Simulation-based optimization for determining AGV capacity in a manufacturing system

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Abstract

We consider a manufacturing system that uses Automated Guided Vehicles (AGVs) for material handling. Increasing the capacity of the AGVs used can lead to increased throughput and reduced inventory-holding costs. However, AGVs are typically expensive. Hence modeling the economics of buying an additional vehicle is an important problem from the standpoint of making a system lean. Optimization of the AGV's capacity can be performed analytically only under some simplifying assumptions about the system. We present a simulation-optimization approach to determine the optimal capacity of an AGV in a closed loop path, where the AGV is used as a device for pick-up from machines and drop-off at a conveyor. Our focus in this work is on optimizing the capacity of the AGV.

Keywords
Automated Guided Vehicles, simulation-optimization.

1. Introduction
Automated guided vehicles (AGVs) have now become commonplace in the manufacturing world. Manufacturers of electronic goods and large automobile manufacturers are some well-known examples of industries that use AGVs in their manufacturing operations. The usage of AGVs in the US has increased significantly in the last few years because of increasing labor costs associated with human-operated material-handling systems [8]. It is the case, however, that AGV systems themselves tend to be very expensive. Even a single vehicle can cost several thousand dollars. On the other hand, even one AGV can significantly reduce the material-handling time and thereby increase throughput and reduce inventory. As such, before buying an AGV, it is prudent to perform an analysis of its capacity versus the benefits it provides. Oftentimes, the capacity of an AGV can be increased by using a trailer.

A system with multiple AGVs is often divided into separate compartments (see Bozer and Srinivasan [3] and Bozer and Park [2]) in which one vehicle serves a dedicated set of workstations. In this paper, we focus on the analysis of a closed loop with one vehicle. The literature presents some mathematical models for measuring the performance of such a single-loop path; see [19], which uses a queuing approximation from [6] and see [10], which uses a Markov chain approximation. However, both of these papers make numerous assumptions about the system in the process of developing a tractable mathematical model. Some of the assumptions are: the inter-arrival time of jobs at the machines is exponentially distributed [19] and the time of travel from one machine to another is deterministic [10]. In this paper, we attempt to study the capacity-optimization problem while relaxing such restrictive assumptions. To this end, we develop a simulation model of the system and use it for optimization of the AGV's capacity.

The rest of this paper is organized as follows. Section 2 presents an overview of the literature related to this problem. The system studied along with the simulation model is described in Section 3. Section 4 discusses the results of our empirical analysis, and Section 5 concludes this paper.

2. A Literature Review

We now describe some of the main papers in the literature on modeling AGV systems. Maxwell and Muckstadt [15] discusses an analytical model with deterministic assumptions; their goal is to determine the number of AGVs needed. An interesting extension of this model has appeared in Leung *et al.* [13] who consider additional vehicle types. Egbelu [5] has presented four analytical models for a similar system. The work of Tanchoco *et al.* [17] revolves around using a queuing software for an analysis of the number of AGVs needed. Wysk *et al.*[21] use the same software but also model empty vehicle travel. Bakkalbasi [1], Mahadevan and Narendran [14], and Srinivasan, Bozer and Cho [16] are some additional noteworthy works that formulate analytical models. Koo *et al.* [11] employ a queuing model to find the AGV-fleet size under a variety of vehicle selection rules. Vis *et al.* [20] develop a model for automated terminals. The problem considered in Chevalier *et al.* [4] has two stations. Finally, Johnson and Brandeau [9] is an excellent overview of design issues in stochastic material-handling.

As discussed above, we seek to break away from the trend in the literature which is for the most part toward analytical models and for determining the fleet size of AGVs. We consider a single closed loop path in which one AGV is used, and thus our attention is focussed on the capacity of the vehicle. Furthermore, instead of using analytical models that make restrictive assumptions, we used simulation-based optimization (see Gosavi [7]). Also, our goal is to determine (i) the effect of the AGV capacity on inventory in the system and (ii) the optimal capacity of the AGV.

3. The Model

The system we consider is shown in Figure 1. The AGV starts at the drop-off point, where it is empty, and it travels along a fixed path to Machine 1. At Machine 1, it picks up loads if there are any waiting. If possible it picks up all the loads at the queue near Machine 1. It then goes to Machine 2. If there is unused capacity, it picks up loads at Machine 2. Again, if possible, it picks up all the loads at Machine 2. Then it makes it way back to the drop-off point, which is for example a conveyor belt, and there it unloads all the loads it is carrying. It then makes it back to Machine 1, and the cycle repeats. The time for travel from the drop-off point to Machine 1, that from Machine 1 to Machine 2, and then from Machine 2 to the drop-off point are assumed to be random variables of known distribution. The inter-arrival time of jobs at each machine is also assumed to be a random variable of a known distribution. The time spent in loading at the machines or unloading at the drop-off point is assumed to be fixed and known.

We simulate the above-described system in a discrete-event simulator, written in C (see Law and Kelton [12]). This system could also be simulated in ARENA or some other commercial discrete-event simulator. We have used C so that we can run *numerous* different configurations and obtain optimization results in a reasonable amount of time. Since we will be optimizing over just one variable (the AGV's capacity), which is discrete, and since our C programs take a very short time to run, we can perform an exhaustive enumeration of all solution points for optimization via simulation.

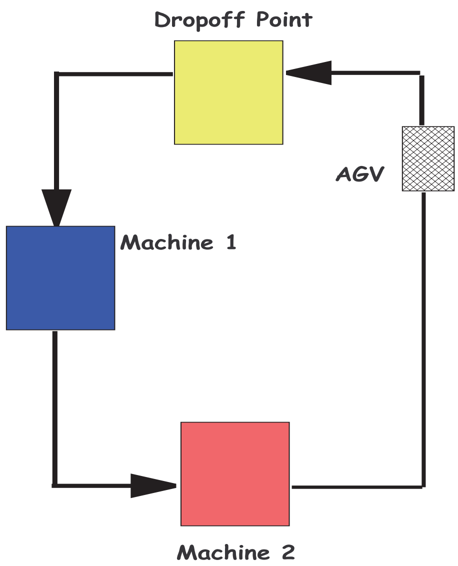

Figure 1: A schematic view of the closed-loop path.

Our goal is to solve the following optimization problem. Let Z denote the capacity of the AGV and let $\mathsf{E}[I_i]$ denote the average inventory near Machine i. Then our optimization problem can be modeled as:

$$\text{Minimize } Z \text{ such that}$$

$$\sum_{i=1}^{n} \mathsf{E}[I_i] < K \qquad (Model\ 1)$$

where K is a manager-set upper threshold on the allowable total average inventory in the system and n denotes the number of machines in the closed loop. Oftentimes, a good estimate of K is available to a manager inclined to using lean principles. If the cost of holding inventory is known, an alternative model would be to:

$$\text{Minimize } C \cdot Z + h \cdot \sum_{i=1}^{n} \mathsf{E}[I_i] \qquad (Model\ 2)$$

where h denotes the holding cost of inventory per unit item per unit time and C denotes the cost of an AGV proportional to its capacity. Models of this nature will be the subject of future research. We focus on Model 1 here. One attractive feature of Model 1 is that it does not need any cost inputs. A variant of these models has been studied in [18].

4. Numerical Results

In this section, we describe the results of our experiments with simulation-based optimization of the system described in Figure 1. We begin by defining some of the system parameters needed as inputs to the simulation model.

We have used the uniform distribution to model the travel time from one station to another in Figure 1. (Note that any other distribution can be just as easily used since our model is simulation-based.) Let $TXY-L$ denote the maximum value of the uniform distributed random variable that models the travel time from station X to station Y. Similarly, let $TXY-U$ denote the minimum value of the same random variable. We have 3 stations in our study: Drop-off point, which we will refer to as Station 0, Machine 1, which will be referred to as Station 1, and Machine 2, which will denote Station 2. Also, the fixed time spent at any station (for loading or unloading as the case may be) will be denoted by SX where X denotes the station number. The inter-arrival time of jobs at both machines is assumed to have a gamma distribution parameterized in our notational convention by (k, λ); the mean value of the random variable is then defined by k/λ. Table 1 shows the values of the input variables and some other variables associated with every example (Case) of the system studied.

Table 1: Input variables for Systems studied

Case	$T01-L$	$T01-U$	$T12-L$	$T12-U$	$T20-L$	$T20-U$	$S0$	$S1$	$S2$	k	λ
1	8	12	9	11	10	14	3	1	1	10	3
2	5	15	6	15	20	24	3	1	1	10	3
3	10	14	7	13	8	15	3	1	1	10	2
4	10	15	8	14	19	25	3	1	1	10	3
5	5	14	12	16	10	17	3	1	1	10	2

The simulations for each AGV capacity are run for 10 replications in which each replication is simulated for 10,000 time units. The results of optimizing with Model 1 are presented in Table 2. Figure 2 shows how the optimization is performed for Case 1 by a point-wise evaluation of each capacity. Simulation (which implies 10 replications here) for each capacity takes less than 1 second on a standard Linux machine available at the Missouri University of Science and Technology. Hence, optimization over the approximately 45 values of AGV capacity, which represent all of the feasible points in the solution space, can be performed in less than 1 minute. Figure 2 also shows that beyond a certain point, increase in AGV capacity does not yield any further reduction of the total inventory in the system. This is typical of all the cases that we studied.

Table 2: Optimized Systems. The superscript * denotes the fact the quantity is associated with the optimized system.

Case	K	Z^*	$\mathsf{E}[I_1^*]$	$\mathsf{E}[I_2^*]$	$\sum_{i=1}^{2} \mathsf{E}[I_i^*]$
1	11.60	26	5.7797	5.7469	11.543460
2	14.90	33	7.394480	7.504555	14.899036
3	8.21	21	4.116817	4.093067	8.209885
4	15.70	35	7.847086	7.846179	15.693265
5	9.00	20	4.452376	4.497897	8.950272

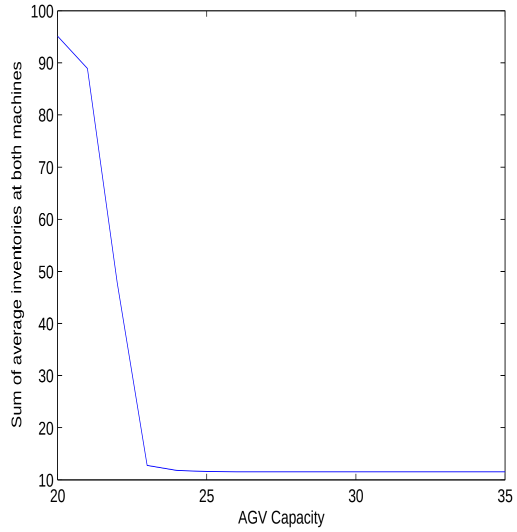

Figure 2: A plot of AGV capacity Vs total inventory.

5. Conclusions

Our numerical results show that simulation optimization of a single-loop AGV system is a feasible approach that can solve capacity-design problems under realistic considerations. Most of the models in the literature that deal with capacity of the vehicle are analytical and make restrictive assumptions about the system that may not be true of all the real-world systems. While the results we obtained are encouraging, we intend to extend this work to a problem of larger dimension with several machines. Some other possible extensions of this problem are to consider multi-loop paths and other optimization models, e.g., Model 2.

References

[1] Bakkalbasi, O., Flow Path Network Design and Layout Configuration for Material Delivery Systems, unpublished Ph.D. dissertation, Georgia Institute of Technology, Atlanta, GA, 1989.

[2] Bozer, Y.A. and J.H. Park. New Partitioning Schemes for Tandem AGV Systems. *Progress in Material-Handling Research, 1992*, Braun-Brunfiled, Inc., Ann Arbor MI, 317-332, 1993.

[3] Bozer, Y.A. and M.M. Srinivasan. Tandem AGV Systems: A Partitioning Algorithm and Performance Comparison with Conventional AGV Systems. *European Journal of Operational Research.* 63, 173-191, 1992.

[4] Chevalier, P., Pochet, Y and Talbott, L., Design of a 2-stations automated guided vehicle systems, *Quantitative Approaches to distribution logistics and supply chain management*, A. Kolse, M. Speranza, and L. Wassenhove (Eds), Springer, Germany, pp. 309-329, 2002.

[5] Egbelu, P. J., The Use of Non-Simulation Approaches in Estimating Vehicle Requirements in an Automated Guided Vehicle Based Transport System, *Material Flow*, 4, 17-32, 1987.

[6] Gendreau, M. Etude Approfondi d'un Modele d'Equilibre pour l'Affectation des Passagers dans les Reseaux de Transport en Commun, *Unpublished Ph.D. Dissertation*, University de Montreal, 1984.

[7] Gosavi, A. *Simulation-based optimization: Parametric Optimization Techniques and Reinforcement Learning*, Springer, Boston, 2003.

[8] Heragu,S, *Facilities Design.* 3rd Edition, CRC press, Boca Raton, FL, 2008.

[9] Johnson, M.E., and Brandeau, M.L, Stochastic Modeling for Automated Material Handling System Design and Control, *Transportation Science,* Vol 30, No 4, pp. 330-348. 1996.

[10] Kahraman, A.F, Gosavi, A., and K. Oty. Stochastic Modeling of an Automated Guided Vehicle System with One Vehicle and a Closed Loop Path. *IEEE Transactions on Automation Science and Engineering,*5(3), pp 504-518, 2008.

[11] Koo, P., Jang, J. and Suh, J., Estimation of Part Waiting Time and Fleet Sizing in AGV Systems, *The International Journal of Flexible Manufacturing Systems,* Vol 16, pp. 211-228. 2005.

[12] Law, A. M., Kelton, W. D., *Simulation Modeling and Analysis*, McGraw-Hill Inc., New York, 2000.

[13] Leung, L.C, Khator, S.K., and Kimbler, D. Assignment of AGVs with different vehicle types, *Material Flow*, Vol 4, No 1-2, pp. 65-72, 1987.

[14] Mahadevan, B. and Narendran, T. T., Estimation of Number of AGVs for FMS: An Analytical Model, *International Journal of Production Research*, Vol. 31, No.7, pp. 1655-1670, 1993.

[15] Maxwell, W.L. and Muckstadt J. A., Design of Automated Guided Vehicle Systems, *IIE Transactions*, 14, 2, 114-124, 1982.

[16] Srinivasan, M. M., Bozer, Y. A., and Cho, M., Trip-Based Handling Systems: Throughput Capacity Analysis, *IIE Transactions*, Vol. 26, No. 1, pp. 70-89, 1994

[17] Tanchoco J. M. A., Egbelu P. J., and Taghaboni F., Determination of the Total Number of Vehicles in an AGV-based Material Transport System, *Material Flow*, Vol. 4, No. 1-2, p. 33-51, 1987.

[18] Tansupawuth, T., Optimizing the capacity of an AGV using a stochastic simulation, MS Thesis, Colorado State University-Pueblo, 2002.

[19] Thonemann, U.W., and Brandeau, M.I. Designing a single-vehicle automated guided vehicle system with multiple load capacity, *Transportation Science,* Vol 30, No 4, pp. 351-353, 1996.

[20] Vis, I., de Coster, R., Roodbergen, K., and Peeters, L. Determination of the number of AGVs required at a semi-automated container terminal, *Journal of the Operational research society*, Vol 52, No 4, pp. 409-417, 2001.

[21] Wysk, R.A., Egbelu P. J., Zhou, C., and Ghosh, B. K., Use of Spread Sheet Analysis for Evaluating AGV Systems, *Material Flow*, Vol 4, pp. 53-64, 1987.