Multi-Agent Negotiation Strategies and the Flow of AGVs

Andrew Wallace
AAWallace@iee.org

***Abstract*— This paper presents research that has been conducted into the utilisation of heuristics to improve the performance of an agent based Automated Guided Vehicle (AGV) controller. The agent based controller has been shown to maintain the deadlock free flow of AGVs within a free space world model. However, the performance in terms of deliveries was lower than a comparable industrial controller. Heuristics were used to ascertain whether or not an AGV could be redirected during negotiations. Experiments were conducted using simulations and one heuristic was found to improve the performance of the agent based controller significantly.**

I. Introduction

One aspect of flexible or holonic manufacturing systems (see, for example, [1] and [2]) is the transfer of material. This can be achieved either by conveyor belt, manual labour or by the use of fork lift trucks. The fork lift trucks can be either manually driven or automated. The use of automated fork lift trucks, referred to as Automated Guided Vehicles (AGV) (figure 1 shows a typical AGV), can have a cost advantage over other methods and, from the perspective of flexible or holonic manufacturing systems can offer a dynamic, reconfigurable, method of material handling. Such flexibility can make them an attractive solution for such systems.

However, AGV systems are not without their problems (see for example [3], [4] or [5]). The main one is concerned with maintaining the delivery rates of materials. This is achieved by controlling the movement of AGVs (referred to as flow). Research has been conducted into the flow control of AGVs by the use of agents (see for example [6] and [7]). Agents are used to manage resources in the system and allocate them to AGVs. This method has been shown to be deadlock free. However, the level of performance in terms of the number of deliveries made per hour was less than the performance of a comparable industrial system during those time the industrial system was deadlock free.

As the agent method was able to maintain deadlock free AGV flow during times that the industrial system was not it does appear to be a viable method of control if the performance could be improved. This paper presents research into improving the performance of the agent based AGV system by modifying the heuristics used during negotiation. The paper is of the following form; section II presents the method of flow control as sequential resource allocation; section III, presents the method of negotiation; section IV presents the modified negotiation heuristics; section V presents the experimentation conducted to evaluate the performance of the modified heuristics; section VI presents the results of those experiments; section VII presents a summary of the work undertaken; section VIII presents the conclusion from the experiments and section IX presents future work.

II. Sequential resource allocation in AGV systems

AGV systems are material handling systems. They provide a method of transporting material from one location to another in a manufacturing plant. A typical industrial manufacturing system consists of a set of one or more AGVs (A), a network (or guide path), referred to as a layout, defining the allowable paths that an AGV is permitted to travel on and a set of stations (G), which are located at points and define the load and unload locations for the AGVs. An AGV receives instructions from a central dispatcher instructing the AGV to collect a load from one station (the load station) and deliver it to another (the unload station). An AGV controller is, therefore, required to maintain the movements of the AGVs within a predefined world model.

Central to the AGV's method of navigation is the use of a layout which is a form of a free space world model. This model is constructed of a set of vertexes, called points (P), which defines xy coordinates within the world domain and a set of arcs,

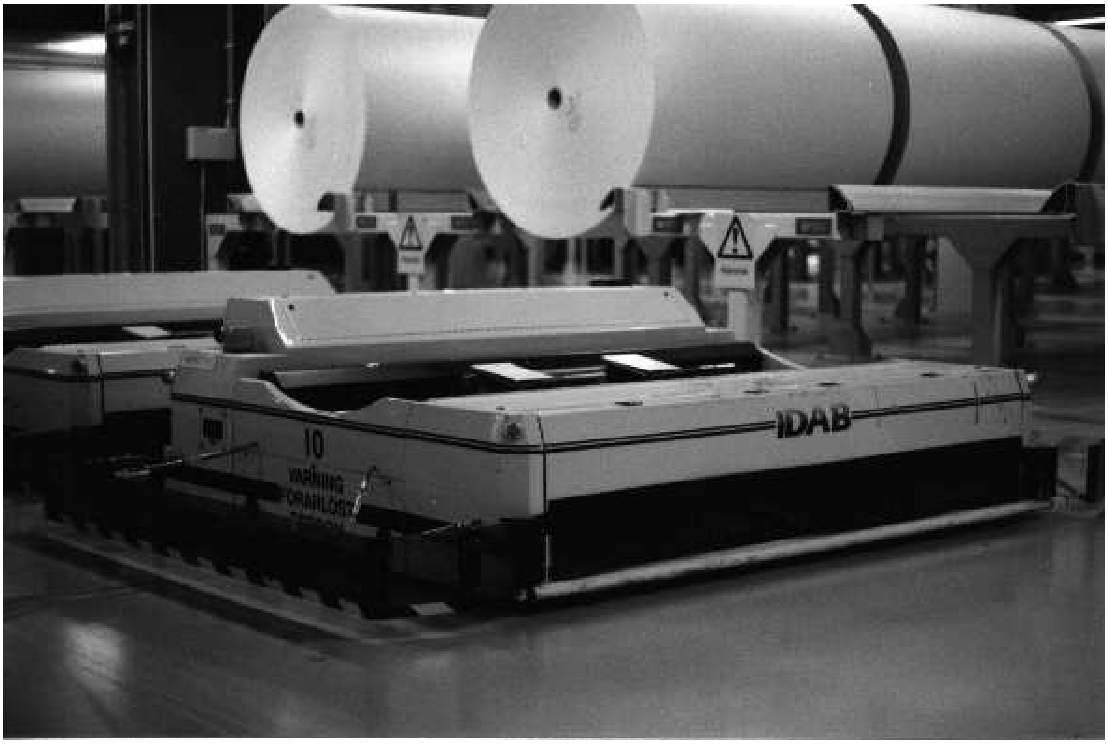

Fig. 1. An AGV

called segments (S), which define the paths from one point to another. Each has a capacity, $c(e) = 1$ (where $e \in P$ or $e \in S$). The segments are directed and, therefore, the layout can be considered to be a digraph, $D = (P, S)$. The unload and load stations, G, are located at points within the world domain (that is to say $G \subseteq P$). Therefore, for an AGV to be able to travel from station to station it requires a set of segments, called a route, that will define a path from station to station. In a typical industrial controller, the AGVs route (or part of it) is then allocated to the AGV and can only be utilised by the allocated AGV. Therefore, the segments and points of an AGV system can be considered to be the resources of the system. The movement, or flow, of AGVs can, therefore, be considered to be a sequential assignment, $f(e)$, of segments and points to AGVs such that $f(e) \leq c(e)$, where $e \in \mathbf{S}$ or $e \in \mathbf{P}$ and the flow control problem is then to maintain the movement of AGVs (see [8] and [9] for examples of research into sequential resource allocation). However, AGV systems have additional complexities that are not found in other sequential resource allocation problems.

A. *Blocking relationships*

As AGVs are physical devices, collisions between AGVs can occur and, therefore, for an AGV controller a method to prevent collisions must be implemented. For a typical AGV system this means introducing blockings. A blocking is an association between network elements on different paths such that if any one of the associated elements are allocated to an AGV all other elements can not be allocated to any other AGV. This results in an interference between otherwise non-connected paths through a digraph and can lead to deadlock or late deliveries occurring. A deadlock is a circular wait state where an AGV can not release its network resources until other AGVs have released theirs. The other AGVs can not release theirs until the first AGV has released its resources, thus the system is brought to a stand still.

B. *Deadlocks in AGV systems*

Deadlocks can be handled by prevention, prediction and resolution. Prevention is conducted at design time and can be difficult in large and complex AGV systems. It involves ascertaining all possible states that lead to deadlock and can lead to an under utilisation of resources. Prediction involves looking-a-head for deadlocks and carrying out appropriate action so the deadlock does not occur. This method has the disadvantage in that deadlocks may be detected too late for alternative action to be undertaken. Resolution is where the deadlocks are resolved when they occur. This can involve "breaking" the rules that govern the system and / or human involvement. An alternative method is to use a combination of approaches. One such combination is the utilisation of agents to control the flow of AGVs. Such a system uses local knowledge of the system to prevent and predict the occurrence of deadlocks at run time with some success.

C. Using Agents to maintain flow control

As flow control can be considered the sequential allocation of resources to AGVs this can be achieved by managing individual resources and allocating them as and when they are needed to AGVs. This can be considered a task and as such can be allocated to an agent. For the purpose of this research, an agent is considered to be an autonomous module that carries out one well defined task at a given level of abstraction. To achieve the overall system's objectives a set of inter communicated agents, called a society of agents, are utilised. For an AGV system, the resources are the segments and points as well as the AGVs. These resources can be managed by assigning an agent to each. However, this is not sufficient to prevent deadlocks as deadlocks can occur due to the way segments form groups (such as loops, where a path comes back to its starting point). Therefore, groups of resources, such as loops, are also required to be managed.

III. CONFLICT RESOLUTION

Conflicts occur in the system when one or more AGVs require a common resource such as a segment or point. Conflicts are detected when an agent attempts to ascertain the free state of another agent and finds other agents that require the same resource. When an AGV agent requires a route it initiates an enquiry with the first segment agent on its route to ascertain whether or not the segment that that agent manages is free and, therefore, can be allocated by the AGV agent. A segment agent always passes on any enquiry to the point agent managing its end point, as an AGV travels from point to point. The enquiry continues to the next segment and end point on route until it reaches an agent that manages a safe point or a mission point. A safe point is a point that has no blocking relationships. The enquiry also extends to other agents that form a blocking relationship with the segment or point agents on the AGV's route. When a conflict is detected the agents negotiate. If an agent lost negotiations it would attempt to redirect itself to an alternative destination. This was seen to be inefficient during the original experimentation with the agent based AGV controller as the negotiations did not take into account whether or not the losing AGV was able to be redirected, as in many cases it was not. This resulted in the AGVs remaining in the same position and re-negotiating after a time out. Negotiations would continue until an AGV that was able to be redirected lost negotiations.

IV. NEGOTIATION HEURISTICS

In an attempt to improve the negotiation algorithm a number of heuristics were introduced that take into account whether or not the AGV was able to be redirected to either a safe point or a mission point or both. The heuristics are as follows:

- Safe point then mission point
- Random
- Nearest on route
- Random nearest on route
- Safe points only
- Mission points only

For the safe point then mission point heuristic a list of safe points and mission points arranged in an arbitrary order where searched. For the random heuristic the same set of safe and mission points were searched but in a random order. The nearest on route heuristic search for the nearest safe or mission point that were on route and then the random variation search the same set of points in a random order. The last two heuristic searched a list of either all safe or all mission points in the system.

V. EXPERIMENTATION

To evaluate the performance of the heuristics a simulation approach was taken. To maintain as much realism as possible an actual industrial layout was utilised in the experiments and a simplified view of the layout is shown in figure 2. It consists of two loops with the direction of AGV flow indicated by the arrows. The layout is 30m wide and up to eight AGVs were used in the actual AGV system. The AGVs running in this layout are also known to encounter deadlock in the actual industrial system.

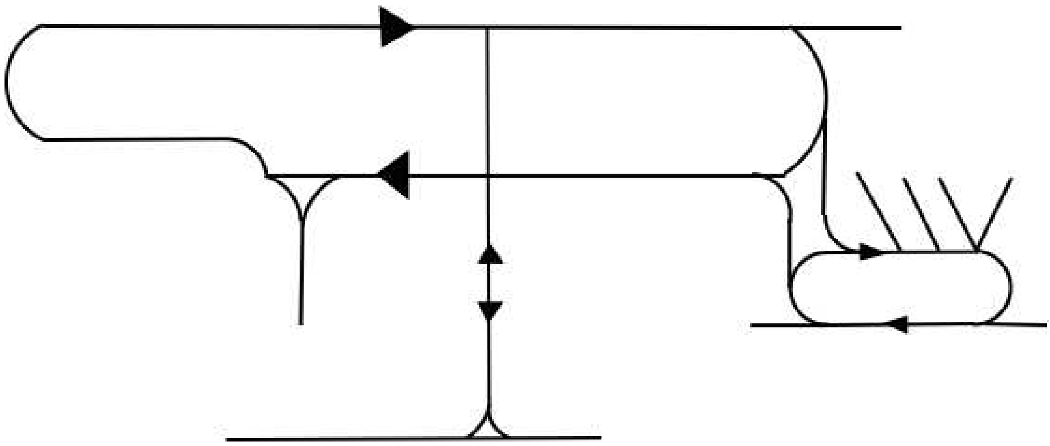

Fig. 2. AGV Layout Used in Experimentation

Four sets of experiments were conducted as follows:

- Variation in the number of AGVs
- Variation in the time-outs used for negotiation
- Path selection algorithm
- A Comparison of the industrial system using Automod

The number of AGV varied from two to eight, where one was considered a trivial case and eight was the maximum for the layout given. The time-outs were varied as this can have an effect on how long an AGV takes before a conflict is resolved and, therefore, effects the movement of other AGVs. To ascertain if the path selecting algorithm effected the performance with different negotiation algorithms two different path selecting algorithms were assessed. The first being shortest path and the second being the shortest free path. For a comparison a simulation was run using Automod to represent the performance of an actual industrial AGV system. Automod is an industrial simulation package for assessing the performance of an industrial system and, therefore, value judgements can be made. Each simulation was run for 30 hours in simulated time.

VI. RESULTS

Table I present the number of deliveries made per hour for varying number of AGVs using different heuristics. For each heuristic, as the number of AGVs increase the number of deliveries made also increases. However, the safe point then mission point heuristic delivers the largest number of deliver of 242 per hour. The next highest delivery rate of 227 was obtained from the safe point only heuristic. The random nearest on route produced the worse number of deliveries of 182 per hour.

Table II shows the number of deliveries made per hour for eight AGVs using the shortest free path algorithm for each type of heuristic used. This can be compared to the results for eight AGVs in table I as the shortest path algorithm was used for those results. It can be seen from the results that the shortest free path results in a decrease in the number of deliveries. For example, the safe point then mission point heuristic was 196 deliveries per hour for the shortest free path algorithm compared to 227 obtained with the shortest path algorithm. The random nearest on route heuristic, again, produced the worse results of 131 deliveries per hour. This lower performance achieved using the shortest free path can be attributed to the format of the layout. As it is constructed of loops the shortest free path will tend to be longer than the shortest path.

Table III presents the results from varying the time-out before negotiations began. The results are for 2s, 5s, 10s and 20s time outs with eight AGVs in the layout. Table I uses 15s time. The results show that as the time out is decreased the number of deliveries increase. The highest number of deliveries of 263 deliveries per hour was, again, achieved with the safe points then mission point heuristic. The random nearest on the way achieved the worse performance of 195 deliveries per hour.

The final table, table IV shows the results obtained from the Automod simulation and the original agent based AGV controller. Comparing the results from table IV and the best heuristic results from table III it can be seen that the safe point then mission point heuristic out performs the Automod simulation. The Automod simulation shows

Heuristic	Number of AGVs	Max. Number of Deliveries per Hour
Safe point then mission point	8	242
	7	218
	6	188
	5	159
	4	132
	3	99
	2	69
Random	8	213
	7	191
	6	168
	5	145
	4	120
	3	95
	2	68
Nearest on route	8	187
	7	167
	6	155
	5	141
	4	124
	3	99
	2	68
Random nearest on route	8	182
	7	166
	6	150
	5	140
	4	124
	3	98
	2	69
Safe points only	8	227
	7	203
	6	178
	5	153
	4	127
	3	100
	2	70
Mission points only	8	209
	7	191
	6	171
	5	150
	4	126
	3	99
	2	70

TABLE I

NUMBER OF DELIVERIES PER HOUR FOR DIFFERENT HEURISTICS WITH VARYING NUMBER OF AGVS

Heuristic	Max. Number of Deliveries per Hour
Safe point then mission point	196
Random	191
Nearest on route	135
Random nearest on route	131
Safe points only	174
Mission points only	182

TABLE II

RESULTS FOR THE SHORTEST FREE PATH USING 8 AGVS

a maximum delivery rate per hour of 224, whereas the safe point then mission point heuristic shows 263 deliveries per hour with a time-out of 2s. This can be attributed to the improved negotiations that allow an AGV that is capable of being redirected to be redirected thus improving the flow of AGVs.

Heuristic	Time outs	Max. Number of Deliveries per Hour
Safe point then mission point	2s	263
	5s	261
	10s	252
	20s	237
Random	2s	228
	5s	224
	10s	220
	20s	207
Nearest on route	2s	197
	5s	196
	10s	188
	20s	182
Random nearest on route	2s	195
	5s	192
	10s	187
	20s	179
Safe points only	2s	241
	5s	241
	10s	233
	20s	220
Mission points	2s	211
	5s	210
	10s	208
	20s	206

TABLE III
RESULTS FOR TIME-OUTS

Number of AGVs	Automod Results	Original Agent Based Controller Results
8	224	82
7	204	88
6	183	93
5	161	97
4	133	92
3	104	83
2	73	63

TABLE IV
AUTOMOD AND ORIGINAL AGENT BASED CONTROLLER RESULTS SHOWING THE NUMBER OF DELIVERIES PER HOUR

The safe then mission point heuristic takes into consideration all possible points that an AGV can be redirected to. The order does appear to have some significance as the heuristic out performed the random variation.

VII. SUMMARY

AGVs are a material handling system used in industry. AGVs follow a free space world model, called a layout, based on a digraph to navigate. Due to the nature of the digraph and AGVs it is possible for such systems to deadlock. An agent based AGV controller has been shown to maintain the flow of AGVs even in layouts that are know to deadlock when utilising a standard AGV controller. However the agent based controller has lower efficiency than an industrial controller during time when the industrial controller is deadlock free. In an attempt to improve the performance of the AGV controller a set of heuristics were used to improve the negotiation algorithm utilised in the agent based controller. Experiments were conducted using simulation and the results compared to the industrial controller as simulated using Automod and the original AGV controller.

It was found that a heuristic using safe points then mission points to ascertain whether or not it was possible to redirect an AGV improved the performance of the AGV controller significantly. This improvement was also found to increased if a low time-out value of 2s before negotiations commenced was also used. The overall performance was then found to be better than the Automod simulation.

VIII. Conclusion

Improvements were obtained by altering the negotiation algorithm, therefore, it can be concluded that an agent based controller that manages local resources and negotiates to resolve conflicts can offer an improvement in the flow control of AGVs when compared to an industrial controller as simulated by Automod. Further, it can be concluded that the optimal negotiation algorithm to use is one that takes into consideration the possibility of an AGV to be redirected based on selecting safe points then mission points. It can also be concluded that the time-out utilised before negotiation commence should be short (such as 2s).

IX. Future work

The current agent based AGV controller utilise agents to manage resources such that there is a one to one mapping between agents and resources such as AGVs, points and segments. Paths are allocated based on the free state of the resource managing agents. It could be advantageous to manage only groups of resources based on pathlets, where a pathlet would correspond to the minimum number of segment that can be allocated to an AGV. This could allow time sharing between AGVs that have a common pathlet on their respective routes. This is one area for future research.

An additional area of possible future research would be to research the allocation of resources utilising agents and local network knowledge in other network or sequential resource allocation systems, such as transport or logistic systems. In a logistic system the resources are the roads, railways, airways or shipping lanes and a "blocking" would be equivalent to road congestion or other stoppages such as an accident. The agent could manage local road segments or even pathlets and redirect goods as and when needed to maintain optimum flow.

X. Acknowledgement

The author would like to acknowledge the help and assistance give during this research project by Professor Ian Sillitoe of the Robot Research Group at the University of Borås in Sweden and Mrs E. Wallace BSc.

References

[1] C. Versteegt and A. Verbraeck, "Holonic control of largscale automated logistic systems," in *IEEE 5^{th} International Conference on Intelligent Transport Systems*, pp. 898–903, 2002.

[2] T. Ganesharajah, N. G. Hall, and C. Sriskandarajah, "Design and operational issues in agv-served manufacturing systems," *Annals of Operations Research*, vol. 76, pp. 109–154, 1998.

[3] J. M. A. Tanchoco and D. Sinriech, "Osl — optimal single-loop guide paths for agvs," *International Journal of Production Research*, vol. 30, no. 3, pp. 665–681, 1992.

[4] F. Taghaboni-Dutta and J. M. A. Tanchoco, "Comparison of dynamic routing techniques for automated guided vehicle system," *International Journal of Production Research*, vol. 33, no. 10, pp. 2653–2669, 1995.

[5] C. W. Kim and J. M. A. Tanchoco, "Operational control of a bidirectional automated guided vehicle system," *International Journal of Production Research*, vol. 31, no. 9, pp. 2123–2138, 1993.

[6] A. Wallace, "Application of ai to agv control — agent control of agvs," *International Journal of Production Research*, vol. 39, no. 4, pp. 709–726, 2001.

[7] A. Wallace, "Flow control of mobile robots using an intelligent agent system," in *EUREL European Advanced Robotics Systems Masterclass and Conference - Robotics 2000*, April 2000.

[8] S. A. Reveliotis, M. A. Lawley, and P. M. Ferreira, "Polynomial-complexity deadlock avoidance policies for sequential resource allocation systems," *IEEE Transactions on Automatic Control*, no. 42, pp. 1344–1357, 1997.

[9] A. Wallace, "Sequential resource allocation utilising agents," *International Journal of Production Research*, vol. 41, pp. 2483 – 2500, July 2003.