac{D_i}{ULS_i} \times SETCH \times NPPY \qquad (4\text{-}1)$$

$$SETC_i = \sum_{j=1}^{NWS} SETC_{ij}$$

$$SETC_i = \sum_{j=1}^{NWS} t_{ij} \frac{D_i}{ULS_i} \times SETCH \times NPPY$$
$$= \frac{D_i}{ULS_i} \times SETCH \times NPPY \times \sum_{j=1}^{N_i} t_{ij}$$

2. The handling cost per product (HC_i) is also another important factor that needs to be minimized in this design procedure. It is a function of the handling requests from each output port and storage opening, respectively. The handling cost per hour is assumed given. Equation (2) is used to obtain the annual handling cost (See [I])for details.

$$HC_{ij} = HR_{ij} \times HCPH \times NPPY \times \frac{D_i}{ULS_i}$$

$$HC_i = HPCY \times NPPY \times \frac{D_i}{ULS_i} \times \sum_{j=1}^{N_i} HR_{ij}$$

3. The storage cost can be obtained by multiplying the number of production and withdrawal kanbans times the storage cost per container per year, as equation (3) indicates:

$$SC_{ij} = SCPCPY \times (NPK_{ij} + NWK_{ij})$$

$$SC_i = SCPCPY \times \sum_{j=1}^{N_i} (NPK_{ij} \times NWK_{ij})$$

4. The inventory carrying cost per product (ICC_i) can be also obtained by multiplying the annual inventory carrying cost rate times annual work-in-process in both the storage buffer and the input port times the variable cost per product for each workstation:

$$ICC_{ij} = F \times Cv_{ij} (AWSO_{ij} + AWIP_{ij})$$

$$ICC_{ij} = F \times \sum_{j=1}^{N_i} Cv_{ij} (AWSO_{ij} + AWIP_{ij})$$

$$AWSO_{ij} = (NPK_{ij} - Lsp_j) \times ULS_i$$

$$AWIP_{ij} = (NPK_{ij} - Lsh_j) \times ULS_i$$

5. Equation (5) is used to obtain the total cost per product (TCi). Equations (1) through (4) are used to obtain the cost elements in equation (5):

$$TC_i = SETC_i + HC_i + STOC_i + ICC_i$$

From this analytical design, the following remarks can be drawn: It would be better to increase the unit load size as much as possible to minimize the total cost, which is the objective function. Performance measures should be checked to meet the requirements, after which storage openings are determined.

3.3 Control of MHSS

Determining optimal dispatching rules is a difficult task because successive service times are not independent and the stochastic nature of the problem [12]. For these reasons, expert system technology can be applied to solve the problem of selecting dispatching rules of the S/R machine for the micro-load AS/RS. The expert system named MAterial Handling Control Expert System (MAHCES) has been developed to select the most suitable vehicle dispatching rule. MAHCES is also capable of checking 'what if' some parameters vary for the dispatching rule selected. Four different S/R machine dispatching rules are considered in developing the expert system: first-come-first-served(FCFS), nearest-neighbor (NN), shortest-first (SF), and sweep [13, 14, 15, 16].

There are two different entities in the MAHCES knowledge base: control-rule and sensitivities.

The control-rule entity identifies the appropriate dispatching rules while the second entity investigates the possible sensitivities (throughput and utilization) of all input conditions. MAHCES includes the following three phases:

phase 1: data input;
phase 2: dispatching rule selection; and
phase 3: sensitivities.

Phase 1: the system accepts constraints necessary for the proper selection of the dispatching rule of the S/R machine for micro-load AS/RS. These constraints include queuing space, material flow, and type of layout.

Phase 2: in this phase, MAHCES requires the user to indicate the type of flow and desired type of layout. Based on the chosen flow, layout, and other constraints provided in phase 1, MAHCES suggests a suitable dispatching rule of the S/R machine for micro-load AS/RS. Sample rules employed in the knowledge base are shown below.

Rule control1
IF: type of flow is UX
AND jobs have to be kept flowing in terms of control
AND priorities are not involved in jobs
THEN: select the job that arrives earliest at the assembly cell.

Rule issue1
IF: the policy is that jobs should keep flowing
OR some jobs require priority
OR priorities are associated with all jobs
THEN: control issue is that jobs have to be flowing.

From Rule control1 above, it can be observed that if the type of flow is 'UX-flow' and jobs have to be kept flowing in terms of control and priorities are not involved, the FCFS rule is selected. It should be noted that 'Rule issue1' is supported to be activated before 'Rule control1' is satisfied, because 'Rule issue1' is a hypothesis (intermediate) rule.

Phase 3: Sensitivities are checked by increasing or decreasing the value of the parameters, e.g., pulling time, processing time, velocity of S/R machine, number of workstations, and unit load size. Several critical factors are presented to determine whether throughput, workstation, or S/R machine utilization are increased or decreased. It is noted that sensitivities are only represented as either "increasing" or "decreasing". A sample rule which generates sensitivities is provided below.

Rule FCFS1
IF: FCFS is selected
THEN: [IF: Sensitivities Entity has: unit
load size is increasing
AND pulling time is increasing
THEN: S/R utilization is decreasing].

It should be pointed out that when the decision for dispatching policy generated in phase 2 (control-rule entity) is selected, trends of several input parameters can be observed from the results of these rules. Although this system has limitations discussed above, it quickly provides the MHS designer with answers to 'what if' questions regarding constraint or variable changes, and with better understanding of the control system for micro-load AS/RS. Obviously, further research is needed to enhance the knowledge structure for extensive sensitivity analysis.

4. TESTING AND VALIDATION OF IMHSS

This analytical design has been validated by comparing it with the results of the simulation model to see if there are any discrepancies between the two models. Using the analytical model, the total costs are calculated for unit load sizes equal to five, ten, fifteen, and twenty. The two results are illustrated in Table 1. These alternatives are tested to see whether they are feasible in terms of throughput and machine utilization. These results are also illustrated in Table 2. It is noted that the analytical results are very close to those from simulation assuming all FCFS.

	Analytical Results				Simulation Results			
Unit Load Size	5	10	15	20	5	10	15	20
Total Cost	59,000	29,000	21,000	18,055	62,800	31,000	22,062	19,036

Table 2. Performance Measures of S/R Machine

System I/O Location	1	2	3
Throughput	780	785	787
Utilization	0.57	0.51	0.47

5. CONCLUSIONS

The difficulties encountered in designing complex MHSS cannot be resolved by the exclusive use of analytical methods. The complexity of the design problem can be solved by combining both AI and analytical models. The proposed methodology described in this paper improves design capabilities of traditional models. This research also provides insight into the feasibility of object-oriented design for MHSS and the analytical effectiveness of existing and proposed models. The major contributions of this research are summarized as follows:

1. The hierarchical design of selection, design, and control of MHSS for electronic assembly (micro - load AS/RS) is proposed. While the analytical model provides the designer with detailed system performance measures, it lacks the capability of providing explicit recommendations of system improvements. This limitation is overcome by designing hierarchically (macro - and micro-level) the MHSS. The IMHSS utilizes model-based analysis for estimating system performance and total costs, and employs multiple expert systems for both determining design parameters and recommending design improvements based on performance results from the analytical model.
2. A new methodology is proposed for MHSS design using an "object-oriented and knowledge-based system". This methodology is easy to use, modify, and extend for large-scale manufacturing applications by combining the logic of expert designers and hierarchical object-based systems.

6. FURTHER RESEARCH

The development of IMHSS in this research has raised several important issues, and there are other issues which need to be addressed to allow the IMHSS to become more adaptable and flexible within other manufacturing environments. The main interest areas for future IMHSS enhancement include: object-oriented simulation and enhancement of the existing knowledge base. Since the design of material handling systems involves many performance measures of state-dependent systems, the simulation technique is considered to be the most useful tool.

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