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## Conference Paper

# Review of Comprehensive Approaches in Optimizing AGV Systems

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# Review of Comprehensive Approaches in Optimizing AGV Systems

*Isidro Ramos Torres, Luis Felipe Romero Dessens, José Luis Martínez Flores  
and Elías Olivares Benítez*

This paper shows how researchers have focused their optimization studies in AGVs design and control optimization. This article discusses comprehensive approaches identified in other research papers. The four features examined were: focus-problem, solution methodology, manufacturing environment, and metrics. The five different optimization environments recognized and used to explore the AGV's performance were: facilities design, production planning, scheduling of machines, manufacturing system and design-control. Based on statistical tools, trends are identified in integrated approaches and maps of the conditions of the approach and solution methodologies.

**Keywords:** Material Distribution, Comprehensive Approach, Operational Control, AGV System

## 1 Introduction

Material Handling (MH) is a set of activities that has important implications on the performance of a manufacturing plant, warehouse, distribution centres, and container terminals. MH is composed of activities of distribution, storage, packaging and Control of materials (ASME; IMMS, 1985). Tompkins, et al., (2003) highlight the importance of MH, which represents between 30% up to 75% of the cost of manufacturing a product, MH utilizes around 25% of the total staff, uses up to 55% of the total space and uses up to 87% of the time of all activities.

Materials distribution (MD) is considered a relevant source of opportunities that provides important challenges to industry (Anbuudayasankar, et al., 2014). The dynamic conditions of the technological environment and competitiveness in the industry have added new elements to the problems mainly derived from the application of new technologies such as: the electronic data exchange (EDI), Global Positioning System (GPS), Geographic Information System (GIS), Intelligent vehicles-Systems of roads (IVHS) (Psaraftis, 1995).

The technological innovation in AGVs (Automatic Guided Vehicles), AGCs (Automatic Guided Cars) and hybrids Fork Lift Truck systems has been growing since year 2005 (Vis, 2006). It has made available increasingly autonomous vehicles equipped with better communication, liaison and information processing systems. These increased capacities facilitate dynamic operation of problems of AGVs in MD (Psaraftis, 1995). The MD using AGVs has additional features to the classical problem of distribution VRP (Vehicle Routing Problem), mainly derived from a dimensional scale; among these features are included: the possibility of collisions of AGVs, the need for

routes design, for determining the frequency of travels, and for design of load capacity, among others (Qiu, et al., 2002).

The ways to address MD problems also evolve given the greater demands of the competitive environment and the innovation in the aforementioned technologies. The evolution of research approaches in this field changed in several areas, in some with more advances than others. This research is limited to 49 articles published in the last ten years related to the optimization of AGVs systems in different manufacturing environments. Also, this paper characterises the used approaches in design and control AGVs systems in MD through the identification of 4 features: Approach, Solution Methodology, Manufacturing System and Metrics. The incidence of various comprehensive approaches and their relationship with the other attributes are explored as the main issue here.

This article is organized in sections as follows: Section 1 describes the model used for the literature characterisation, Section 2 shows the main approaches characteristics found in the literature, Section 3 contains a discussion of the statistic results and summary of single and comprehensive approaches and finally, Section 4 presents the study conclusions.

## **2 Characterisation Model**

The Problems about optimizing design and control of AGVs systems are related with operational and tactical decisions (Vis, 2006). Often these decisions are taken to solve different problems and are treated jointly since

they have an interactive relationship. Sequenced or simultaneous treatments with one or more matching objectives of tactical/operational problems are referred here as comprehensive approaches.

Each item of literature was characterized in a binary table of occurrences recorded in the form of the attributes: 1) Specific types of problems treated, 2) solution methods, 3) manufacturing environment and 4) metrics. The first attribute element contains the focus of each article, which is the element that identifies and groups the revised papers.

The occurrence proportions of each element's attributes were obtained, and Pareto charts were used to identify usage trends. Once grouped, proportions for each approach were calculated.

### **3 Identification of Simple and Comprehensive Approaches**

Four types of problems associated to the Design and Control of AGVs systems were found in this review: designing AGVs systems, controlling AGVs systems, Scheduling of Machines, Production planning and Design of Facilities, all in a given manufacturing environment. The Comprehensive approaches are graphically represented by intersections as shown Figure 1.

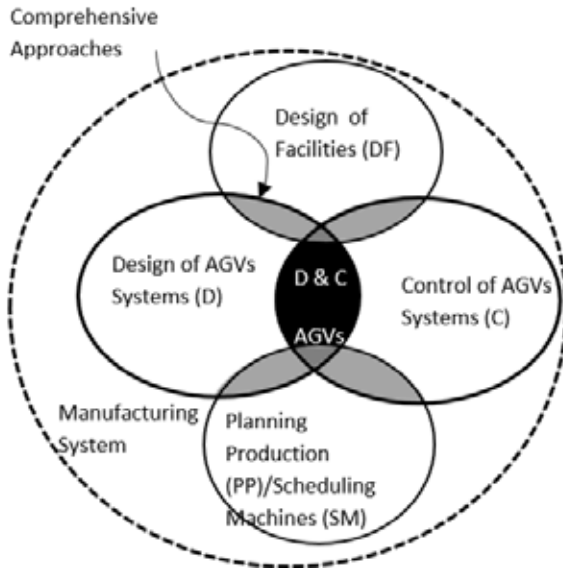


Figure 1 Associated problems to the Design and Control of AGVs systems  
(source: own contribution)

The literature characterization allowed the identification of comprehensive approaches as shown in Figure 1; the comprehensive approaches are:

C-D: Control and Design of AGVs systems,

C-DF: Control of AGVs systems and Facilities Design,

C-D-FD: Control and Design of AGVs systems and Design of facilities,

C-FD: Control of AGVs and Design of facilities,

C-PP: Control of AGVs systems and Production Planning,

C-MS: Control of AGVs systems and Scheduling of Machines,

D-FD: Design of AGVs and Design of Facilities,

D-PP: Design of AGVs systems and Production Planning.

Figure 2 shows the comprehensive approaches that were found and their classification as tactical and/or operational problems in a cross table.

| Operational problems     | Tactical problems       |                        |                          |      |
|--------------------------|-------------------------|------------------------|--------------------------|------|
|                          | AGVs Systems Design (D) | Facilities Design (FD) | Production Planning (PP) |      |
| AGVs systems Control (C) | C-D                     | C-FD                   | C-PP                     | C-MS |
| Machines Scheduling (MS) | Not found               | Out of interest range  |                          |      |
|                          | D-FD                    |                        |                          |      |
|                          | D-PP                    |                        | D-PP                     |      |

Figure 2 Comprehensive approaches found (source: own contribution)

## 4 Essential Features of Approaches of Papers

This section describes the single and integrative approaches identified in the literature and their relationship with solution methodologies.

### 4.1 Single Approaches

#### 4.1.1 AGVs Systems Control

The AGVs systems design includes problems of: routes design, traffic management, determination of Pick-up and Drop-off points (P/D), number and location of points, fleet size determination, idle points number and location, battery management and fault management. AGVs control issues can contain activities such as: dispatching of loads, route choice and AGVs scheduling (Vis, 2006).

#### 4.1.2 AGVs Dispatching

Dispatching can be done in two ways: 1) Assign the AGV charge (WorkCentre-initiated) or 2) Assign an available AGV load (Vehicle-initiated) (Vis, 2006). The WorkCentre-initiated for the study of dispatching is used by Bin Md Fauadi, et al. (2013), in addition they investigate the effect of multi-loads using an integer programming model. Moreover Confessore et al. (2013), treat the dispatching strategy vehicle-initiated using a minimum cost flow network model and obtain solutions by linear programming and heuristics.



### 4.1.3 AGVs Scheduling and Routing

Lin, et al., (2006) analysed the Scheduling and routing of AGVs using an evolutionary algorithm called i-awGa. Aized, (2009) studies the impact of the route flexibility using Petri nets.

### 4.1.4 AGVs scheduling and routing dynamic features

Some researchers added elements of the AGVs dynamics such as traffic conflicts and route flexibility. Strategies to avoid these difficulties are different, some use mathematical models through heuristic and meta-heuristic algorithms and/or with exact solutions. Duinkerken, et al. (2006), studied the scheduling and free of conflicts short route allocation problem. Also, Strap, et al. (2007) solved this problem by mixed integer programming. Kesen & Baykoc (2007) dealt with the allocation problem under a Just in Time (JIT) philosophy where bi-directional route flow was allowed. Nishi, et al., (2009) raise the problem of routing using a timed Petri nets model whose solution is optimized by heuristics. Nishi & Tanaka, (2012) use a Petri net model combined with evasion of conflict rules.

Ghasemzadeh, et al. (2009) addresses the free bi-directional conflict in a network topology problem proposing a heuristic algorithm. Liu & Kulatunga (2007) studies the same case using a Simulated Annealing (SA) and an ant colony optimization (ACO) algorithm; Likewise Udhayakumar & Kumanan (2010) propose a GA and ACO algorithm to optimize workload balance, minimising transportation time and maximising the AGVs use. In order to avoid traffic conflicts, Chiew & Qin (2009) address the problem on a large scale by proposing a concurrent bi-tonic algorithm. Other research predicts possible collisions, such is the case of Nishi, et al. (2007), which

added a sequence of re-routing and predicts the probability of collisions through Markov Chains. Fazlollahtabar & Mahdavi-Amiri, (2013) add the uncertainty of machines, operators and products in a genetic algorithm controlled by fuzzy logic.

Real-time data allows greater dynamism in the decisions under this environment. Nishi, et al., (2006) dealt with the problem of routing under an environment of real time requirements (dynamics). The developed algorithm is based on mathematical programming in a strategy of parallel computing.

## **4.2 Comprehensive Approaches of Papers**

### **4.2.1 Design & Control of AGVs systems (D-C)**

The design and control of AGVs systems have a mutual relationship due to the effect of the decisions of one over the other and their effect on the overall system performance (Vis, 2006). This interaction makes it necessary to use integrative approaches, not only between design and control problems but also with other collateral problems.

#### **4.2.2 Scheduling and Routing**

Xidias & Azariadis, (2011) studied the sequencing and routing of autonomous vehicles considering the restrictions of space available for movements, which suggests a bounded surface genetic algorithm.

#### **4.2.3 Forming Tandems and Independent Zones**

Tandem formation consists of partition in materials demand areas. This suggests the circuit formation with non-overlapping routes which allow

material transfer points. Tandem formation is a form of establishing control through the design of circuits and P/D points and that the vehicles are commonly exclusive for each tandem.

In this review numerous approaches based on tandems and independent zones were found, such is the case of Shalaby, et al. (2006) who present a two-way route tandem formation approach in which a binary programming and a probabilistic model are combined to estimate the amount of empty travel. Ho & Liao (2009) propose the formation of zones of load sharing and dynamic control whose objective is to determine the amount and area size of each zone; it uses procedures of partition and Simulated Annealing algorithm (SA). ElMekkawy & Liu (2009) dealt with the same case by adding the problem of AGVs programming using two-way route tandems, used a mimetic algorithm Genetic Algorithm (GA) and local search. Rezapour, et al. (2011) designed Tandems and assign bi-directional paths to unique vehicles: the solution model proposed integrates (SA) and tabu search (TS). Multiple load strategy is used by Kim & Chung (2007) in addition to the approach by Tandems and sequencing of AGVs using Traveling Sales Problem (TSP) and Markov chains.

Definition of independent zones differs slightly from the tandems, since a zone does not use material transfer points. This criterion is used by Namita, et al. (2011), who proposed the partition of exclusive areas of demand to avoid traffic conflicts. The proposal is based on heuristic rules that include a simulation model. Zheng, et al. (2013) proposed the formation of non-exclusive areas, which was conducted by simulation test bench.

In an effort to design a system of AGVs and evaluate control, Kahraman, et al. (2008) dealt with the problem viewing the load capacity of the AGVs.

The proposed model evaluates performance through Markov Chains to avoid the uncertainties of the AGVs operation.

#### **4.2.4 Control of AGVs Systems & Scheduling Machines (C-MS)**

Integration of programming AGVs and machines is a very common approach in AGVs system optimization. The synchronization of both activities has been found to allow the manufacturing system to work better.

In this review we found similar approaches with a diversity of solution proposals. The most common is the use of genetic algorithms, such is the case of Kumar, et al., (2011), which proposes a GA integrated into a computer system. Jerald, et al., (2006) propose an Adapted GA (AGA). Reddy & Rao, (2006) create a GA hybrid with ordering non-named (NSGA-II). In a multi-objective study, Chen, (2008) proposes a (MOGA) Mimetic algorithm that considers operation machining times, balancing workload of machining and ability of inheritance (MEFI) is used in a multi-agent approach. Erol, et al., (2012) used artificial intelligence to generate solutions in real-time.

#### **4.2.5 Control AGVs & Production Planning (C-PP)**

When manufacturing system elements operate asynchronously, to obtain an adequate operation is more complicated. The synchronization strategy is used for production planning, machine programming sequences and material handling activities. Fazlollahtabar et al., (2010) propose a mathematical programming model which considers demand fluctuations and restrictions of machines integrated to AGVs programming. Using mixed integer programming Khayat, et al., (2006) developed a production and dispatching model of AGVs programming. Nishi, et al. (2011) addressed the

same problem adding free of conflict traffic and bi-directional ways routing using a mixed integer programming model.

Sequencing of AGVs and production scheduling is integrated by Udhaya-kumar & Kumanan, (2012), using a model based on ACO and PSO; their algorithm considers the number of AGVs empty returns. Tuma, et al., (2013) used Buffers flags and a genetic algorithm model (AGA + TS) for production and AGVs programming. They considered the demand variability as a stochastic element. The model is optimized using Response Surface Methodology (RSM).

#### **4.2.6 Design AGVs Systems & Design of Facilities (D-FD)**

The inside distribution formation and determination of each tandem is an issue addressed by Salehipour & Aloha, (2014) using an integer programming mixed model. Gamberi, et al. (2009) approached the buffers space required model (ILFA) and used the Hillier's rules based on a linear programming model. Ventura & Rieksts, (2007) focused in a dynamical approach to locate idle points in the P/D. A non-linear integer programming model was proposed to solve this approach.

#### **4.2.7 Control of AGVs Systems & Facilities Design (C-FD)**

Some elements of the facilities design were found in an integrated way, they are: the P/D point's location, idle/ dwell and supply sources as well as the inside tandems layout. The following subsections show the description of the integration of Facilities Design into AGVs control systems problems.

#### 4.2.8 P/D (Pick-up and Drop-off Points)

Lee & Srisawat, (2006) investigated the effect of heuristic rules in the dispatching and P/D location points, under a strategy of multiple-load using simulation models. Also Asef-Vasiri, et al. (2007) integrated the determination of routes and P/D location points, on one-way circuits that uses heuristics and binary integer programming for neighbourhood search. The route planning is also treated by Nishi & Maeno, (2010) modeled by Petri nets decomposition with several independently created subnets to locate the delivery places for each subnet. The algorithm for the shortest path has a time penalty function.

#### 4.2.9 Location of Idle/dwell (I/D) AGVs Points

Location of the (I/D) points is treated in Ventura & Rieksts (2009) by integrating the dynamic programming routing in a model restricted by AGVs time availability.

## 5 Statistical Results

To determine the approach trends and their relationship degree, the papers were examined to identify their manufacturing environment, solution methods and used metrics, using counting techniques, Pareto charts and proportion estimates  $\hat{p}$ .

## 5.1 Statistics of Single Approaches

Tables 1, 2 and 3 show the estimated incidence rate  $\hat{p}$  of individual approaches, manufacturing systems, solution methods and metrics, respectively. Table 1 shows that studies dealing with AGVs Control issues (individual and integrated) have a use proportion of at least 80%. Also FMS environments are used in 85% of cases, as shown in table 2. Table 3 shows that solution methods have a more homogeneous proportion use. However, the most recurring methods are integer programming, heuristics, genetic algorithms (including evolutionary) and simulation.

Table 1 Incidence ratio for single approaches

| Approach | Frequency | $\hat{p}$ | $\pm \text{int (95\%)}$ |
|----------|-----------|-----------|-------------------------|
| C        | 44        | 0.898     | 0.085                   |
| D        | 19        | 0.388     | 0.136                   |
| MS       | 9         | 0.184     | 0.108                   |
| FD       | 8         | 0.163     | 0.103                   |
| PP       | 6         | 0.122     | 0.092                   |

\* Frequencies are not mutually exclusive

\*\*Sample size n=49

Table 2 Incidence ratio for manufacturing systems

| Manufacturing system | Frequency | $\hat{p}$ | $\pm \text{int (95\%)}$ |
|----------------------|-----------|-----------|-------------------------|
| FMS                  | 42        | 0.857     | 0.098                   |
| Job Shop             | 29        | 0.592     | 0.138                   |
| Flow Shop            | 23        | 0.469     | 0.140                   |

\* Frequencies are not mutually exclusive

\*\*Sample size n=49

Table 3 Incidence ratio for Solution methods

| Method            | Frequency | $\hat{p}$    | $\pm \text{int}(95\%)$ |
|-------------------|-----------|--------------|------------------------|
| Int. Programing   | 17        | <b>0.347</b> | 0.133                  |
| Heuristics        | 15        | 0.306        | 0.129                  |
| Genetic Algorithm | 13        | 0.265        | 0.124                  |
| Simulation        | 13        | 0.265        | 0.124                  |
| Regression/Doe    | 6         | 0.122        | 0.092                  |
| Petri Nets        | 5         | 0.102        | 0.085                  |
| Tabu Search       | 5         | 0.102        | 0.085                  |
| Dyn. Programing   | 3         | 0.061        | 0.067                  |
| Flow nets         | 3         | 0.061        | 0.067                  |
| Annealing Simul.  | 3         | 0.061        | 0.067                  |
| Ant Colony (ACO)  | 3         | 0.061        | 0.067                  |
| Fuzzy logic       | 3         | 0.061        | 0.067                  |
| Markov Chains     | 2         | 0.041        | 0.056                  |
| Correlation       | 2         | 0.041        | 0.056                  |
| Particle (PSO)    | 1         | 0.02         | 0.039                  |
| Parallel Comp     | 1         | 0.02         | 0.039                  |

\* Frequencies are not mutually exclusive, \*\*Sample size n=49

## 5.2 Trends of Single Approaches

Figure 3, shows that the most commonly integrative approaches used are: C, D-C, MS-C, and C-PP. This is not surprising since in terms of absolute frequencies, at least 80% of the articles address independent or combined control problems.



Flexible manufacturing systems (FMS) and Job Shop (JS) are a main trend. FMS is used almost twice as often as any other system approached (see Figure 4). The solution methods used are homogeneous, however; we can identify four methods: integer programming (Int-Pr), heuristics (HE), genetic algorithms (GA) and simulation (see Figure 5).

Figure 6 shows the proportion of use of the metrics, which shows a greater uniformity than the use of the solution methods, however we can identify metrics whose use frequencies can be twice as much as the rest of the metrics, and these are: time of computational processing, makespan and time/distance travelled.

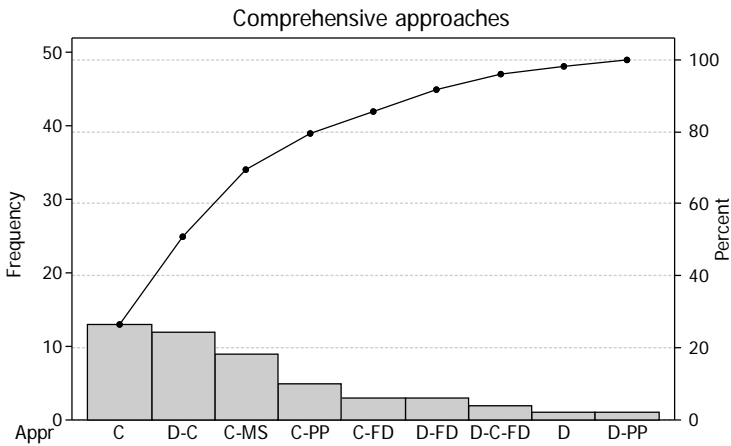


Figure 3 Pareto chart for comprehensive approaches (source: own contribution)

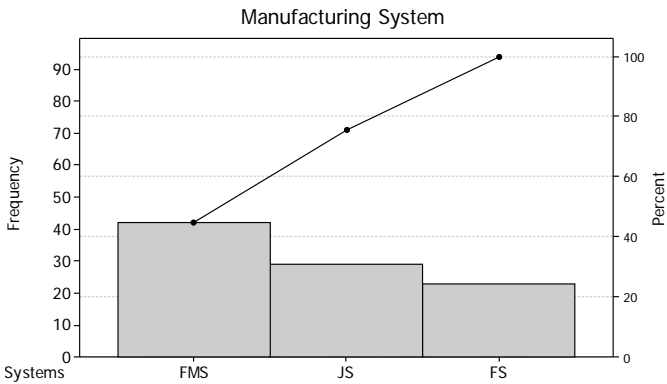


Figure 4 Pareto chart for Manufacturing systems (source: own contribution)

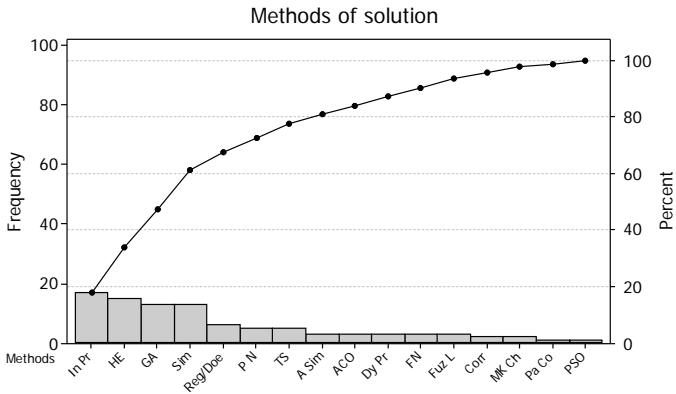


Figure 5 Pareto chart for Methods of solution (source: own contribution)

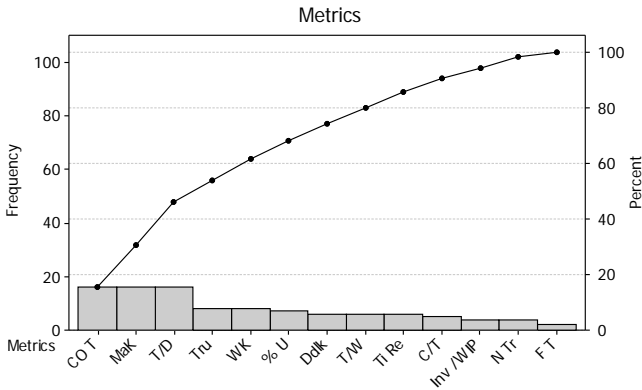


Figure 6 Pareto chart for Metrics (source: own contribution)

### 5.3 Trends of Comprehensive Approaches

As shown in table 5, FMS has the greatest relative occurrence in approaches that include control problems (C, C-FD, D-C-FD, C- MS, C-PP) except in D-FD and C-MS. The trend toward Job-Shop (JS) and Flow-Shop (FS) is higher in the D-FD approach.

Table 5 Relative ratios for manufacturing systems

| Comprehensive Approach | FMS    | JS     | FS     |
|------------------------|--------|--------|--------|
| C                      | 0.8462 | 0.6154 | 0.4615 |
| C-FD                   | 1.0000 | 0.3333 | 0.0000 |
| D                      | 1.0000 | 1.0000 | 1.0000 |
| D-FD                   | 0.6667 | 1.0000 | 1.0000 |
| D-C                    | 0.9167 | 0.9167 | 0.8333 |
| D-C-FD                 | 1.0000 | 0.5000 | 0.5000 |
| MS-C                   | 0.7778 | 0.2222 | 0.1111 |
| PP-C                   | 0.8000 | 0.2000 | 0.0000 |
| PP-D                   | 1.0000 | 1.0000 | 1.0000 |

| Approach      | Solution Methods    |                     |           |            |            |                   |             |            |                     |      |       |                    |               |             |                |             |
|---------------|---------------------|---------------------|-----------|------------|------------|-------------------|-------------|------------|---------------------|------|-------|--------------------|---------------|-------------|----------------|-------------|
|               | Integer Programming | Dynamic Programming | Flow Nets | Petri Nets | Heuristics | Genetic Algorithm | Tabu Search | Simulation | Simulated Annealing | ACO* | PSO** | Parallel Computing | Markov Chains | Correlation | Regression/Doe | Fuzzy Logic |
| <b>C</b>      | 0.23                | 0.00                | 0.08      | 0.31       | 0.38       | 0.15              | 0.00        | 0.31       | 0.08                | 0.15 | 0.00  | 0.00               | 0.08          | 0.00        | 0.23           | 0.00        |
| <b>C-FD</b>   | 0.33                | 0.33                | 0.00      | 0.00       | 0.67       | 0.00              | 0.00        | 0.33       | 0.00                | 0.00 | 0.00  | 0.00               | 0.00          | 0.00        | 0.00           | 0.00        |
| <b>D</b>      | 0.00                | 0.00                | 0.00      | 0.00       | 0.00       | 0.00              | 0.00        | 0.00       | 1.00                | 0.00 | 0.00  | 0.00               | 0.00          | 1.00        | 0.00           | 0.00        |
| <b>D-FD</b>   | 1.00                | 0.00                | 0.00      | 0.00       | 0.33       | 0.00              | 0.00        | 0.00       | 0.00                | 0.00 | 0.00  | 0.00               | 0.00          | 0.00        | 0.00           | 0.00        |
| <b>D-C</b>    | 0.42                | 0.00                | 0.08      | 0.00       | 0.33       | 0.17              | 0.17        | 0.50       | 0.08                | 0.00 | 0.00  | 0.08               | 0.08          | 0.08        | 0.08           | 0.00        |
| <b>D-C-FD</b> |                     |                     |           |            |            |                   |             |            |                     |      |       |                    |               |             |                |             |
|               | 0.50                | 0.00                | 0.00      | 0.00       | 0.50       | 0.00              | 0.00        | 0.50       | 0.00                | 0.00 | 0.00  | 0.00               | 0.00          | 0.00        | 0.00           | 0.00        |
| <b>MS-C</b>   | 0.11                | 0.11                | 0.11      | 0.00       | 0.22       | 0.89              | 0.22        | 0.00       | 0.00                | 0.00 | 0.00  | 0.00               | 0.00          | 0.00        | 0.00           | 0.33        |
| <b>PP C</b>   | 0.60                | 0.20                | 0.00      | 0.20       | 0.00       | 0.20              | 0.20        | 0.00       | 0.00                | 0.20 | 0.20  | 0.00               | 0.00          | 0.00        | 0.20           | 0.00        |
| <b>PP D</b>   | 0.00                | 0.00                | 0.00      | 0.00       | 0.00       | 0.00              | 0.00        | 1.00       | 0.00                | 0.00 | 0.00  | 0.00               | 0.00          | 0.00        | 1.00           | 0.00        |

\*Ant Colony Optimization

\*\*Particle Swarm Optimization

Table 7 Relative ratios for Metrics

| Comp Approach | Metrics  |               |              |           |               |                         |             |                 |               |             |                |           |                |
|---------------|----------|---------------|--------------|-----------|---------------|-------------------------|-------------|-----------------|---------------|-------------|----------------|-----------|----------------|
|               | Makespan | % Utilization | Work balance | Time/Wait | Time Response | Time-distance travelled | No. Travels | Throughput rate | No. Deadlocks | Cost/Travel | Inventory -WIP | Flow Time | Computing Time |
| C             | 0.15     | 0.23          | 0.08         | 0.23      | 0.15          | 0.38                    | 0.08        | 0.31            | 0.23          | 0.08        | 0.08           | 0.08      | 0.38           |
| C-FD          | 0.00     | 0.00          | 0.33         | 0.00      | 0.33          | 0.33                    | 0.00        | 0.33            | 0.00          | 0.00        | 0.33           | 0.33      | 0.67           |
| D             | 0.00     | 0.00          | 0.00         | 0.00      | 0.00          | 0.00                    | 0.00        | 1.00            | 0.00          | 0.00        | 1.00           | 0.00      | 0.00           |
| D-FD          | 0.00     | 0.33          | 0.33         | 0.33      | 0.33          | 0.33                    | 0.00        | 0.00            | 0.00          | 0.33        | 0.00           | 0.00      | 0.33           |
| D-C           | 0.08     | 0.08          | 0.33         | 0.00      | 0.08          | 0.42                    | 0.17        | 0.17            | 0.25          | 0.00        | 0.00           | 0.00      | 0.33           |
| D-C-FD        | 0.00     | 0.50          | 0.00         | 0.00      | 0.50          | 0.50                    | 0.50        | 0.00            | 0.00          | 0.50        | 0.00           | 0.00      | 1.00           |
| C-SM          | 0.89     | 0.11          | 0.11         | 0.11      | 0.00          | 0.11                    | 0.00        | 0.00            | 0.00          | 0.22        | 0.00           | 0.00      | 0.22           |
| C-PP          | 1.00     | 0.00          | 0.00         | 0.20      | 0.00          | 0.20                    | 0.00        | 0.00            | 0.00          | 0.00        | 0.00           | 0.00      | 0.00           |
| D-PP          | 0.00     | 0.00          | 0.00         | 0.00      | 0.00          | 1.00                    | 0.00        | 0.00            | 0.00          | 0.00        | 1.00           | 0.00      | 0.00           |

## 6 Conclusions

This paper was conducted to learn about the state of the art regarding the orientation of the approaches of researchers associated to operational control of AGVs in the last ten years. It is useful to know the integration degree of approaches and advances in the use of solution methods to visualize the different approaches to develop an improved method to solve a similar problem.

For the above, forty nine papers reviewed related to AGVs design and control systems were characterized by four factors: approach, manufacturing environments, solution methods, and metrics used as a performance evaluation for AGV proposed system models. Six comprehensive approaches were identified: 1) machine scheduling -control (C-MS), 2) production planning- AGVs design (D-PP), 3) production planning- AGVs control (C-PP), 4) AGVs design-facilities design (FD-D), 5) AGVs control-facilities design (C-FD), 6) AGVs design-AGVs control-facilities design (D-C-FD).

From general statistics:

- The most frequently four integrative approaches used were identified: C, D-C, C-SM and C-PP.
- At least 80% of the papers are related to control problems.
- The FMS and JS are above 70% of manufacturing environments focus.
- Solution methods that show increased frequency of use are: Integer programming, heuristics, genetic algorithms and simulation (in the range of 15% - 19% each one).

- The most commonly used metrics are: Computational processing time, makespan time/ travelled distance and whose frequencies of use very similar (around 18% each one).

From relative statistical information (inside comprehensive approaches):

- In C-MS approach, genetic algorithms are used as solution method in almost 9 of 10 cases.
- Approaches C-PP and C-MS tends to use makespan (100% and 89% respectively) as a performance metric.

It can be said that this indicates that researches are currently oriented towards issues of AGVs control systems and that classical methodologies such as (integer and dynamic programming, and flow networks), adaptable heuristic and meta-heuristics algorithms and simulation models prevail.

The computational processing time used for information and processing technologies, is still the most important performance variable. The proposed solution methods usually are compared against other models depending on performance variables, such as processing time of AGVs system and/or methodology performance.

Some trends of integrated approaches are very strong, as in the AGVs control and machines scheduling approach (C-MS), which are used at a high 89% rate of occurrence. Genetic algorithms and makespan are among the most mentioned. The makespan use is also very recurrent in the focus of AGVs control of and production planning (C-PP).

The dynamic elements found in the characterization of integrative approaches were not considered in the purpose of this paper. Nevertheless,



studying this subject carefully to find out if there is any relationship between this dynamic elements and the attributes described in this work would be interesting.

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