MMHS

Metamorphic Material Handling System

Final Report

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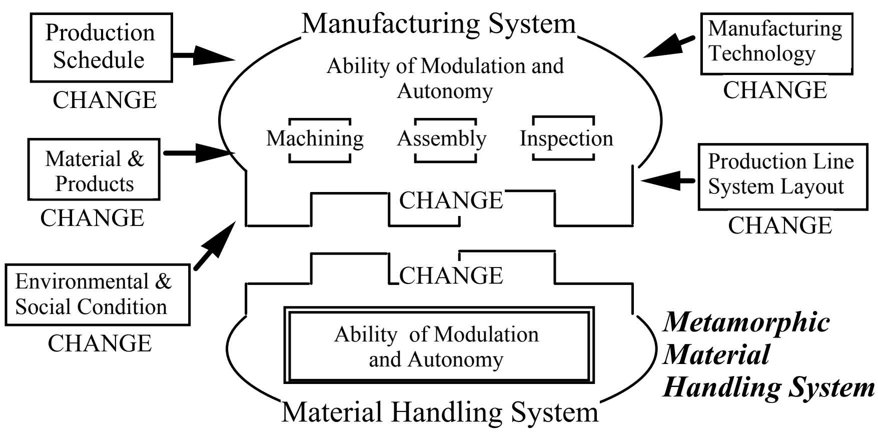
A. Summary of Project

1. Introduction

The next-generation material handling system should be a highly automated system based on next-generation technologies, provided with flexibility capable of changing its own structure or function in response to changes from manufacturing systems, and autonomous functions to enhance system reliability. Such system is defined as "**Metamorphic Material Handling System"**.

MMHS Project was the fifth international R&D project in IMS program, and its was to contribute to industries, optimize life cycle of equipment, produce a system most suited to the global environment, and respect humanity through research and development activities.



MMHS project perform research and development activities focusing on the following four points.

(1) ***Life cycle optimization***
(2) ***Environmentally conscious manufacturing***
(3) ***User-friendliness***
(4) ***Contribution to global industry productivity***

2. Project Objectives

The philosophy underlying the next-generation material handling system is to realize a more flexible system, which was the concept of MMHS project when proposed. At the same time, the system should be capable of improving the state of the art with a long-term view, as well as satisfying requirements for the next-generation manufacturing industry. Subjects and objectives of MMHS project conceived from this viewpoint were as follows.

(1) ***Responsive***

Responsive to changes that may take place in manufacturing technology and environment, type of product or material to be handled, work schedule and load

(2) ***Flexible***
Capable of transforming itself and altering its function to meet any change in handling requirements

(3) ***Autonomous***
Able to make decisions on its own (to enhance system availability)

(4) ***Highly automatic***
Incorporated with next-generation automation technology

(5) ***Multi-functional***
Having such functions as assembling, packaging and disassembling, besides transporting

(6) ***Modularized***
Composed of various modules, each with a distinct function; e.g. planning module, basic module, tool-setting module, communication module, capable of associating or dissociating one another to organize themselves into a configuration as required

(7) ***Multi-level***
Designed into multi-level sub-systems so as to be capable of cooperating other independent material-handling equipment including AGVs and mobile robots

(8) ***Compatible***
Capable of adapting itself to other existing material-handling systems

3. Project Structure

At the beginning, MMHS consortium consisted of 28 partners from five regions, and four Working Groups were organized on Work Package basis because MMHS project had four Work Packages.

The management structure consisted of two parts for general administration and technical administration. The formed was defined as "Executive Committee" and the later as "Technical Committee", but these were not independently held.

4. Work Packages Plan

Key technological themes of MMHS project were selected as concrete research subjects, such as *Autonomous Actions*, *Modularization*, *Systematization of Material Flow* and *Man-Machine Interface*. Therefore MMHS project had four Work Packages and 19 Tasks in four WPs when proposed.

However, the original WPs Plan was obliged to change at the middle of the period of MMHS project, because several partners, especially in EU region, withdrew. Consequently, only a half part of WPs and Tasks have been finally completed.

WP1: Metamorphic Hardware

Metamorphic Material Handling System requires material handling equipment with functions that can respond to changes or alterations in material handling demands that arise from the side of flexible manufacturing systems. Research on modularisation methods was carried out in WP1 for realizing such material handling equipment. A module is a group of elements with specific functions. Realization of MMHS by modularization refers to the dissociation of material handling equipment into such element groups, selection of appropriate modules if necessary, according to changes in material handling demands from manufacturing system, and re-organization into material handling equipment of a different form in order to realize the required material handling tasks.

Tasks of WP1 revised in driving were below, and ones of thick characters were fulfilled.
Task 1.1: **Modularization/Standardization**
Task 1.2: **Practical Operating System**
Task 1.3: Changeable Mechanical Machine Layout of the MMHS
Task 1.4: Control and Communication Architecture

WP 2: Metamorphic Cooperation Behavior

The study on MMHS (Metamorphic Material Handling Systems) had been started with the aim of developing a highly versatile material handling system. Over a decade has passed since the trend had been set toward the flexible manufacturing system following the realization of the limitations of the mass production system. In the meantime, various systems were proposed such as the **bio-type** production system and the autonomous decentralized production system. Many of them, however, were just paper plans and they rarely resulted in the construction of an actual system. In the scene of the manufacturing industry, material handling takes up much of the cost and labor of the whole industry as does its essential fabrication and assembly. To realize efficient material flow in the process of fabrication and assembly, developing a highly versatile material handling system is the paramount issue as one of manufacturing technologies.

To seek a solution to the problem described above, WP2 approached from a viewpoint of hardware control and set its overall purpose to the development of application technology of AGV intended for constructing a highly versatile material handling system.

Tasks of WP2 revised in driving were below, and ones of thick characters were fulfilled.
Task 2.1: **Cooperative Transport in Material Handling**
Task 2.2: **Autonomous path planning and Handling Planning**
Task 2.3: A Decision Making Strategies System
Task 2.4: Traffic Recognition and Safe Movement

WP 3: Material Flow for Metamorphic Material Handling System

Despite a great deal of research so far made on a next-generation manufacturing system, a clear conclusion as to the configuration of theses systems had yet to be drawn. However, trends of changes that can rightfully be called signs pointing to the next-generation manufacturing system had gradually been brought into focus. In spite of these changes in manufacturing configurations, the concepts of material flow systems at that time, and the subsystems and components used in the systems, still assumed the mass-production. Accordingly, a study on a next-generation material flow system tailored with the overall framework of new manufacturing systems in the future was indispensable.

The objective of this work package was to structure the concept of material flow system adaptable to the next-generation manufacturing system, arrange and systematize the requirements for subsystems and components based on the concept, and investigate fundamental technologies for the implementation.

Tasks of WP3 revised in driving were below, and ones of thick characters were fulfilled.
Task 3.1: **Methods for Planning, Design and Evaluation of Material Flow for MMHS**
Task 3.2: **Requirements to Infrastructure**
Task 3.3: **Integration with Warehousing and Manufacturing Software**
Task 3.4: Organizational Integration
Task 3.5: **Virtual Modeling of Material Flow Systems**

WP 4: Human Integration and Man-Machine Interface

The idea in this work package was to study how human workers can be integrated to the production and material handling systems. The workers could be embedded as parts of the production chain before, but they will have an overview of the whole production system and better chances to affect the production process. They also can make active decisions instead of just being a passive part of the production line. A new generation of Man Machine Interface will be developed in order to achieve this level in production automation.

Tasks of WP4 revised in driving were below, and ones of thick characters were fulfilled.
Task 4.1: Man-Machine Interface
Task 4.2: Hybrid Operation Modules
Task 4.3: **Human-Inclusive Material Flow Systems**

B. Project Results and Achievements

1. Impact of Achievements

1.1 Industrial Impact

MMHS project has supplied some parts of key technologies for the next-generation material handling systems to Manufacturing Industry. There are conceptual issues and more concretized materials. And also they are for both user industries and manufacturing industries of material handling equipment, including MMHS partners.

(1) Common impact to all industries

- Concept of MMHS (Metamorphic Material Handling System) will be an important guide to the next-generation material handling systems.
- As the results of WP1, a effectiveness of MMHS has been verified and an applicable domain of MMHS has been cleared.
- To realize Modularized AGVs proposed in WP1 will be environmentally conscious manufacturing system.
- Prototype AGV developed in WP2 will be able to use in actual factories with small changes in the near future.

(2) Impact to User Industries

- Method of Path-planning/Guide-planning proposed in WP2 and WP3 will raise the efficiency of manufacturing systems.
- Data Base structured in WP3 will make easy to select the optimum equipment for various material handling systems by oneself.
- To design a concept of human work within automated material handling systems will realize User-friendliness in manufacturing systems.

(3) Impact to Engineering/Manufacturing Industries in Material Handling Systems

- Since antonymous behavior in material handling systems in WP2 was proposed, many elements in this field has been dfined.
- Systematization of the next-generation material flow shows a frame of R&D in the field of material handling systems.
- Layout Design Supporting System will be immediately useful in actual work, such as planning, engineering and design material handling systems.

1.2 Auxiliary Results to Consortium Partners

All partners participating to MMHS project were developing not only supplying own technologies, but also utilizing other partner’s ones. That is, MMHS project was progressing by supplementing respective technologies mutually in MMHS consortium.

Consequently, all MMHS partners obtained some important skill and technologies, in the field of material handling systems, during a process of this project similarly as the results of project.

The most significance for all partners participating to MMHS project was to promote the international joint research on material handling systems, which was not accomplished before then. Through mutual enlightenment in MMHS project, almost of partners could learn working environments, customs, and cultural backgrounds in other region and obtained new relationship with other partners.

Of course, they will be able to deal in market products, methods and tools in accordance with IPR conditions specified in the Consortium Cooperation Agreement, and will contribute to the expansion of their own organization.

2. Achievements on Technologies

2.1 Achievements in Work Packages

2.1.1 WP1

In the first year of MMHS project started, four plants were visited, and research was carried out on modularized material handling system based on the studies on actual manufacturing and material handling lines in the plants. From the second year, studies were restricted to heavy machinery plants, and practical applications of modularized material handling equipment were investigated and designed.

As the results of the above mentioned, WP1 obtained several achievements as follows.

- Investigation and Analysis for actual manufacturing factory.
- Requirements for the Next-generation Material Handling Systems
- Conceptual Design for modularized AGVs in actual factory
- Verification for operating system of modularized AGVs

2.1.2 WP2

WP2 started the international research and study on MMHS in 1995. The team The results and achievements of WP2 are described below as the final report.

- "Control in transport of heavy material (in aboveground handling system)" explains a transfer method of large and heavyweight structure.
- "Control technology for autonomous coordinated work of handling robot" pursues the improvement in characteristics of manipulators built in mobile robots.
- "Experiment on autonomous traveling using miniature AGV" presents the realized control method for enhancing autonomous transportability with AGV.
- "Realization of regrasping coordinated handling by a group of wheeled mobile robots" presents an obstacle avoidance plan intended for the handling of large material by four mobile robots and demonstrates that flexible handling can be achieved by introducing the regrasping technique.

- “Flexible handling system through coordination of conveyor-equipped AGV” proposes conveyor-equipped AGV and show the availability of handling methods from belt conveyor to ordinary AGV. In addition, the method of effective use of the system on production site is presented through the simulation of handling.
- “Introduction of autonomous unattended vehicle to FMS” discusses the avoidance of collision of AGV and the dispatching problem.

2.1.3 WP3

The realizations of WP3 were multiple and the main objectives of each task have been reached.

Task 3.1: Methods for Planning, Design and Evaluation of Material Flow for MMHS

- Fundamental Structure of the Next-generation Planning Support System
- Systematization of Material Flow System
- Layout Design Supporting System in Consideration of Space
- Exact Formulation for Dispatching and Conflict-Free Routing of AGVs
- Transfer Batch Sizing in Flexible Manufacturing Systems

Task 3.2: Requirements to Infrastructure

- Guidepath Design for an Automated Guided Vehicle System : Locating the Pick-up and Delivery Stations
- Simultaneous Location of I/O Stations and Orientation of Path Segments in Automated Guided Vehicle System Design
- Optimal Bi-directional Spine Layout for Overhead Material Handling Systems

Task 3.3: Integration with Warehousing and Manufacturing Software

- Operational Analysis of Storage Carousel with Independently Controlled Rotary Racks

Task 3.5 : Virtual Modeling of Material Flow Systems

- Data Input Model for Virtual Reality-Aided Facility Layout

2.1.4 WP4

As the results of WP4, the followings were obtained.

- A report outlines the general specifications of the Man Machine Interface
- Contradictory concept of human work within automated material handling systems

2.2 Representative Results in Detail

2.2.1 WP2-PJ5: Flexible Handling System through Coordination of Conveyor-Equipped AGVs

(1) Outline

A flexible manufacturing system had been under consideration in a variety of forms for the production of a variety of products in small quantities. One of the element technologies to realize such system was an efficient, flexible and automated handling system, which would bring about a shorter production cycle and lower cost. Cranes, conveyors, and AGV (automated guided vehicles) were the available handling equipment with their respective advantages and disadvantages.

In this study, a belt conveyor-equipped AGV, which is a flexible handling module directed toward the production of a variety of products in small quantities, was proposed.

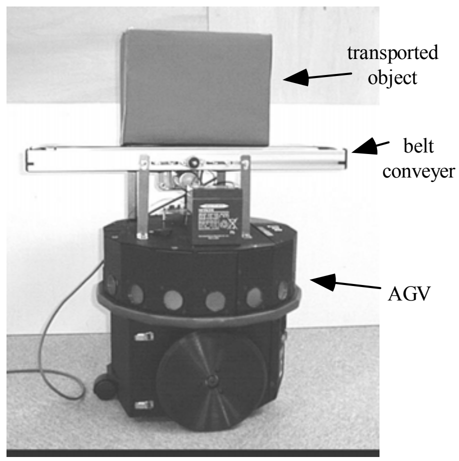


Fig. Belt conveyor-equipped handling module

(2) Conclusion

As a new transport module for constructing efficient and flexible material handling systems, an AGV loaded a belt-conveyer was proposed. Using this module, hand-over operation between two modules have been possible. Prototype modules were created and hand-over experiments were made to measure motion characteristics of the modules. Transport simulations were made for a model plant layout by using the values in the former experiments. The results showed the effectiveness of the proposed module from the viewpoint of transport efficiency, especially for cellular-type or process-type plant layouts.

2.2.2 WP3-PJ3: Next-generation Planning Support Systems

(1) Outline

This research focused on Task 3.1 "Methods for Planning, Design and Evaluation of Material Flow for MMHS" in WP3 "Material Flows for Metamorphic Material Handling System", and was part of the international joint research conducted jointly with Canadian Partner(s).

Planning/design techniques and methods used when planning and designing material handling systems had not been standardized and shared among designers. As a result, the dependence on ability, knowledge and experience of individual designers was large. This matter showed that not only could differences arise in the results of a plan depending on the designer, but also considerable labor and expenses were incurred considering time aspects. Consequently, various kinds of planning support systems were necessary for resolving such an issue.

Considering the needs mentioned above, this research placed additional emphasis on the preparation of layout from time and technical aspects during the planning and design stage, and a layout preparation support system has been constructed. And also the method used for developing the layout preparation support system was Genetic Programming (GP), which enables a large number of results to be obtained within a short time.

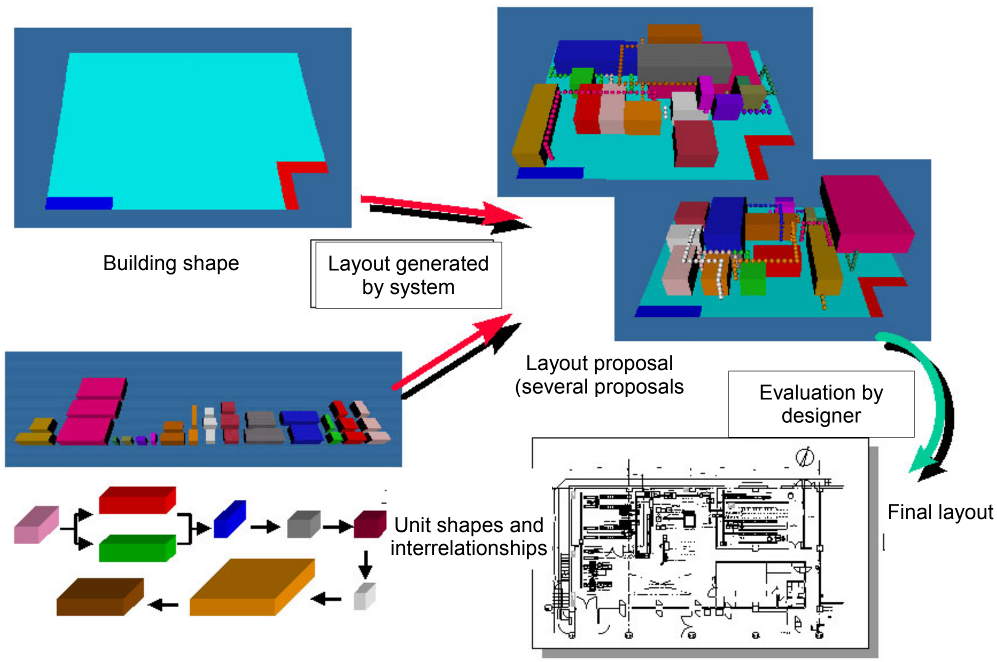


Fig. Illustration of proposed system

(2) Conclusion and results

From the outcome of this research, it was observed that multiple layout proposals satisfying the given basic conditions can be obtained without depending on the designer's abilities when performing the planning and design of material handling systems. That is, the load on the designers in preparing layout proposals by trial and error in the layout design process which required several days in the past, can be reduced considerably and the designers can concentrate on the detail design of the layout.

Furthermore, considering that effective tools for the layout design process did not exist, the results of research last year and this year will most likely become the core for planning MMHS henceforth.

C. Partners List

Region	Member	Work Package				Research (F) Year		
		WP 1	WP 2	WP 3	WP 4	1997	1998	1999
JAPAN	**KAJIMA CORPORATION**	○		○		○	○	○
	DAIFUKU CO.,LTD.			○		○		
	HAZAMA CORPORATION		○			○		
	HITACHI ZOSEN CORPORATION	○				○	○	○
	NISSAN MOTOR CO.,LTD.		○			○	○	
	WASEDA UNIVERSITY		○	○	○	○	○	○
	THE UNIVERSITY OF TOKYO		○			○	○	○
CANADA	**ECOLE POLYTECHNIQUE MONTREAL**	△		○		○	○	○
	POLY-Bro Inc.			△		△		
	Les ROUES BLEUTEC Inc.			△		△		
The US	**PURDUE UNIVERSITY**		△	○		○	○	○
	IOWA STATE UNIVERSITY			○		○	○	○
	UNIVERSITY OF ILINOIS			○		○	○	○
EU	**DE MONTFORT UNIVERSITY**	△	△	△	△	○	○	△
	IMS LTD.	△	△	△	△	△	△	
	DAIMLER BENZ AG		△	△	△	△	△	
	WINDHOFF AG	△	△		△	△	△	
	FRAUNHOFER INSTITUTE(Fhg-IML)	△	△	△	△	△	△	
	FRAUNHOFER INSTITUTE(Fhg-IPA)	△	△		△	△	△	
	SALOMON AUTOMATION			△	△	△	△	
	PROFACTOR PRODUKTIONSFORSCHUNGS	△	△		△	△	△	
	SIPA-AUTOMATED PRODUCTION SYSTEMS		△		△	△	△	
	ISA-DTA		△		△	△	△	
	UNIVERSITY OF PADUA		△		△	△	△	
EFTA (Switzerland)	Swiss Federal Institute of Technology, ETH Zurich					△		
	TELECOM PTT					△		
	PITNEY BOWES AG					△		

Thick Characters : International Coordinating Partner / Regional Coordinating Partner

D. History of MMHS Project