Modelling and Analysis of an Integrated Automated Guided Vehicle System using Coloured Petri Net

Tauseef Aized, Koji Takahashi, Ichiro Hagiwara

Abstract— **This paper analyses an automated guided vehicle system which is embedded in a multi-product, multi-line, multi-stage flexible manufacturing system. Three different guide path configurations have been developed for this study and the performance of the manufacturing system has been discussed from the perspective of these configurations. The system has been modeled through coloured Petri net method and some of the results are presented**

Key words— **automated guided vehicle system, coloured Petri Net, performance measurement**

I. Introduction

In modern manufacturing environments, automated guided vehicle systems (AGVS) have become an integral part of overall manufacturing systems. An AGVS contains one or more Automated Guided Vehicles (AGVs) which are driverless vehicles used for horizontal movement of materials. AGVs are commonly used in facilities such as manufacturing plants, distribution centers, warehouses and transshipments. While designing an AGVS, many strategic, tactical and operational issues have to be considered. The main ones are: guide path design, estimating the number of vehicles required, vehicle scheduling, routing and deadlock resolution. An AGVS is a discrete event dynamical system (DEDS) which is event driven, asynchronous and non-deterministic in nature. Petri Net are powerful techniques to model such systems in that they can handle complex system modeling concepts and constraints. Moreover, coloured Petri net (CPN) provides compact models of large systems with a higher level of abstraction [1]. Hence, this study uses CPN method for modeling the system.

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The contribution of this study is that it analyses three different guide path configurations for an integrated automated guided vehicle system which is embedded in a flexible manufacturing system. These guide path configurations have been developed in such a way that in the first case, an AGV has been allowed to serve only same machine resources thus forming a dedicated relationship between machines and the AGVs. The second configuration explores a limited flexibility as AGVs can serve every machine and the assembly station relevant to a specific manufacturing cell. In the third case, the flexibility of the AGVS is increased and every AGV can visit any machine or assembly station throughout the manufacturing system. Thus the aim of the development of the AGVS configurations is to gradually enhance the flexibility in AGVS and examine the performance for each configuration so that the best configuration can be proposed. The details of these three AGV guide-path configurations are discussed in section 3. Two of the three configurations have mixed uni/bidirectional guide-path layouts. Moreover, this study also presents the application of advanced tools like CPN Tools and shows how these powerful tools can be used to analyze a manufacturing system.

II. Coloured Petri net (CPN):

This study uses the definition of CPN given in [2].A hierarchical CPN is a tuple HCPN= (S, SN, SA, PN, PT, PA, FS, FT, PP) satisfying the following requirements

1. S is a finite set of pages such that:
   Each page $s \in S$ is a non-hierarchical CPN:
   CPN= ($\sum$s, Ps, Ts, As, Ns, Cs, Gs, Es, Is)
   (The non-hierarchical CPN is defined in [2])
   The sets of net elements are pair wise disjoint:
   $\forall\ s_1, s_2 \in S: [s_1 \neq s_2 \ \Box\ (Ps_1 \cup Ts_1 \cup As_1) \cap (Ps_2 \cup Ts_2 \cup As_2) = ø\ ]$.
2. SN $\Box$ T is a set of substitution nodes.
3. SA is a page assignment function. It is defined from SN into S such that: No page is a sub page of itself:
   $\{ s_0\ s_1 \ldots s_n \in S^* \mid n \in N_+ \ \Box s_0 = s_n \ \Box \forall k \in 1..n: s_k \in SA(SN_{sk-1})\} = ø$.
4. PN $\Box$ P is a set of port nodes.

5. PT is a port type function. It is defined from PN into {in, out, i/o, general}.

PA is a port assignment function, FS □ Ps is a finite set of fusion sets, FT is a fusion type function and PP $\in S_{Ms}$ is a multi-set of prime pages. For details of PA, FS and FT, we refer to [2]. The conceptual details of CPN from practical view point are also given in [3].

III. AGVS CONFIGURATIONS:

This study is an extension of our previous studies [4] and [5]. It is aimed to extend the FMS modeling of [6] by integrating the AGVS with previously developed FMS. The overall configuration of the FMS [6] is shown in figure 1. It has two manufacturing and one assembly cells where as each manufacturing cell has two production lines and the assembly cell has two assembly stations.

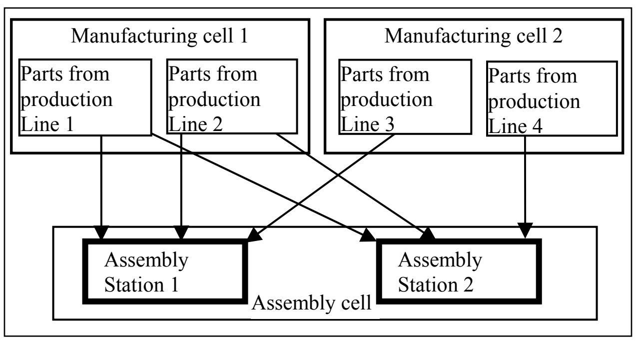

Figure 1 : Overall manufacturing system

The integrated AGVS is analyzed by developing three guide-path configurations of AGVS. These configurations range from rigidly dedicated to flexible relationships between AGVs and machines. In configuration 1 (C1), AGVS is modeled in a way that an AGV is provided between any two adjacent machines or a machine and the assembly station .Each AGV is serving corresponding machines in both production lines of a manufacturing cell and this holds true for both cells. This configuration, shown in Figure 2, has rigid relationships between AGVs and the machines/ assembly stations. The rigid AGV-machine relationship of C1 is relaxed in configuration 2 (C2). Here, a dock has been developed for the parking of all AGVs in each manufacturing cell. All the AGVs are allowed to serve any pick, pick/ delivery or delivery point within a manufacturing cell and the corresponding assembly station but the AGVs can not serve the other manufacturing cell or assembly station. In this configuration, a limited flexibility is added in the AGVS. This is shown in Figure 3. The limited flexibility of AGVS of C2 has been enhanced in configuration 3 (C3) where all AGVs are parked at one dock and every AGV can serve any pick, pick/delivery or delivery point throughout the FMS. This is shown in Figure 4. C1 has a bidirectional whereas C2 and C3 have a mix of uni/bidirectional guide path layouts.

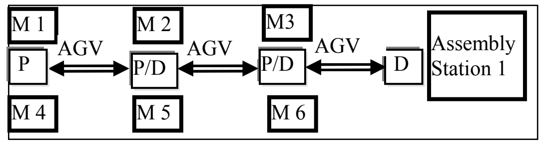

Figure 2: AGVS Configuration 1

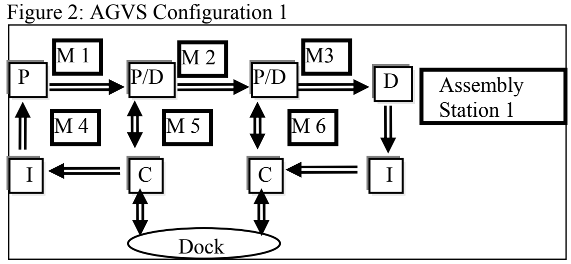

Figure 3: AGVS Configuration 2

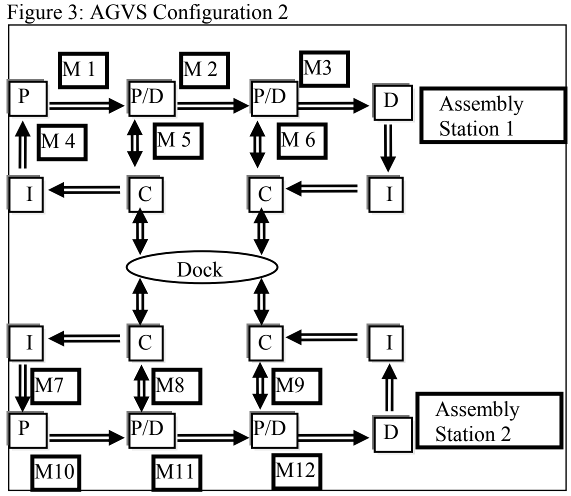

Figure 4: AGVS Configuration 3

Legend: M (i) --Machine (i), P--Pick up point, P/D--Pick/Delivery point, D--Delivery point, C--Control point, I--Intersection point.

IV. CONTROL POLICY:

The main objective of the control policy is to satisfy demands for transportation as fast as possible and without occurrences of conflicts among AGVs. The control of AGVS is developed in a way that it is hierarchical in nature and has two layers of hierarchy. The first layer represents the overall control of AGVS whereas the second layer which contains Controllers 1, 2 and 3 act to control the first, the second and the third Machines' pick and/ or delivery points on each production line respectively.

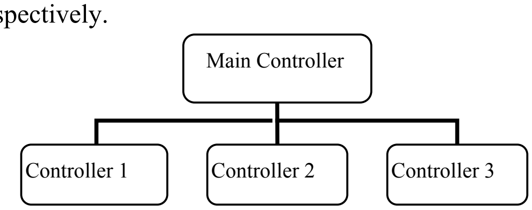

Figure 5: AGVS hierarchical control format

Due to non-deterministic nature of the manufacturing system, on-line scheduling methodology has been used. We have used multi-attribute workstation initiated dispatching rule. This multi-attribute dispatching rule consists of two rules, that is, Shortest Travel Distance First (STDF) rule and Look ahead dispatching rule, as all AGVs are scheduled depending upon the shortest distance and look ahead policy. The look ahead rule uses advance information about the loads to be available shortly to dispatch vehicles. The joint use of these two rules makes vehicles available too quickly and hence improves overall system performance. The deadlock and collision is avoided by specifying the capacity of each guide path in this model.

V. CPN MODELING:

The model is developed by using CPN Tools which is a CPN based program developed on the basis of CPN ML language. The CPN ML language is derived from Standard ML which is a general purpose Language. All transportation operations are modeled using exponential distribution functions. The Model has a three-layered hierarchical format as is shown in Figure 6. It has a super page ‘Model’ and eight pages which are connected to ‘Model’ through hierarchical relationships, only one sub page ‘AGV Control 1’ is shown in Figure 7 due to space limitation.

VI. SIMULATION ASSUMPTIONS:

The following are the simulation assumptions:

- The lengths of all guide path segments are the same.
- When any AGV enters into any guide path segment, it will continue traveling till the end of the segment.
- The AGV speed for all segments path is the same.

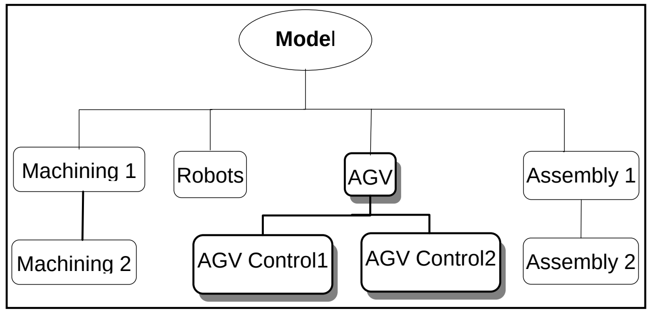

Figure 6: Model Format showing hierarchical relationships.

VII. RESULTS AND DISCUSSION:

Table 1 gives the summary of all input factors and output responses for this study. Among the input factors, number of AGVs is the only factor which is not available in C1. This is because C1 has a fixed number of AGVs due to rigid relationship between machine/ assembly station and AGVs. All input factors are changed over five levels which are shown in Table 1. The output responses are mean throughput, mean cycle time, mean WIP and mean AGV response time. The response time is not calculated for C1 because AGVs are only serving the specific pick, pick/ delivery and delivery points and are almost immediately available when are needed and hence AGV response time is negligibly small. This study uses four stage SPC approaches [7] to find out steady state results.

Table 1: Input Factors and Output Responses

	Input Factors							Output Responses	
Configurations	Factors	units	L 1	L 2	L 3	L 4	L 5	Responses	units
C1,C2,C3	NoK	Number	1	2	3	4	5	Mean Throughput	Number of Products/ day
	MLT	minutes	1	2	3	4	5	Mean Cycle Time	minutes
	MMT	minutes	5	10	15	20	25	Mean WIP (MWIP)	Number of Products
	MAT	minutes	5	10	15	20	25	Mean AGV utilization	% time
C2, C3	AGV	Number	2	4	6	8	10	Mean AGV Response	% time

L: level, NoK: number of kanbans, MLT: mean material loading/ unloading time, MMT: mean machining time, MAT: mean assembly time, AGV: number of AGVs, % time: percentage of total time

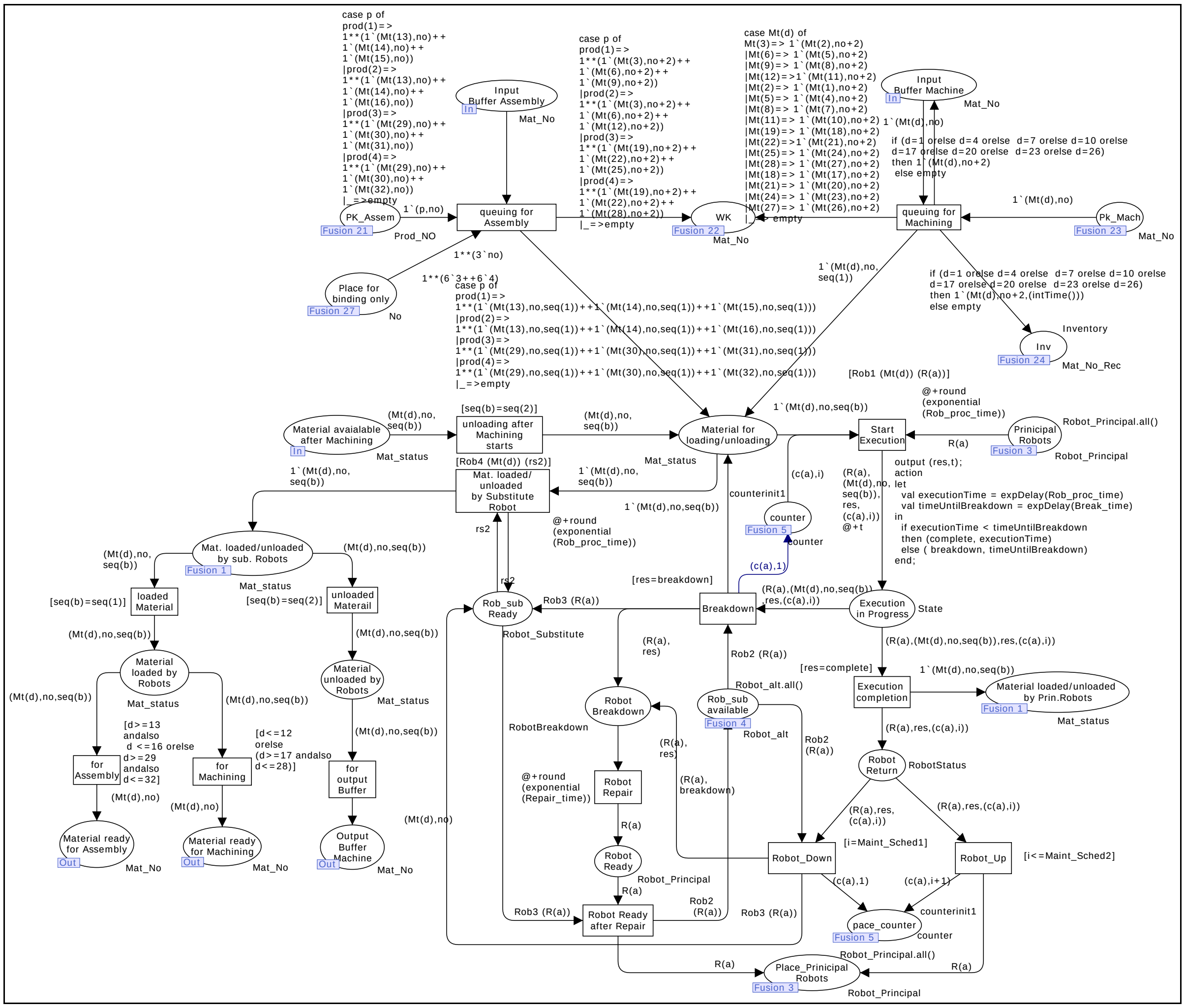

Figure 7: A snap shot of sub page "AGV Control1" taken from CPN Tools

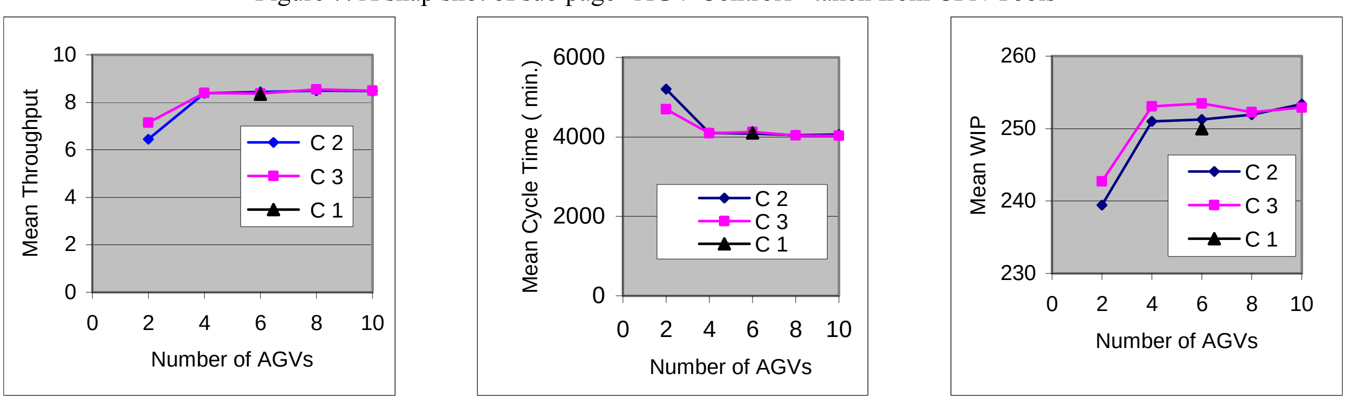

Figure 8: The Impact of Guide-Path Configurations

Figure 8 shows the relationship between the guide-path configurations and the performance measures. There is only one datum point for C 1 in all these graphs because C1 has a fixed number of AGVs which is six. The mean throughput of the FMS is increasing as number of AGVs increases in both C2 and C3 but this increase is not significant beyond four numbers of AGVs. This graph also shows that if C1 is used, the throughput is almost the same as that of four numbers of AGVs in C2 and C3. The cycle time is decreasing as number of AGVs increases up

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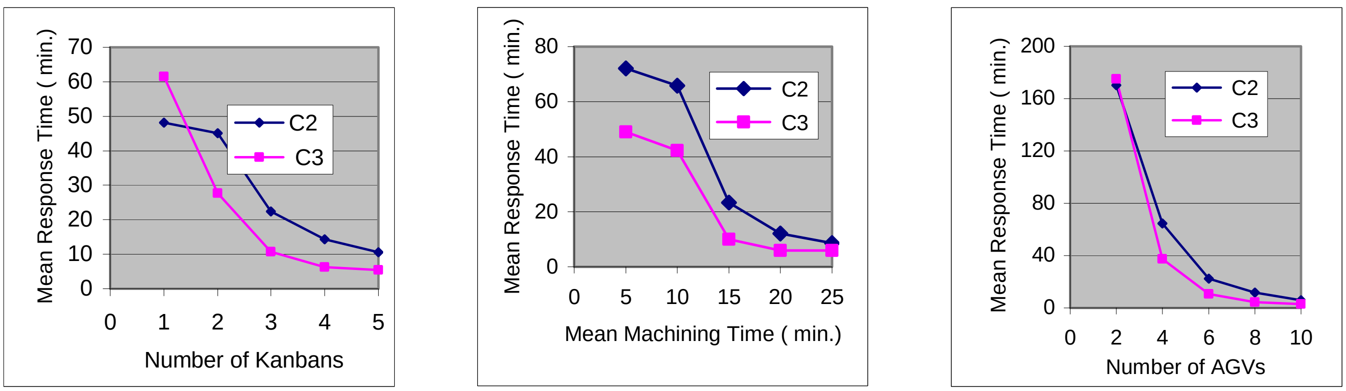
to four numbers of AGVs, beyond which there is no further decrease shown. The same trend is shown for Mean WIP. From all these graphs, it is clear that if we use four numbers of AGVs in either C2 or C3, it can yield the same performance levels as that of C1 in which there are six numbers of AGVs. From this, it is concluded that when flexibility is added to a rigid AGVS in terms of guide-path configurations and number of AGVs, the same performance measures can be achieved by decreasing the number of AGVs from six to four. This indicates a decrease in both capital and running cost of the overall system due to lower number of AGVs. The graphs of Figure 9 show the impact of the guide-path configurations on AGV response time. Here, C1 has not been considered because C1 has a dedicated AGVS and the response time of AGVs, whenever these are called from any workstation, is negligibly small as these have to serve only specific pick-up points. As the number of kanbans is increased, the AGV response time is decreased but this decrease is more significant in C3 than in C2. This indicates that C3 which is more flexible exhibits less response time than C2. The same trend is shown when mean material loading/ unloading time, mean machining time and mean assembly time is increased. If the number of AGVs is increased, the AGVs response time is decreasing as more AGVs means their quick availability, again C3 shows quicker availability than C2. At a number of ten AGVs, the AGV response is almost equal to the dedicated guide path configuration that is C1. This concludes that the performance of AGVS in terms of mean response time is improving when flexibility is added to the AGVS as C3 has lower response time than C2.



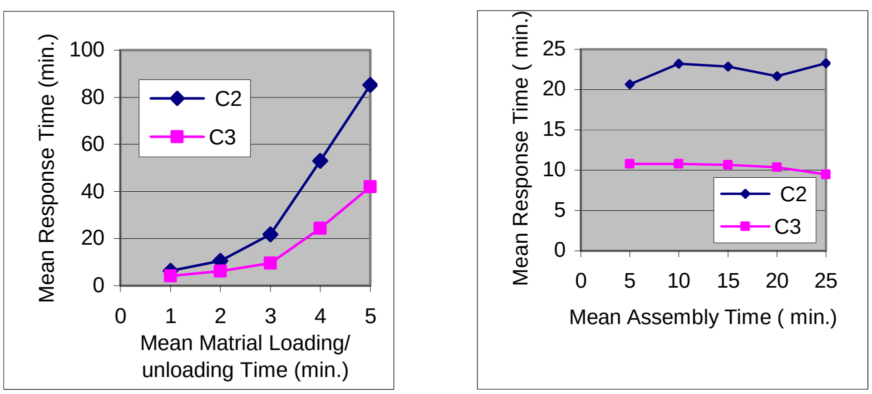
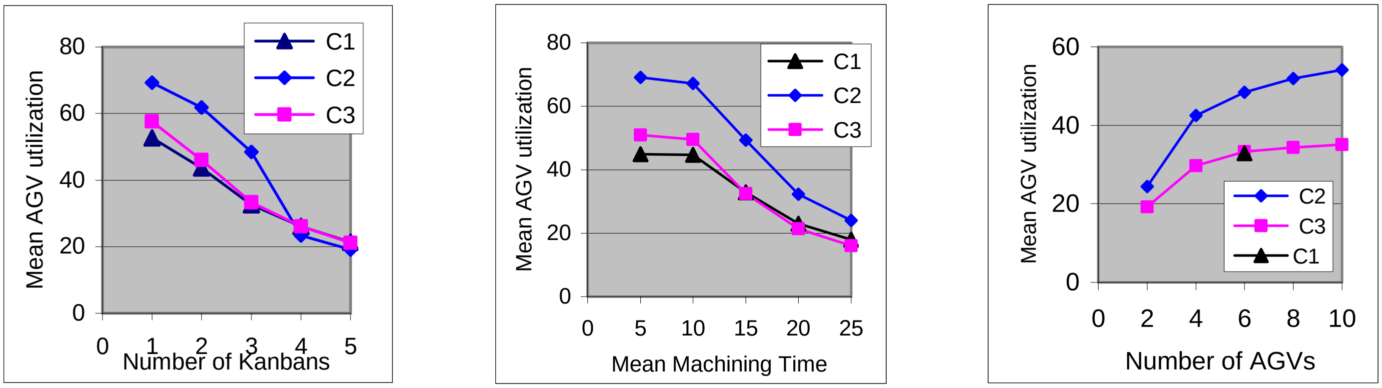
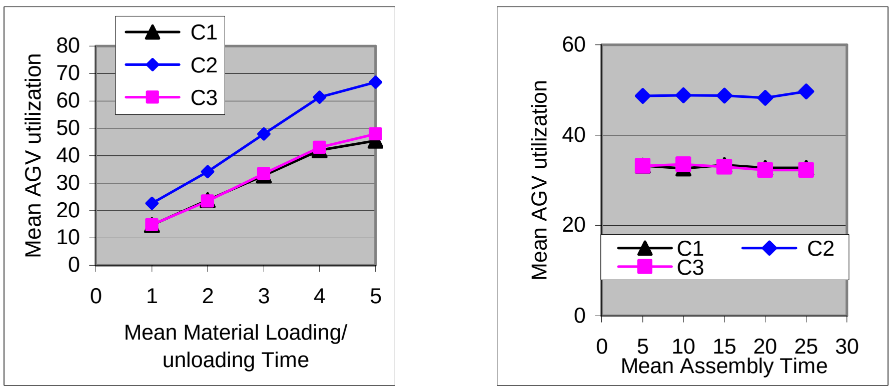


Figure 9: Impact of guide- path configurations on AGV response time

Figure 10 shows the impact of guide-path configurations on AGV utilization. The AGV utilization decreases with an increase in number of kanbans for all C1, C2 and C3 but utilization is higher in C2 compared with other configurations whereas it is almost same in C1 and C3. The same trend is shown for other input factors like mean material loading/ unloading time, mean machining time, mean assembly time and number of AGVs.





Apparently, it seems that C2 is better than other configurations as far as AGV utilization is concerned but higher response time of C2 compared with C3 indicates that the higher utilization of C2 is due to the fact of its delayed availability compared with C3. Hence, it is concluded that C3 is better than C2, although its AGV utilization is lower than C2.

Figure 10: The relationship between guide-path configurations and AGV utilization

VIII. Conclusion

This study has attempted to apply advanced tools of coloured Petri net method to model and analyze the practical constraints of an integrated automated guided vehicle system. The responses have shown improvement as the AGVS guide path flexibility has been increased. We want to extend this study to analyze more characteristics of AGVS which include AGV congestion. Also, the utilization of other resources like machines and robots will also be calculated and finally this study will attempt to find best guide path configuration based on FMS performance using design of experiment and response surface methods.

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