A Structured Approach to Material Handling System Selection and Specification for Manufacturing

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Abstract

The problem of selecting and specifying material handling systems for manufacturing operations is challenging because of the variety of technologies available for material handling tasks and the significant fixed costs of systems. Most of the previous work in this area usually does not address the possibility of selecting from among different technology types, such as forklift truck and AGVS, nor do they reflect the possibility of selecting and/or partitioning material handling tasks and assigning them to technology applications. This paper presents a four-step approach to the problem, consisting of task extraction, filtering tasks and matching them with resources, task aggregation, and system selection.

Keywords

material handling, system specification, fast analysis

1. Introduction

Most of the previous work in this area has been in the selection of equipment from within a technology type, or the specification of a system for given task requirements. The most popular approach is a rule-based system. Typical attributes are those that pertain to material (or what is being moved: type, volume, shapes, size, weight), move (or attributes such as distance, rate, frequency, source, destination), and methods (such as load/unload). Applications include sort conveyors [1], industrial trucks [2], and general equipment [3, 4]. A recent work [5] by the College-Industry Council on Material Handling Education (CICMHE), provides a list of attributes for tasks and equipment that have generally been used in published approaches to selection of material handling equipment. In [6], a knowledge-based system is described that was devised to assist facility designers in the selection and configuration of materials handling equipment. The system utilizes preference directed search to capture improved designs by dynamically acquiring new preferences throughout the design process.

In [7] an integrated model for solving the facility layout is given, with pickup/drop-off locations and material handling equipment selection decisions, solved using a heuristic algorithm. Another model which integrates material handling equipment selection and specification (including material handling interface equipment) and path/load dependent unit load size is by [8]. In [9] simulation is presented as a feasible, inclusive, and cost-effective means of evaluating alternative automated material handling solution approaches and equipment components.

The deficiency of most rule-based systems is that they usually ignore the fact that many tasks can be performed by more than one equipment type. There is little guidance for the designer in grouping tasks so that they can be performed by an economical system, recognizing the cost structures of most material handling systems, which includes significant fixed costs.

2. Overview of Approach

The research addresses four issues relating to integration of material handling (MH) equipment into a manufacturing environment. The first is task extraction to extract information about individual material handling tasks. The second is filtering and matching of individual tasks with individual resources, without regard to system performance and economy. The third is aggregation of tasks into sets that are then matched with technologies. The fourth is system selection and specification. This last step requires a suite of fast analysis tools that allow the designer to obtain performance and cost information for technology selection. An optimization routine is then used to select among the combinations. These four major tasks are shown in Figure 1.

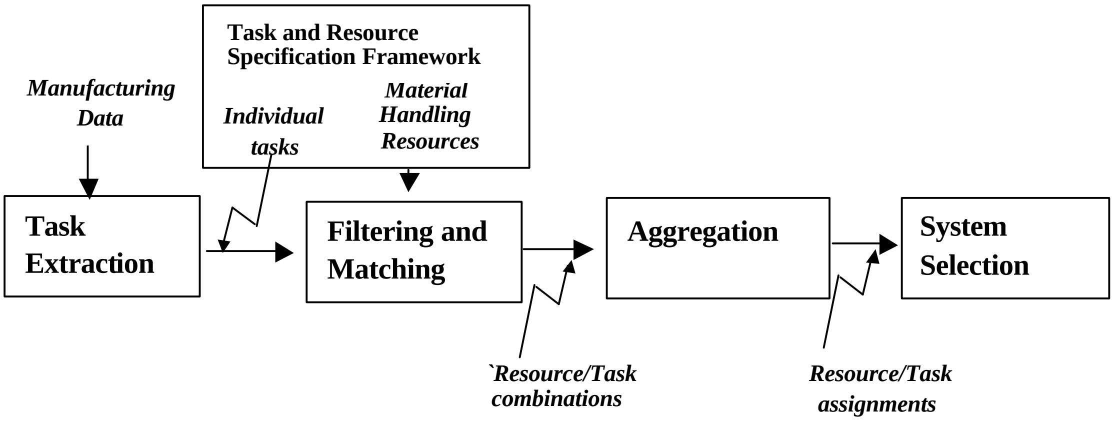

Figure 1. Major steps of procedure for selecting and specifying MH equipment for manufacturing

3. Task Extraction

A fundamental approach to describing the tasks to be performed by a material handling system is individual task specification. Here the physical attributes of the load, such as weight, size, fragility, etc., and the task, such as vertical displacement, horizontal displacement, positioning accuracy, etc., are important. An example of an *individual task specification* is given in Table 1. Each item in Table 1 would be specified by a numerical value(s) (e.g., 50 kg), a qualitative scale value (2 on a scale of 1 to 5), or logic value (yes or no). The focus clearly is on the mechanical ability needed to perform the task.

Table 1. Example of individual task specification (partial list)

Pick-up point, 3D	Temperature control needs
Deposit point, 3D	Max acceleration on item
Horizontal, vertical access?	Vibration control needs
Time for move, min, max	Balance/stability needs
Weight of item	Static electricity protection
Size of item	Static/dynamic interface with MH equipment
Value of item	Lifting aids, handles on item
Unit load configuration	Supports at MH interface
Orientation requirements	

Parallel to the individual task specification is the development of individual resource specifications. The approach here is to classify material handling technologies into groups that have similar geometric functionality. In a hierarchical system, this is the first level. A preliminary analysis shows that the following classes are needed:

a. Containers, including pallets, slip sheets, wire cages, tote boxes of corrugated and other materials [10].
b. Accessories, including mechanical grippers, suction grippers, slings and ropes, magnets, pallet forks, clamps, booms.
c. Cranes, including bridge crane, gantry crane, jib crane, mobile crane, single-point hoists, monorail hosts.
d. Vehicles, including unpowered carts and dollies, platform trucks, forklift trucks, automated guided vehicles (AGV), overhead electrified monorails (OEM). Subclasses are based on manual/powered, floor supported/overhead supported, path-bound/path-free, horizontal travel only/vertical travel, position of operator: at floor level, elevated.
e. Conveyors. Subclasses are based on synchronous/asynchronous, accumulating/non-accumulating, spur capability or not, load supported above/below, bulk/discrete, open/enclosed.
f. Sorting devices, including transfer cars, fully populated conveyor loops, conveyor loops with individual carriers or trains of carriers.

g. Storage/retrieval devices, including unit load and bulk load. Subclasses are based on pallet systems, item pick systems used in distribution centers.

4. Filtering and Matching

Parallel to the individual task specification is the development of individual resource specifications. A filtering and matching process then eliminates technologies that are not capable of satisfying the requirements of individual tasks and to match single-task resources with the needs. Table 2 shows a partial list of attributes for a technology; the attributes would have numerical, scale, or logical values similar to Table 1. Table 3 shows an example where movement tasks eligible for fork lift truck are identified. Figure 2 is a symbolic representation of how the tasks and resources are matched (upper part of figure) to match candidate technologies with tasks. The output of this step is a list of individual resource task-combinations, such as r_1t_1, r_1t_5, r_1t_{12}, ..., r_2t_1, r_2t_3, r_2t_{14}, ..., r_7t_3, r_7t_9, r_7t_{24}, r_7t_{29},....

Table 2. Example of individual resource capability, overhead electrified monorail (partial list)

Pick-up point, min positions from floor, wall, ceiling	Temperature: ambient
Vertical access with hook/hoist	Acceleration
Horizontal access with load carrier	Vibration: frequency
Max travel, 3D	Pendulum swing: amplitude
Speed, min, max	Balance/stability: good
Weight capacity	Static electricity: can protect
Size capacity	Interface with mfg. process equipment: static
Longit. control: (1.5 cm	Recirculate carriers: yes
Axial control: (0.5 cm	Minimum load spacing, m
Max incline: 2 deg.	Asynchronous control: yes
Floor quality required: none	Switching: yes
Orientation: can rotate item	

Table 3. Example of screening movement tasks eligible for fork lift truck
(shaded entries represent conflicts; only tasks 12 and 15 are eligible.

Task	**weight, kg**		**size, m^3**		**lifting aid possible**		**stability needed**	
no.	**> 100**	**< 100**	**> 0.03**	**< 0.03**	**pallet**	**hook**	**< 1 deg.**	**none**
1	X		X		X		X	
2		X	X			X		X
3		X		X				X
4		X	X		X			X
5	X		X			X	X	
6		X		X		X		X
7		X		X				X
8		X	X					X
9	X			X				X
10		X		X				X
11		X		X		X		X
12	X		X		X			X
13		X		X				X
14		X		X				X
15	X		X		X			X

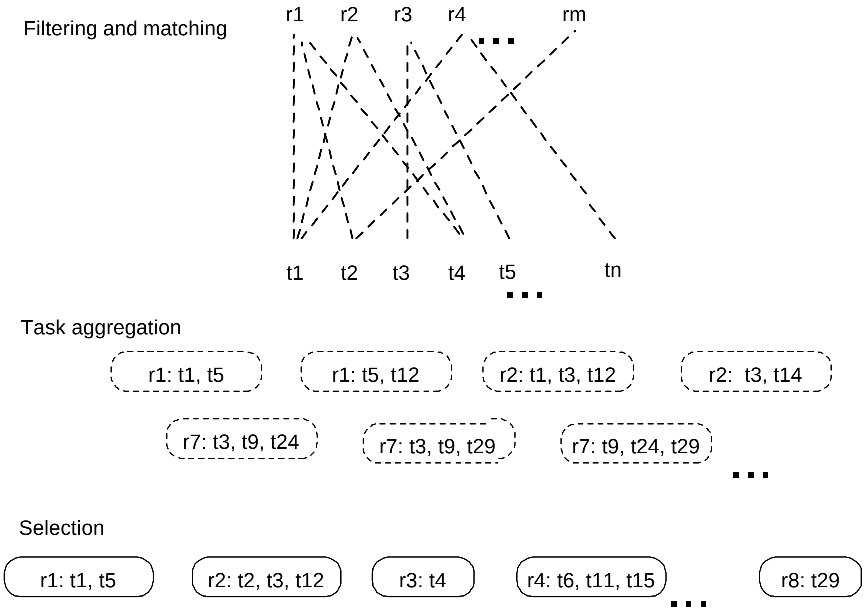

Figure 2. Filtering and Matching, Task Aggregation, and System Selection and Specification

5. Task Aggregation

This step involves the selection and aggregation of material handling tasks and their assignment to a candidate technology. Because of the flexibility of material handling equipment with respect to load type and placement/movement within the factory, there will be considerable overlap among the (individual resource-multiple task) combinations. For example, pallets can be transported by pallet jack, platform truck, fork lift truck, automated guided vehicle, and pallet conveyor. Lifting can be accomplished by hoists, jib cranes, gantry cranes, and bridge cranes; depending on the application, a fork lift truck may be used for lifting.

Some typical *system task requirements* include: number of movements per time period, mean and variance of demand rates, number of pick-up/deposit points and locations, capability for change in pick-up/deposit points, synchronous travel need, sequencing capability need, and accumulation capability need. In such situations it is more difficult to select technologies because of the wide variety available and the time needed to estimate performance and costs. To address these issues, aggregation techniques for combining individual tasks are being developed.

One form of aggregation is clustering based on the physical attributes used in task and resource specification. There may be more than 20 attributes, and this number may overburden a statistical clustering technique [11]. One approach is to identify the more important attributes and select these for aggregation or let these drive the aggregation in the initial stages. Another approach is to allow the critical attributes to depend on the material handling resource. Some of the attributes may be used to filter resources to be matched to the tasks, such as synchronous travel, sequencing capability, and accumulation capability.

Task no.	origin coord.		destination coord.		group no.
	X	Y	X	Y	
1.0	1.3	2.8	6.2	5.9	A
2.0	1.1	8.5	9.0	3.9	B
3.0	1.8	0.4	6.8	8.5	A
4.0	0.9	6.8	9.2	7.0	B
5.0	2.8	0.5	8.0	9.0	A
6	6.5	0.9	3.8	9.4	C
7.0	3.0	5.5	9.0	8	B
8	5.5	3.0	6.5	9.0	C

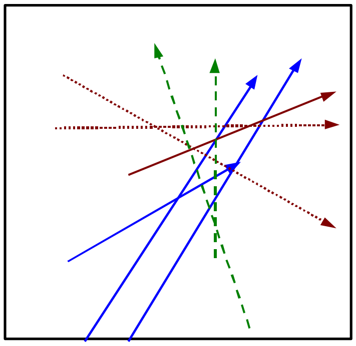

Figure 3. Example of clustering by origin-destination coordinates.

A third form of aggregation is based on origin/destination coordinates to form sets of tasks to be served by conveyor. Figure 3 shows an example for two-dimensional clustering; the techniques can also be applied to three dimensions, for applications of transporting items between floors. The outcome of this step are sets of resource-tasks combinations: $\{r_1: t_1, t_5\}$, $\{r_1: t_5, t_{12}\}$, $\{r_2: t_1, t_3, t_{14}\}$, $\{r_2: t_3, t_{14}\}$, $\{r_7: t_3, t_9, t_{24}\}$, $\{r_7: t_3, t_9, t_{29}\}$, $\{r_7: t_9, t_{24}, t_{29}\}$, ...

6. System Selection

The step of selecting from among the overlapping sets of *resource-tasks combinations* is accomplished within an optimization framework, specifically a covering problem. Each material handling task t_i forms a row of the constraint matrix. The columns correspond to application sets s_k of specific technologies. Column generation thus involves selecting a resource-task combination, for example $\{r_7: t_3, t_9, t_{29}\}$, and performing fast analysis to obtain the number of fixed resource units to accomplish the tasks in the set.

The resource units needed for each application set are translated to cost coefficients for the objective function, reflecting both fixed and variable costs of installation and variable costs of operation. The importance of a realistic cost structure cannot be overemphasized. It is not unusual for the fixed installation cost, representing system design and control system but no moving hardware, to exceed $100,000. Further, the moving hardware often can accommodate additional tasks with little increase in variable costs of installation and variable costs of operation.

The approach is then to optimize over a given set of available columns (resource-task combinations) so that each individual task is covered only once. Infeasibilities may occur because a task is covered more than once; this can be resolved by generating a new column without that task. Other possibilities exist here, including starting strategies, and pair-wise exchange of (compatible) tasks.

To obtain the cost coefficients for each resource-task combination a suite of *fast analysis tools* are needed. Such tools are being developed for each topology, with variations within a topology governed by selection of numerical parameters. The tools are less burdensome than simulation or combinatorial optimization, but more realistic than steady-state performance with no interference or idle time. Some examples of such tools are given here.

The first three methods represent a series of more detailed procedures that apply to all types of vehicle systems, including forklift, automated guided vehicles, and overhead electrified monorail. The last two methods apply to conveyor systems.

a. Development of from-to chart based on unit loads but incomplete product routing data. One of the challenges in material handling specification is that the transport data is not known with certainty, or if it is then the number of product routings is unmanageably large. A tool currently under development will enable the designer to specify a limited number of product routings, based on Pareto analysis, and develop the from-to portion in unit loads (constrained by weight and volume). These product routings are then used to develop a transition matrix that is used to generate additional routings and flows to compensate for those not entered by the designer. Perturbations of the transition matrix allow for robustness analysis.

b. Empty vehicle requirements analysis by factoring, or by first-order approximation followed by factoring. The simple factoring method reflects an assumption of first-come, first-served (FCFS) vehicle dispatching, which usually results in pessimistic performance estimates. The first-order approximation method, involving only arithmetic operations in spreadsheet cells, approximates better the typical proximity-based dispatching rules in a vehicle system. A version of this tool has already been developed for educational purposes.

c. Vehicle requirements analysis by representing the vehicle fleet as a single multi-server queue. Once both loaded and empty vehicle trips are known for a design period, then the stochastic behavior of the system can be modeled as a queue. Since the desired fleet utilization is usually below 85%, to avoid downtime of expensive manufacturing process equipment, the modeling shortcut of using a single, multi-server queue, should not result in any gross distortions. Buffers at the manufacturing process interfaces can be represented by a finite queue capacity.

d. Network flow models together with mean-variance analysis can be used to specify configuration of conveyor systems in manufacturing. Reserve capacity is usually considerably greater than in vehicle-based systems, with design factors of 0.4 to 0.85 (actual handling capacity compared to theoretical capacity) not being unusual [12, 13]. The design factor can be included in the decision rules, since different applications may have different inherent variabilities of demand.

e. For the cranes and hoists it is possible to adapt cycle time formulas from the automated storage/retrieval systems that have been studied so much [10].

7. Conclusions

The goal of this research is to develop an approach to material handling system selection and specification that satisfies the following three characteristics: (a) it is a bottom-up approach that uses manufacturing data such as facility layout and parts routing, (b) it is fast enough so that a system designer can evaluate different options with respect to grouping material handling tasks and technologies, and (c) it can be used for both design of new plants and evaluation of existing plants in the face of changing production requirements. The problem is important because material handling costs account for a major part of manufacturing costs, and material handling systems impact production scheduling flexibility.

The research identifies where and how the information for the material handling requirements are to be collected. Ultimately, the data collection would be part of the manufacturing process specification. Certainly, the elements related to item characteristics and access to the manufacturing process interface should be available to the process designer. Currently, however, a designer has to develop some data, such as locations for pick-up/deposit points. In recent work, the researchers have demonstrated the use of plug-ins for commercial CAD software to extract the pick-up/deposit centroids and the use of automated routines to extract other information [14]. A CAD representation of a plant layout, additional information such as storage location heights (not normally represented on a layout), and parts information such as size and weight have been used to automatically extract the material handling task characteristics and match them with MH resources. Fast analysis tools have been developed to aid in specifying systems. Current work is focused on aggregation and system selection.

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9. References

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