Characterization of automatic guided vehicle dispatching rules

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Hardware failures notwithstanding, the ability of an automated system operating according to promised potential is dependent upon the operational control measures in force. In this paper, some heuristic rules for dispatching Automatic Guided Vehicles (AGVs) in a job shop environment are presented. The rules are useful for assigning priorities to work stations requesting the services of a vehicle for material pickup. The likely effects of these rules on the performance of a job shop are postulated. Simulation results to demonstrate the effects of these rules are also presented.

A Barrett Unicar 140 system operating at Avon Products, Newark, Delaware, U.S.A. The vehicles shown have power roller decks for transferring unit loads between fixed floor conveyor stations.

Introduction

Automated material handling systems, though more flexible and capable than their counterpart (non-computer controlled systems), do pose more serious and challenging operational control problems. These control problems increase with the level of system automation. The manner by which these problems are resolved

Received August 1983.
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determines the operating effectiveness of the total system, as typified by an Automatic Guided Vehicle (AGV) system.

In a manufacturing environment consisting of several machine centres performing different machining functions, a typical part or unit load visits several centres before its machining requirements are satisfied. A unit load continues to circulate in the shop between work centres until it receives its last service. It is this transition of unit loads or parts that generate the vehicle dispatching (task assignment) problem in an AGV system. On the completion of a delivery task, a vehicle is reassigned to another mission immediately if there is any unattended handling task in the facility. Otherwise, the vehicle is set idle and continues to remain idle until a handling task appears, at which time it may be reassigned. If at the time a vehicle is released from a task (i.e., when it completes a task), there is only one outstanding (unattended) mission in the facility, then the vehicle task assignment problem may be trivial. On the other hand, if multiple unit loads are awaiting pickup simultaneously at different locations in the facility, then the vehicle task assignment presents a serious operational control problem that involves matching the vehicle to the task. This problem also appears in another form. When multiple vehicles are idle (unassigned) simultaneously and a pickup task arises, appropriate criteria must be established for selecting an idle vehicle to assign the task (i.e., matching task to vehicle). In a job shop environment where there is no recognized flow pattern of unit loads, vehicles in an AGV system can be dispersed throughout the network or concentrated in a region at any particular time. Vehicle distribution in the network is an operational control problem. The selected control measures, by which vehicles are assigned tasks, can affect material flow, buffer storage requirements in the departments, machine utilization, and vehicle effectiveness.

The vehicle dispatching decisions fall into two categories. The first category is a decision involving the selection of a vehicle from a set of idle vehicles to assign to a unit load pickup task generated at some part of the facility. This class of decisions involves a single work centre and one or more vehicles, and is generally the result of a request from a work centre for vehicle service. The decision is to determine the appropriate vehicle to assign to the pickup task. The secondary category of decisions involves the selection of a work centre from a set of work centres simultaneously requesting the service of any vehicle, a decision which usually involves a single vehicle and multiple work centres. The vehicle involved has just completed a delivery task and requires reassignment to another pickup task. At the time the vehicle became available, several pickup tasks exist in the shop at various departments. The decision is to prioritize the departments and to dispatch the vehicle to the department with the highest priority.

In this paper, the first class of problems is referred to as ‘Work centre initiated task assignment (dispatching) problems’ while the resulting rules to resolve them are referred to as ‘Work centre initiated task assignment (dispatching) rules’. The second class of problems is identified as ‘Vehicle initiated task assignment (dispatching) problems’. The corresponding methods for problem resolution will be referred to as ‘Vehicle initiated task assignment (dispatching) rules’. Details of each rule subclass will be presented shortly.

Background work

Most available research reports on AGV systems are hardware oriented rather than operational [8, 13]. Technical publications on hardware developments are
protected by corporate confidentiality and proprietorship. Materials available on AGV system operations are mostly success stories relating to specific applications [1, 5, 6, 7]. Fortunately, tremendous insight can be gained on AGV dispatching through work done in physical distribution and transportation. The problem of controlling in-plant industrial vehicles is merely a microscopic representation of the problems present in physical distribution. The vehicle dispatching problem was first written on by Dantzig and Ramser (1959). Since then, various forms of the problem have been identified in public transportation [3, 11], airlines [14, 15], mining [18], and manufacturing [12, 13, 16], to cite only a few.

There is some recent work on vehicle dispatching directed specifically to the control of Automatic Guided Vehicles (AGVs). Maxwell (1981) and Maxwell and Muckstadt (1982) address the problem of determining an optimum schedule for dispatching vehicles that result in minimum vehicle fleet size. Integer programming was employed for seeking the optimum solution, and the problem environment was a paced assembly operation in manufacturing setting. The application environment of the work in Egbelu (1982) and Egbelu and Tanchoo (1982) was a job shop. The shop was assumed to be dynamic in the sense that jobs are continuously admitted into the shop. The study objective was to characterize vehicle dispatching rules in a job shop environment with a constrained layout, and simulation was the analysis tool. Other work on vehicle dispatching in a manufacturing setting includes that by Blair (1980) and Russell and Tanchoo (to appear).

A workcentre initiated task assignment problem

Figure 1 is a representation of a typical machining centre in an AGV system. It consists of one or more machines, an incoming unit load queue, and an outgoing unit load queue. For simplicity, consider the machines to be identical and the queues to be capacititated. Load stands in front of the queues facilitate the automatic transfer of unit loads to or away from the load deck of the transporter. Depending on the part processing rate of a department, unit loads are drawn from the incoming queue, processed, and released into the output queue at some rate. The deposition of a unit load into the output queue also initiates a request by the department for an unassigned vehicle for the immediate removal of the load just deposited. Several

![Figure 1. Schematic representation of a work centre.](image-url)
heuristic rules can be employed for assigning priorities to vehicles for dispatching. These include the following.

(a) Random Vehicle (RV) rule
Under this rule, the pickup task is randomly assigned to any available vehicle in the shop. This is done without regard to the relative location of the vehicles to the point where the vehicle is needed.

(b) Nearest Vehicle (NV) rule
Under this rule, the distance of the vehicle demand point from every available vehicle is computed. Using the travelling speed of the vehicles, the vehicles whose travel distance is computed to be the shortest is dispatched to the vehicle demand point. This is equivalent to dispatching idle vehicle \( j \) such that

\[
 d_j = \min \{ d_i \} \quad \text{for all idle vehicles } i
\]

where \( d_i \) is the distance of vehicle \( i \) from vehicle demand point.

The computation of \( d_i \) is according to the following expressions:

\[
 d_i = d'_i + \sum_{k=1}^{J-1} d(n_k, n_{k+1})
\]

where \( J \) is the number of nodes along the shortest path travelling away from vehicle \( i \) to the point where the vehicle is demanded. (See the Appendix for the representation of an AGV system guide path as a network.) \( d'_i = 0 \), if the vehicle \( i \) currently at a node point. Otherwise, it is the distance of vehicle \( i \) to the next node on its path (i.e. if it is between two nodes). \( d(n_k, n_{k+1}) \) is the distance between the adjacent nodes \( n_k \) and \( n_{k+1} \) such that \( n_k \) precedes \( n_{k+1} \). Distance computation between adjacent nodes is as shown in the Appendix.

Rather than dispatching vehicles based on the shortest distance rule, the dispatching decision could be made based on the shortest travel time. The decision is to dispatch vehicle \( j \) such that

\[
 d_j/s_j = \min \{ d_i/s_i \} \quad \text{for all idle vehicles } i
\]

where

\[
 s_i \quad \text{is the travelling speed of vehicle } i.
\]

For a congested traffic network, the shortest travel distance path is not necessarily the shortest travel time rule.

(c) Farthest Vehicle (FV) rule
This is an antithetical rule to the Nearest Vehicle Rule. Using the definition in the last section, the vehicle \( j \) satisfying the condition

\[
 d_j/s_j = \max \{ d_i/s_i \}
\]

is dispatched to the vehicle demand point. This rule does not provide any direct usefulness as a viable dispatching rule, but it does give the system designer what effect unnecessary vehicle travelling distance could have on system handling effectiveness.
(d) **Longest Idle Vehicle (LIV) rule**

This rule assigns the highest dispatching priority to the vehicle that has remained idle the longest among all the idle vehicles. This is equivalent to dispatching vehicle $j$ such that

$$t_j = \max_{i} \{t_i\}$$

where

$$t_i = T_c - T_i$$

$T_c$ = current time or the time vehicle dispatching decision is to be made.

$T_i$ = time vehicle $i$ was last set idle, $T_c \geq T_i$ for all $i$.

The advantages of this rule are its workload balancing effect on all participating vehicles.

(e) **Least Utilized Vehicle (LUV) rule**

This rule takes advantage of the fact that in most computer controlled AGV systems, time persistent statistics on the utilization of each vehicle are maintained. For idle vehicle $i$, if $U_i$ denotes its mean utilization up to the time the vehicle dispatching decision is to be made, the decision rule is to dispatch vehicle $j$ such that

$$U_j = \min_{i} \{U_i\}$$

Like LIV rule, the Least Utilized Vehicle (LUV) rule acts as a workload balancer among the vehicles in the shop.

Up to this point, attention has been focused on decision rules involving work centre initiated dispatching rules. As mentioned earlier, rule pairs are required to accomplish the vehicle dispatching requirements of an AGV based material handling system. The second rule category is presented next. This is followed by the discussion of experimental results obtained to demonstrate the behaviour of these rules in a job shop setting.

**Vehicle initiated task assignment problems**

From an operational point of view, the most desirable level of handling effectiveness is that which ensures that unit loads completed at a work centre are removed promptly and transported to their subsequent destinations with a minimum of delays. Actual operating conditions do, however, deviate from this scenario. The degree of deviation is a function of vehicle availability, shop loading, shop size, and the layout of the guidance network. Operating conditions do arise when requests for vehicles from work centres cannot be immediately satisfied (i.e., the request is uneventful). This is the case when all vehicles are engaged in missions. Such uneventful requests are therefore logged and considered for satisfaction when a vehicle becomes available. The procedures by which the work centres are dynamically prioritized for service by the released vehicles is the item of presentation in this section.

Like the work centre initiated task assignment problem, several heuristic rules are available for ranking work centres requesting unassigned vehicles. Possible assignment rules are presented as follows.
(a) **Random work centre (RW) rule**

Under this rule, a list of all work centres requesting the service of vehicles is obtained. From this list, a work centre is randomly selected. The released vehicle is therefore dispatched to the selected work centre.

(b) **Shortest Travel Time/Distance (STT/D) rule**

The basis of this rule is to minimize the percentage of time vehicles travel empty. Under STT/D rule, the decision rule is to dispatch the released vehicle to the work centre whose unit load pickup point is closest to the vehicle. Closeness is measured in terms of travel time or distance along the shortest path and in the direction of traffic flow. Again, format for distance calculation is as shown in the Appendix. Although the advantages of this rule seem obvious, it is worthy to note that it is very sensitive to the layout of facilities and location of equipment within the facility. Vehicles are available for reassignment when they are released from a previous assignment. Therefore, vehicle release points generally correspond to delivery stations. If by chance (or by design) the pickup point of some work centre turns out not to be the nearest to any vehicle release point, according to STT/D rule, such a work centre may never qualify to receive a vehicle dispatch. This reduces material flow rate out of the affected work centre. Since new deliveries continue to take place in the centre, the output queue will grow to its maximum capacity, and thereafter machines will be blocked. As the machines continue to remain blocked, new deliveries accumulate in the input queue. Eventually, the input queue grows to its limit. Subsequent vehicles arriving at the station from then on will be blocked from making deliveries. Thus, a stalemate will result, and the possibility of locking exists. The locking phenomenon will be discussed in detail later.

(c) **Longest Travel Time/Distance (LTT/D) rule**

As an antithetical rule to SST/D, this rule assigns the highest priority to the work centre that is farthest away from the vehicle. Again, other than for system experimentation, there is no attractive quality to this rule.

(d) **Maximum Outgoing Queue Size (MOQS) rule**

Suppose \( q_k \) denotes the number of unit loads in the outgoing queue of work centre \( k \) awaiting pickup and \( R_k \) is the number of unit loads in the same queue not yet assigned to any vehicle, where \( 1 \leq R_k \leq q_k \). The decision is to dispatch a vehicle to work centre \( j \) such that

\[
q_j = \max \{ q_k \} \text{ for all } k, \quad R_k \geq 1.
\]

Note that \( R_k = 0 \) for all \( k \) implies there is no unit load in the facility awaiting pickup that has not yet been assigned to a vehicle. In such a case, the released vehicle is set idle.

(e) **Minimum Remaining Outgoing Queue Space (MROQS) rule**

Dispatching decision under MROQS is based on a criticality index that is a function of outgoing queue capacity and length in each work centre. If

- \( Q_k \) is the capacity of output queue at work centre \( k \),
- \( S_k \) is the current length of output queue at work centre \( k \), and
- \( R_k \) is the number of unassigned unit loads waiting in the output queue at work centre \( k \), then
for each centre \( k \) \((R_k \geq 1)\), compute the index, \( C_k \), defined as
\[
C_k = Q_k - S_k.
\]
The decision is to dispatch the available vehicle to centre \( i \) such that
\[
C_i = \min \{C_k\}, \text{ for all } k, R_k \geq 1.
\]
The basis of this rule is to reduce the possibility of work centre blocking occurring.

\((f)\) Modified First Come–First Serve (MFCFS) rule

This rule is a modification of the traditional First Come–First Serve rule. The rule attempts to assign vehicles to departments sequentially in chronological order as requests for empty vehicles are received from departments. When a department places a call (request) for an empty vehicle and the call cannot be immediately satisfied, the time the call was generated is saved. The saved call and time are used for future vehicle assignment decisions. If subsequent calls emanate from a department before an earlier saved call from that department is satisfied, the times of these subsequent calls are not saved. In other words, no department can have two or more outstanding saved calls simultaneously. When a vehicle becomes available, it is assigned to the department that has the earliest outstanding saved call and time. At the moment a saved call from a department is satisfied (i.e., a vehicle is dispatched to the department), the vehicle need of such a department is evaluated and updated in one of two ways:

(i) a zero outstanding call is recorded for the affected department if it needs exactly one vehicle. The number of vehicles a department needs at any time is equal to the number of unit loads awaiting vehicle assignment for pickup from the department.

(ii) if more than one vehicle is required at the department, a new call is saved immediately against the department and the corresponding time associated with the new call is set equal to the time the old saved call was satisfied.

Although this rule does not consider any impending blockages of departments due to imminent exhaustion of queue space, it does ensure that the elapsed time between the placing of a vehicle request by a department and the satisfaction of that request is reduced. The number of assignments made to a department is related to job traffic intensity in that department.

\((g)\) Unit Load Shop Arrival Time (ULSAT) rule

This rule is useful if the design objective is to reduce the time jobs spend in the shop. It accelerates jobs or unit loads through the shop in their order of entry into the shop. At the time a vehicle dispatch decision is to be made, the arrival time into the shop, \( T_k \), of the unit load at the end of each queue that is not yet assigned is determined. The dispatching decision is to send a vehicle to department \( i \) such that
\[
t_i = t^* = \max \{T_i - T_k\}, \text{ for all } k, R_k \geq 1
\]
where \( T_i \) is the current time or time decision is required. The above decision is also consistent if a vehicle is to be dispatched to department \( i \) if
\[
T_i = T^* = \min \{T_k\}, \text{ for all } k, R_k \geq 1.
\]
Performance evaluation

Several combinations of the above rules were tested on a facility using a simulation technique. A simulation program, AGVSim, was developed specifically to simulate an AGV system [10]. In the simulation, the AGVS guide path is modelled as a collection of nodes and arcs, as shown in Fig. A1 in the Appendix. All arcs are considered unidirectional. Nodes represent guide wire intersections, merges, diverges, load pickup stations, and load delivery stations. Safety zones, as shown in Fig. A2 in the Appendix, are constructed around every node to facilitate traffic control at node points. Vehicle movements between points in the network are modelled as series of transitions from one arc to another through interchange ramps (as shown in Fig. A2). Detailed discussion of the simulation modelling can be found in [8].

The shop whose layout is shown in Fig. 2 formed the test facility for the study. Fifteen rule combinations were included in the testing. The facility is a job shop with 13 departments, multiple identical machines per department, and 6 automatic vehicles. Departments 1 and 13 are the receiving and shipping areas respectively. There is a unique input queue and output queue in each department. With the exception of the input queue in the receiving department and the two queues of the shipping department, all queues are capacitated. Each job that arrives into the shop has a certain number of identical components. This lot is then broken down into equal size groups to form unit loads. A unit load, therefore, defines one or more components bound together and transported as a unit [17]. Unit loads belonging to the same job follow the same job route. A job is not completed until its last unit load is completed.

The rules included in the experiments were the following:

(a) *Vehicle Initiated Task Assignment rules*

(i) maximum outgoing queue size (MOQS)
(ii) shortest travel time/distance (STT/D)
(iii) longest travel time/distance (LTT/D)
(iv) minimum remaining outgoing queue space (MROQS)
(v) modified first come–first serve (MFCFS)

(b) *Work Centre Initiated Task Assignment rules*

(i) nearest vehicle (NV)
(ii) farthest vehicle (FV)
(iii) longest idle vehicle (LIV)

Using unit load throughput as a measure of rule performance, Table 1 shows the results of 30 simulation trials, 2 trials per rule combination. All experiments were conducted under similar conditions. The number of asterisks in a cell indicates the number of times the rule combinations resulted in a locking of the shop. A shop is considered locked if the following conditions exist.

1. The input and output queues are simultaneously full at some or all the departments and the machines in the affected departments are blocked.
2. All vehicles transporting unit loads cannot make their deliveries because the input queues are full and there are no available vehicles to free some spaces from the output queues.
3. All empty vehicles dispatched for load pickup cannot get to their destinations due to interference from other vehicles.
Vehicle initiated task assignment rules

<table>
<thead>
<tr>
<th></th>
<th>MOQS</th>
<th>STT/D</th>
<th>LTT/D</th>
<th>MROQS</th>
<th>MFCFS</th>
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<td>*</td>
<td>*</td>
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_Nomenclature:_ MOQS, maximum outgoing queue size; STT/D, shortest travel time/distance; LTT/D, longest travel time/distance; MROQS, minimum remaining outgoing queue space; MFCFS, modified first come–first serve; NV, nearest vehicle; FV, farthest vehicle; LIV, longest idle vehicle.

Table 1. Shop throughput measured in unit loads (* locking encountered by the shop).
Explanation of the shop locking phenomenon

If one observes the data in Table 1, two questions are obvious. First, what are the conditions that can lead a shop to lock? Secondly, why is there little difference in shop performance amongst the rules within the work centre initiated task assignment rule?

In answering the first question, the results above demonstrate the importance of a well-coordinated vehicle dispatching plan, especially when existing facility layout is involved and material flow volume is large. With large volumes of material flow, vehicles are rarely free to allow the invoking of a work centre initiated rule for dispatching vehicles. Instead, dispatching is governed completely by the vehicle initiated rule. Since members of the vehicle initiated rule subclass are generally invoked only when a vehicle is released, and furthermore, since vehicle releases occur at delivery points only, vehicle initiated task assignment rules are very sensitive to the location of material delivery points. However, when STT/D and LTT/D are employed, some departments almost never satisfy the dispatching criteria. Eventually, the output queues become full and subsequently block the machines in that centre. This is followed by a blocking of vehicles making new deliveries in that centre as the input queue itself grows to its maximum capacity. This chain reaction gradually propagates to all vehicles in the shop, causing a complete seizure of material flow. Unless pickup points are well located relative to delivery points, shop locking or at least work centre locking is an inevitable phenomenon whenever rules that are derivative of distance measures are involved.

The answer to the second question follows from that of the first. The last paragraph asserts that when material flow rate is high, work centre initiated task assignment rules are rarely invoked. This implies that the rules become virtually inactive after a few hours of shop operation. Therefore, if no significant performance difference between the rules is realized during the early phase of a shop operating session, no performance differences amongst the rules may ever be realized. In the example problem here, the rules did not exhibit any significant performance differences during the early part of the shop operating session; thus, the similarity in performance.

Operation with automatic intervention and a central buffer area

In practice, when a shop locks, a measure is taken by the shop operators to unlock the shop. This involves dispatching some lift truck operator to release the queues. Alternatively, the intelligence can be built into the vehicles to recognize and initiate actions to diffuse conditions that could lead to shop locking. This scheme requires diverting loaded and blocked vehicles to a central buffer area to have their loads delivered. Thereafter, they are directed to the shop floor to release blocked departments. The vehicles are subsequently returned to pick up the buffered items for delivery at their appropriate destinations. This is just one of a number of automatic intervention concepts.

With all shop conditions remaining unchanged (as previously described), and applying the automatic intervention concept just presented, the shop output increased under the rule combinations that involved MOQS, STT/D and LTT/D. The new output levels ranged from 290 to 596 as against 1 to 108 under the no intervention case. The output levels for rule combinations under MROQS and MFCFCS are the same before and after intervention. Table 2 shows statistics of the central buffer at the 15 rule combinations. Information of this type is useful for
**Automatic guided vehicle dispatching rules**

### Vehicle initiated task assignment rules

<table>
<thead>
<tr>
<th></th>
<th>MOQS</th>
<th>STT/D</th>
<th>LTT/D</th>
<th>MROQS</th>
<th>MFCFS</th>
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<td>6:22</td>
<td>5</td>
<td>1:06</td>
</tr>
</tbody>
</table>

* Nomenclature: MOQS, maximum outgoing queue size; STT/D, shortest travel time/distance; LTT/D, longest travel time/distance; MROQS, minimum remaining outgoing queue space; MFCFS, modified first come–first serve; NV, nearest vehicle; FV, farthest vehicle; LIV, longest idle vehicle.

Table 2. Maximum* and Average* buffer queue length using system antilock mechanism.

specifying the capacity of buffer areas. Incidentally, MROQS and MFCFS does not show any need for intervention and subsequently a central buffer area.

### Shop performance based on infinite queues

Operating rules notwithstanding, the blocking of machining centres are the direct results of capacitated queues. By relaxing the queue capacity constraints, the locking effect will be eliminated. This provides the opportunity to assess the actual buffer space requirements under unconstrained conditions. To explore this postulate, the shop was simulated under the unconstrained (infinite) queue capacity. The simulation results are shown as Table 3.

Looking at the table row-wise, there are virtually no performance differences among work centre initiated task assignment rules as compared to the differences among the vehicle initiated task assignment rules. All rule combinations that have elements of queues in their derivation performed worse than all other cases. MFCFS outperformed all other rules. Ideally, MOQS and MROQS should yield the same throughput, since at infinite queue condition they collapse to the same rule. The difference shown in the table is caused by the variation in tie-breaking rule employed under each policy.

On the other hand, while STT/D performed competitively under the system throughput criterion, it performed poorly when queue characteristics are considered. While queues grew to a maximum length of 13 unit loads under the MFCFS rule, output queues under STT/D rule grew as high as 231 unit loads in some departments.

### Vehicle initiated task assignment rules

<table>
<thead>
<tr>
<th></th>
<th>MOQS</th>
<th>STT/D</th>
<th>LTT/D</th>
<th>MROQS</th>
<th>MFCFS</th>
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* Nomenclature: MOQS, maximum outgoing queue space; STT/D, shortest travel time/distance; LTT/D, longest travel time/distance; MROQS, maximum remaining outgoing queue space; MFCFS, modified first come–first serve; NV, nearest vehicle; FV, farthest vehicle; LIV, longest idle vehicle.

Table 3. Shop unit load throughput at infinite queue condition.
Actually, no loads were picked up from these departments. Given the existing shop layout, STT/D did transform these departments to sink nodes. The enormous buffer space required by STT/D makes it an inoperable rule in facilities where the necessary layout condition is not met and modifications can only be achieved at very high cost.

**Sequential vehicle dispatching rule**

A common practice for vehicle dispatching strategy is to preprogram available vehicles to visit the load pickup points in a sequence that forms a loop. If a pickup station has a load when it is visited, the load is picked up and transported to its destination. Otherwise, the vehicle proceeds to the next pickup station in the sequence. An inherent quality of this strategy is the elimination of any possibility forshop locking. In a new facility, this requires locating the departments along a loop to minimize vehicle travel time. However, in complex facilities with a large number of departments or ones with existing layouts, the flexibility to locate all pickup points along a loop is highly constrained. In such cases, a sequence has to be selected through a heuristic procedure or by solving the corresponding travelling salesman problem.

The sequential dispatching strategy was demonstrated in this study and the resulting shop throughput compared to those obtained under two rule combinations. The tested departmental sequence of

$$1 \rightarrow 4 \rightarrow 13 \rightarrow 11 \rightarrow 10 \rightarrow 8 \rightarrow 6 \rightarrow 2 \rightarrow 12 \rightarrow 5 \rightarrow 9 \rightarrow 7 \rightarrow 3 \rightarrow 1$$

used for the demonstration was not chosen through any optimal producing algorithm. Figure 3 shows the resulting vehicle fixed route for the sequence visitation. Vehicles conveying items were still routed through the shortest path between their origins and destinations.

![Diagram](image.png)

**Figure 3.** A single loop vehicle assignment system based on demonstrative facility.
Table 4 shows the shop output under three vehicle dispatching rule strategies, using two simulation runs per strategy. As can be seen, the sequential dispatching rule performed much lower than the other two rule combinations. This is partly due to the fact that the sequence selected is not optimal and partly because sequential dispatching strategy involves a large number of unproductive vehicle visits to departments at times when such departments had no need for vehicles. In an existing layout of the type given in this problem, where to make a complete round of visits a vehicle may pass through some aisles more than once, sequential vehicle dispatching policy (if adopted) should be justified under a different criteria, such as simplicity of traffic control algorithms and the elimination of shop locking possibility, rather than on its ability to accelerate jobs through the shop.

<table>
<thead>
<tr>
<th>Rule combinations</th>
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_Nomenclature:_ LIV, longest idle vehicle; MROQS, minimum remaining outgoing queue space; MFCFS, modified first come–first serve.

Table 4. Unit load throughput under sequential and nonsequential dispatching rules.

Conclusion

Heuristic rules for dispatching automatic guided vehicles in a job shop with an existing layout have been presented. The characteristics of these rules were demonstrated under several shop operating conditions. The demonstrations indicated that rules which are derivatives of distance measures have several drawbacks if the appropriate layout conditions of a facility and equipment locations are not met. The results also demonstrated how the vehicle dispatching problem and its associated resolution techniques can affect shop design elements such as buffer space requirements in each department, central facility buffer requirements, shop throughput, and identification of poor layout designs. There are, of course, other design issues that are not addressed in this study. These factors include traffic control problems, load transfer mechanisms at load pickup and delivery points, and other operation related issues.

APPENDIX

The wire guide path of an AGV system (Fig. A 1) can be modelled as a network consisting of nodes and arcs. The position of a node can be specified in terms of the Cartesian coordinate system where \((x_z, y_z)\) represents the coordinate of node \(z\).

For traffic control reasons, let a safety zone (i.e., check zone) be defined around every node as shown in Fig. A 2 and let a check point be the intersection point between a check zone and an arc entering a node. The check points are denoted by \(b_i, i = 1, 2, 3, \ldots, n\) in Fig. A 2. Check points are decision points for vehicles in the network. These decisions include intersection crossing, holding for blocking, and negotiating a turn. All vehicle turns are made through interchange ramps as shown
in Fig. A2. Since decisions are made at check points, the flow of vehicles can be modelled as a series of transitions or discrete jumps between successive check points. The transition time required between the check points of two adjacent nodes $a$ and $b$ is a function of the vehicle travelling speed, the degree of traffic congestion between the nodes, and the physical separation of the nodes. Thus, the distance between two check points of adjacent nodes can be represented as $d_{ab}$, where

$$d_{ab} = \begin{cases} 
\sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} + (f - 2e)\phi, & \text{if the distance from node } a \text{ to } b \text{ is Euclidean}, \\
|x_a - x_b| + |y_a - y_b| + (f - 2e)(\phi + 1), & \text{if the distance from } a \text{ to } b \text{ is rectilinear}.
\end{cases}$$
\[ \phi = \begin{cases} 1, & \text{if a turn is required at the check point of node } \alpha \text{ to reach node } \beta, \\ 0, & \text{otherwise.} \end{cases} \]

\( e \) is the distance between a check point and the node it serves.

\( f \) is the length of the smoothed ramps required to negotiate turns. The value of \( f \) is a function of the turning radius of the vehicles that use the network and the maximum allowable vehicle speed. \( f \) can be approximated by \((\pi e/2)\) if the check zone approaches the shape of a square.

The distance between two adjacent nodes \( \alpha \) and \( \beta \) is defined as Euclidean if and only if

\[ x_\alpha = x_\beta \text{ or } y_\alpha = y_\beta, \]

but not both. A distance is considered rectilinear if and only if

\[ x_\alpha \neq x_\beta \text{ and } y_\alpha \neq y_\beta. \]

That is, the node coordinates are completely distinct for the adjacent nodes. The distance equation above assumes arcs can enter or leave a node only along a coordinate axis. Also, arc shapes other than those classified in Fig. A.3 are excluded.

\[ \text{FAMILY ONE} \]
\[ \text{FAMILY TWO} \]

Figure A.3. Characterization of arc according to orientation.


References
[1] 1975, A musical driverless cart! Yes for two sound reasons, Modern Material Handling, 30, 44.