

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

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Keywords: AGV, simulation, Simul8, Inductive Power Transfer**Abstract:** In this paper a comparison is presented for different battery charging concepts of Automated Guided Vehicle (AGV) systems using simulation models. In the focus of our investigation was, what kind of benefits can Inductive Power Transfer (IPT) for an AGV-based material handling system have, which is increasingly applied today. The proper application of IPT systems lets the reduction of the necessary number of AGVs and balances their utilization level.**1 Introduction**

Logistics is the science of planning, execution, and control of the procurement, movement, and stationing of personnel, material, and other resources to achieve the objectives of a campaign, plan, project, or strategy. It may be defined as the ‘management of inventory in motion and at rest’ [1].

In manufacturing plants, the main task of logistics is to supply the raw materials and parts to the workplaces. On the one hand, the precise delivery of finished products to the delivery point, and on the other hand, the movement of semi-finished products between manufacturing cells.

If we look ahead to development, besides traditional push-type production strategies pull-type systems have been conceived as well. Currently, both systems co-exist, and companies search for the right balance, as stated in the article by A. Puchkova, J. Le Romancer, D. McFarlane [2].

During push-type production, the main focus is to forward the workpieces to the next workstation as quick as they can, to avoid unutilized production capacity. This has advantages but also disadvantages, like high inventory holding costs and low inventory turns. The pull-type system drives production based upon customer demand. This kind of perception and service strategy brings the modified material handling structure of raw materials and semi-finished products to the Just In Time (JIT) and Just In Sequence (JIS) manufacturing processes. As a result, servicing the production machines requires increasingly flexible machines, which can be adjusted based on the ever-changing needs.

By simultaneously automating manufacturing and manufacturing logistics, and then managing it with an integrated process control system, it is possible to create a fast and relatively flexible production system that works

efficiently, where process technology and material flow can be easily and accurately monitored and controlled.

In these production and related material supply services, multiple shifts are increasingly required. This increased amount of continuous work cannot be met manually. In the long term and in large quantities this can only be achieved using automation. This is one of the reasons why demand for automatic guided vehicles (AGVs) has become more and more important in the last 60 years [3].

Due to the development of computing and sensors, practically every conceivable material handling task can be automated in some way using mobile robots, and a properly designed automated system can also greatly increase efficiency and work safety by excluding human error factor [4].

AGVs have been playing an important role in the material flow during the past 60 years. The first automated guided vehicle was developed in the early '50s [3]. A tugger truck was converted by Barrett Electronics to assist in warehousing operations. This vehicle was very primitive in comparison with today's techniques: it led to a ground-fed wire that could be followed by the electromagnetic field sensing device. Its construction costs were relatively high, as it had to use so many wires and to lay out the direction in which the truck had to go. A computer controlled which line would be powered to be followed by the vehicle.

In the following 20 years, the applied technique did not change significantly. More and more towing AGVs were being used, and in 1973, Volvo developed a computer controlled system with 280 pcs of AGVs in a Swedish factory. They tried to find a suitable alternative to conventional conveyor line assembly.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Györfvály; Andreas Kluth

The first major breakthrough took place in the mid-'70s: first unit load AGVs were introduced. They have gained popularity because they have not only been able to tug carts, but also have been fitted with the proper accessories as a workbench. AGVs of this type are widely used in warehouses, factories, mills, hospitals. In this article, we will look at the material handling model of a system built from such kind of mobile workstations.

The article by Kabir, Q.S., Suzuki, Y. [5] has pointed out how important the battery and battery management is. By completely agreeing with the content, we outline that a well-built IPT system can be very effective. One critical issue lies predominantly in the AGV's power supply. So, in order to operate an AGV system efficiently, we need to effectively address the current energy supply problems.

2 Energy management in AGVs

In simpler systems, users should change AGV batteries manually after a shift, depending on the degree of utilization. Considering that these drive batteries can weigh more than 10kg, we can assure, that these solutions cannot be said to be user-friendly, but we also need to know that they are factually the cheapest. The article by Kabir, Q.S., Suzuki, Y. [5] has pointed out as well that these solutions require twice as many batteries and, it has special expectations, taking into account the design of the charging bay, and the replacement of the batteries will also pose a serious threat to the workers.

Ergonomics is now becoming more and more important for the AGV manufacturers, so it is no coincidence that a growing number of companies offer automatic charging for this type of systems. In smarter systems, when the truck's battery voltage drops below a certain level, the truck automatically accesses the charging station and informs the supervisor system. This solution is considerably more user-friendly than the first one with the manual replacement, however, there is a disadvantage that while the truck is charging, it cannot perform a material handling task, therefore, in this case, we will need more AGVs, which will result in significant investment costs.

The article by Kabir, Q.S., Suzuki, Y. [5] has also pointed out that Inductive Power Transfer can be used to build up an AGV system without batteries. However, this kind of system is not very flexible, because the AGV can drive only above the Inductive Power Tape. Modifying the track is also very expensive. There are solutions as well where using the Inductive Power Transfer technology, the batteries of the AGVs can be charged contactless, either on the go, or even while standing [6].

As a summary, advantages of IPT systems can be stated as follows:

- Using no moving parts is an advantageous solution regarding long time reliability.
- The absence of live electric contacts increases workplace safety.

- Environmental issues are also significant because IPT enables smaller or the complete absence of batteries, as charging is carried out on longer sections during operation.

In our research topic, we were looking for the possibility of using IPT technology for AGV systems, and if so, which topology and utilization mode would deliver the best benefit for the user.

It should be noted here that there is an increasing demand for the modernization of traditional production structures (e.g. production lines). The reason for this is that the product range on a production line is widening, the material handling processes are becoming more and more complex, leading to bottlenecks over time. Thus, it can be seen that these traditional production structures need to be developed. One of the pioneers of this is the introduction of a more modular manufacturing structure, which is being tested in a wider range.

The idea behind it is production without assembly lines, broken down into the individual work stations. The new assembly stations are occupied by one or two workers. Unlike today, they work steadily at a continuous pace because they no longer have to adapt their activities to the speed of the line. And they do not have to move with the car on a conveyor; they can work in one place. The transport of the components between the stations in modular assembly is taken over by AGVs [7].

The planning methodology of this new type of production systems is extensively described in the paper by Kern, W., Rusitschka, F., & Bauernhansl, T. [8].

In these systems, besides the manufacturing and material handling machines, the importance of the accessory components like sensor networks is increased as described in the paper by Konyha, J., & Bányai, T. [9].

There are also mixed assembly line models possible as described in the paper by Keckl, S., Abou-Haydar, A., & Westkämper, E. (2016) [10]. As concluded from the literature, new type of production structures exists. Material supply can be advantageously implemented using AGV systems. As stated above, AGV systems need efficient power management for the AGVs, used in a flexible production structure, unlike the fixed charging points, an extensive IPT network can be an effective solution.

To be able to prove our assumption, we have developed a simulation model for that kind of AGV-systems, because simulations can be used to examine the behaviour of such kind of material handling systems. Application of simulation in logistics has extensive literature. Straka et al. [11] point out in their paper that in simulation modelling the appropriate first step is the creation of a formalized structure, which can be converted into components of the used simulation software. Neradilova, H., & Fedorko, G. [12] describe the important role of computer simulation used in the Industry 4.0 systems. In the work of Kesen, S.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Győrváry; Andreas Kluth

E., & Baykoç, Ö. F. [13] a comprehensive description of several existing AGV simulation models can be found.

So we have developed a simulated production system where material handling is carried out by AGVs. Simulation models are capable of modelling both conventional and IPT charging.

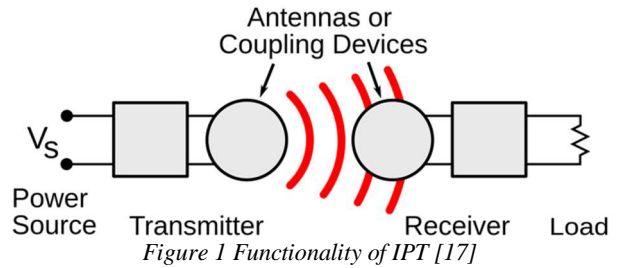
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3 Functioning and simulation modelling of IPT systems

As modelling of IPT systems for AGVs is the main speciality of the proposed simulation model, a short description of the IPT technology follows. Detailed description can be found in [14-16].

In the IPT systems the incoming AC current is first converted to DC and fed to the wave generator. The wave generator has oscillators through which the current flows and this generates microwave electromagnetic radiation.

This will be emitted by the transducer antenna, and received by the “rect-antenna” on the another side, and the energy will be re-converted to DC power, which can be used according to the application (Fig. 1).



However, the energy transfer works only if the mobile vehicle follows the track closely. Even in case of a small deviation, we can calculate with reduced energy transfer.

The following figure (Fig. 2) shows, on the left side, the ratio of the vertical position deviation and the received power, and on the right side, the ratio of the horizontal position deviation and the received power.

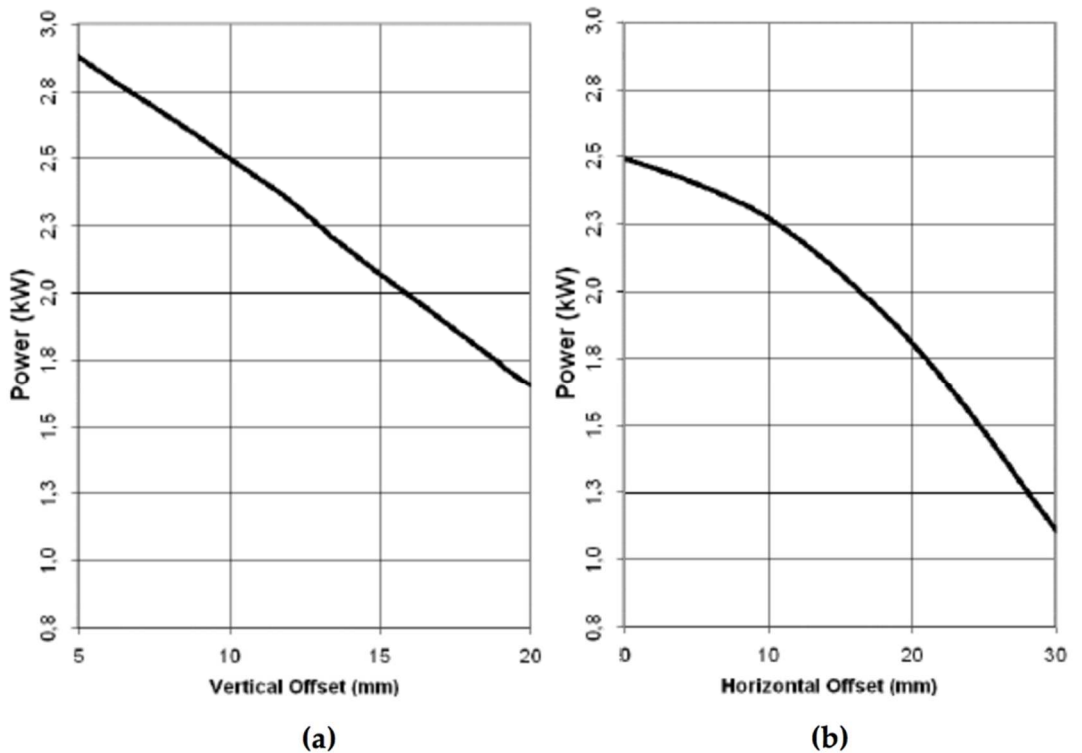


Figure 2 Ratio between the offsets and the power [18]

Figure 2 (a) shows that at a 15 mm vertical offset, there is a drop in power by about 15%, and in case of 20 mm vertical offset, this value is more than 30%. The system is even more vulnerable to horizontal lateral deviation, as shown in Figure 2 (b). At a 10 mm deviation, there is roughly 10% loss of power, at a deviation of 20 mm there is almost 30% of power loss, while in case of a 30 mm deviation, there is a drastically reduced performance by

more than 50%. However, we did not model this during our simulation.

Contrary to popular belief, the IPT system can reach a very high DC-DC power efficiency of 96%, while batteries have approximately 80% of charging efficiency, as described in [15]. This is one of the reasons why AGV systems without batteries have also been justified.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Györfvály; Andreas Kluth

This means, IPT systems can be modelled also as a continuous charging system component. The transmitted capacity is proportional to the time of staying near to the inductive wire.

According to the above, modelling of the IPT system corresponds to a track-type component during which the capacity of the battery changes. By neglecting the machines' idle power consumption, the used energy is proportional to the travelled distance. The charged energy is, however, proportional to the time of the machines' stay or movement above the track segment. If the machine travels along an inductive path of length L , the change of battery capacity can be formulated as follows:

$$\Delta C = a_{const} \frac{L}{v} - b_{const} L \tag{1}$$

where a_{const} is the degree of charging [W/sec], b_{const} is the degree of energy consumption [W/m], and v is speed [m/sec].

If $\Delta C > 0$ (2)

the system is self-supporting, if $\Delta C < 0$ (3)

the system has to be supplemented by additional charging stations. If, during the period of movement, the amount of charged energy does not cover the consumption, then the equipment must be stopped for a shorter or longer period(s) at certain charging points. Of course, this is not necessarily a problem, because IPT systems can also be built up where the AGV can be charged over time while waiting for workpieces next to the workstations.

We should mention one more simplification, which is important regarding the result of our simulation. We have neglected the fact that AGVs have a higher energy demand when they are loaded, than when they are unloaded.

4 Development of AGV Simulation Model

The model has been developed using a widely accepted Discrete Event Simulation (DES simulation) model (with Program Simul8). The following figure (Fig. 3) shows the layout of the created simulation model of an AGV system with conventional charging method.

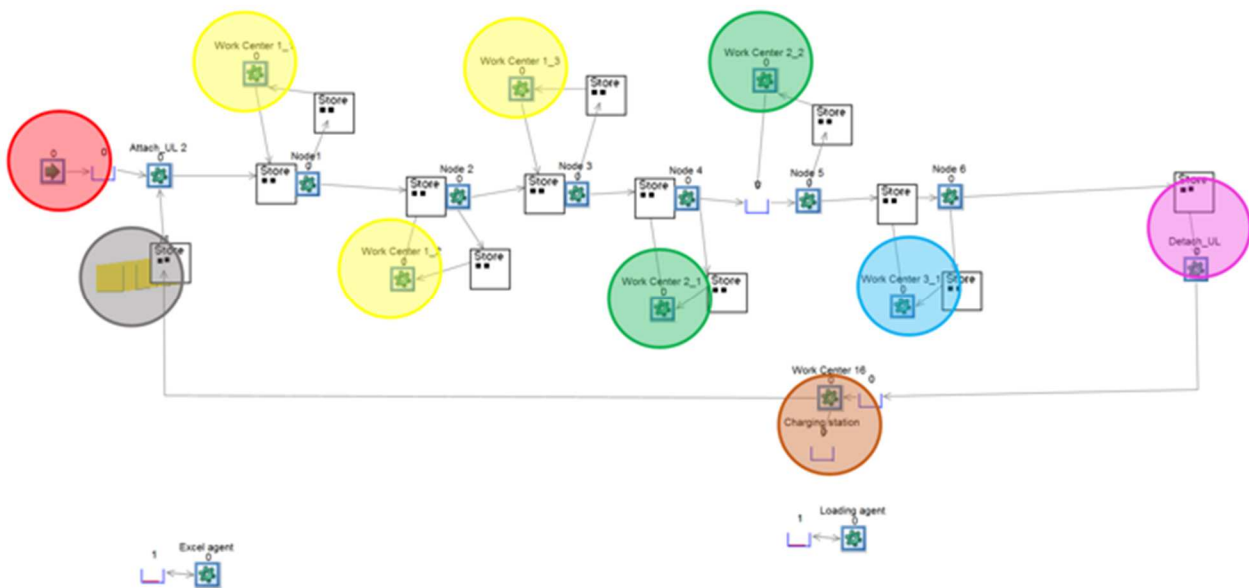


Figure 3 AGV system model in Simul8

This simulated production facility is a modularly designed manufacturing system, using a pull principle. Cycle times in the system are decreasing in the later phases, which helps Work in Process level (WIP level) to be kept at a minimum. This way the number of AGVs in the system is kept at minimum level.

The raw material is generated at a rate of 2.5 min, following a normal distribution with 0.5 min deviation on the input side (red circles) of the manufacturing system. These will be transported by AGVs to the first step of manufacturing (yellow circle). In our simulation, we created three such production cells for the first step.

Routing has been defined so that all three cells are equally used. Next, the finished workpieces are taken by the AGVs to the 2nd stage machines (green circles). There are two machines in this phase in order to suit the demanded capacity. The model routes the products so that utilization is equal. Finally, the AGVs deliver the material for the 3rd workstation (blue circle). There is only one work station in this phase. Finally, the AGVs carry the finished product to the output side (purple circle) and then drive back to the beginning of the system where they wait (grey circle) for the next task.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Györfvály; Andreas Kluth

It is also important to note that the AGVs are waiting on each production site while the workpiece is ready. When determining the consumption data of the AGVs, it was taken into account that the batteries should be discharged with a ratio, to be able to operate the AGV at least one shift without recharging.

At the first run of the simulation, the following logic was applied for the charging of the AGVs: if the charge level of the AGV is 20% or less, the AGV will be removed from the system at the charging station (brown circle) until it was recharged up to 100%.

However, it was to be recognized that with such a simple charging logic, the system cannot be self-sustaining with automatic charging, as all AGVs are discharged at approximately at the same time. Thus, they are simultaneously removed from the system due to charging, which causes that no more free AGVs will remain in the system to do the material handling. So, with the initial set of AGVs and with such a high material flow, the system can only perform its function if, after each shift, the AGVs' batteries are manually replaced.

If more AGVs were to be used (based on industry experience, the AGV manufacturers and distributors usually recommend + 100% for continuous operation), there would be enough free remaining capacity in the

system, that would allow to take out AGVs from the system for recharging. In that case the material handling system with automated recharging would work. Of course, this investigation has a significantly higher investment cost, often the companies are unwilling to pay for it.

In order to keep the number of AGVs at a more constant level, in the second simulation run, a modified charging logic is applied. In this case there is a given number of AGVs at the loading station. If a transport machine arrives at the station, and the number of the AGVs at the station is below a certain level, and the machine is not fully charged, then it goes to the charging station.

So with the simulation we also tried to find out what kind of charging logic should be used, and how many extra AGVs have to be added to the system to perform this kind of automatic charge.

From this point of view, it is conceivable that if this system were to be complemented with an IPT system, we would have to take out the AGVs for less time “from the battle line” for charging.

We have, therefore, investigated two types of IPT systems.

First, we tested the IPT system installed on the long straight sections, so the AGVs could be recharged on the go. This IPT loop is shown as the blue loop in Figure 4.

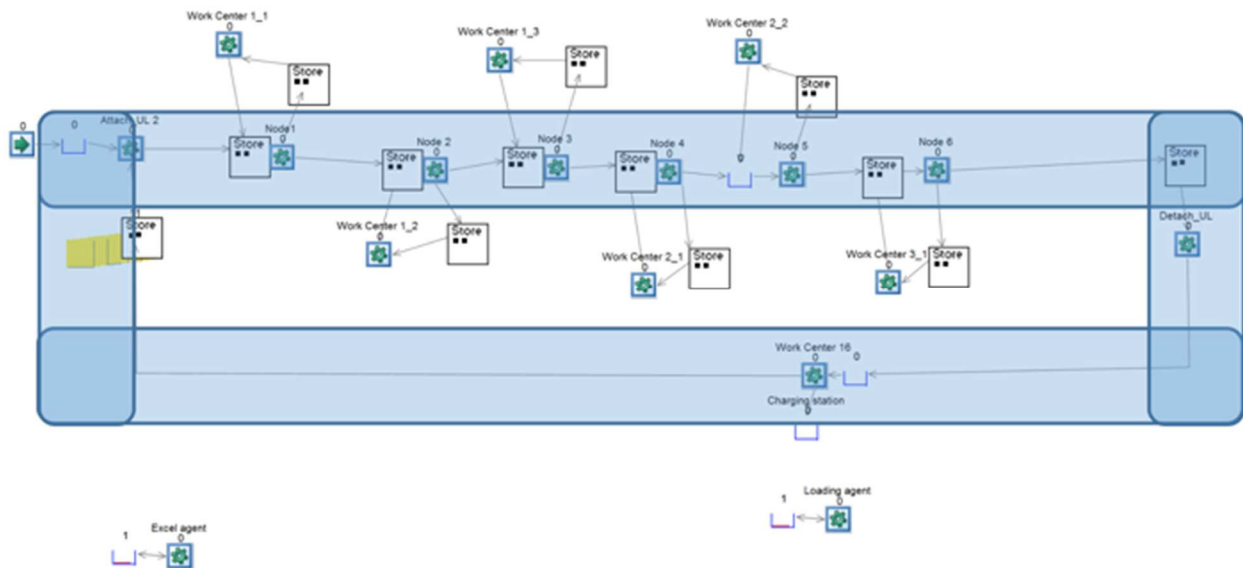


Figure 4 AGV system model in Simul8

Second, we have created a simulation in which the IPT system has been designed to recharge the batteries of the

AGVs whenever they wait for the workpiece on each manufacturing cell. This can be seen in Figure 5.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Györfvályi; Andreas Kluth

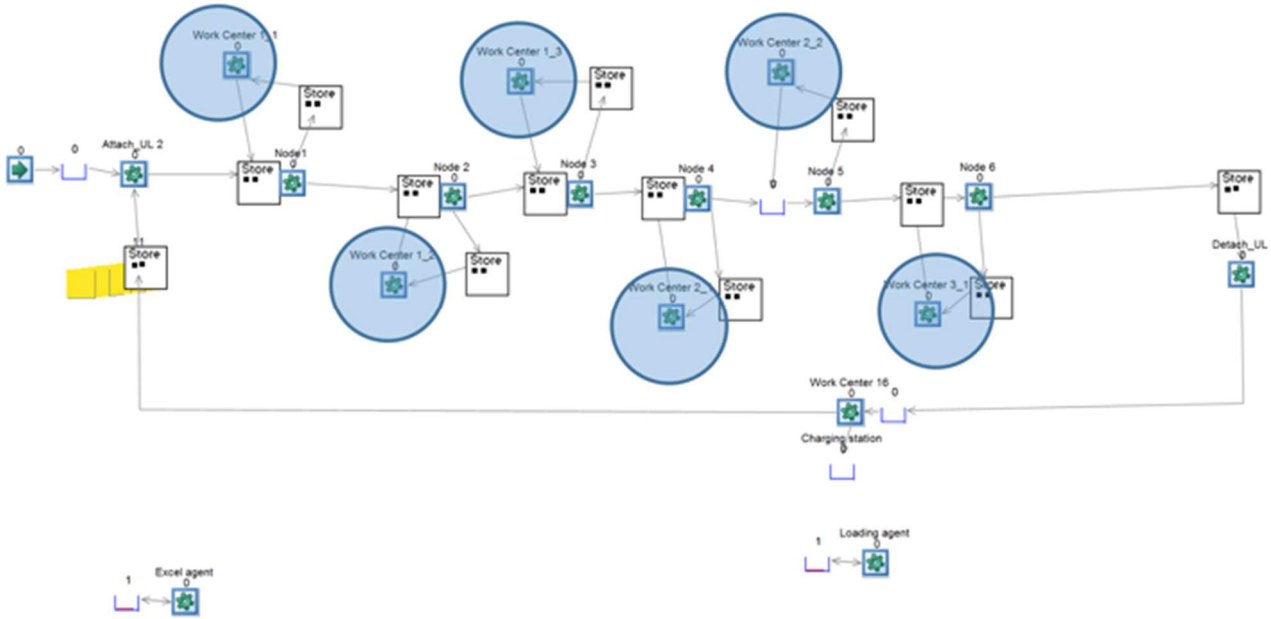


Figure 5 AGV system with IPT charging stations at the work cells

5 Simulation results

Main output of the simulation runs is the judgement if the system is capable of handling the amount of incoming material flow. This can be measured by the amount of incoming, queueing work items of the model. If this amount increases steadily then, there are too few AGVs in the system. The value must be observed over a longer period in order to ignore the distortion coming from initial charging. There is a single input parameter of the different simulation runs: the number of AGVs in the system. Optimal number of AGVs has been determined in an iterative way, by increasing the number of AGVs to the

limit where the number of awaiting work item has no increasing trend.

5.1 Simulation results for the AGV system with conventional automatic charging

As we have seen, with the simple, conventional automatic charging logic, the system was unable to carry out continuously the material handling tasks. This is why we were looking for a better charging logic to be able to operate the system, and parallel with that we investigated the number of AGVs required to the material flow.

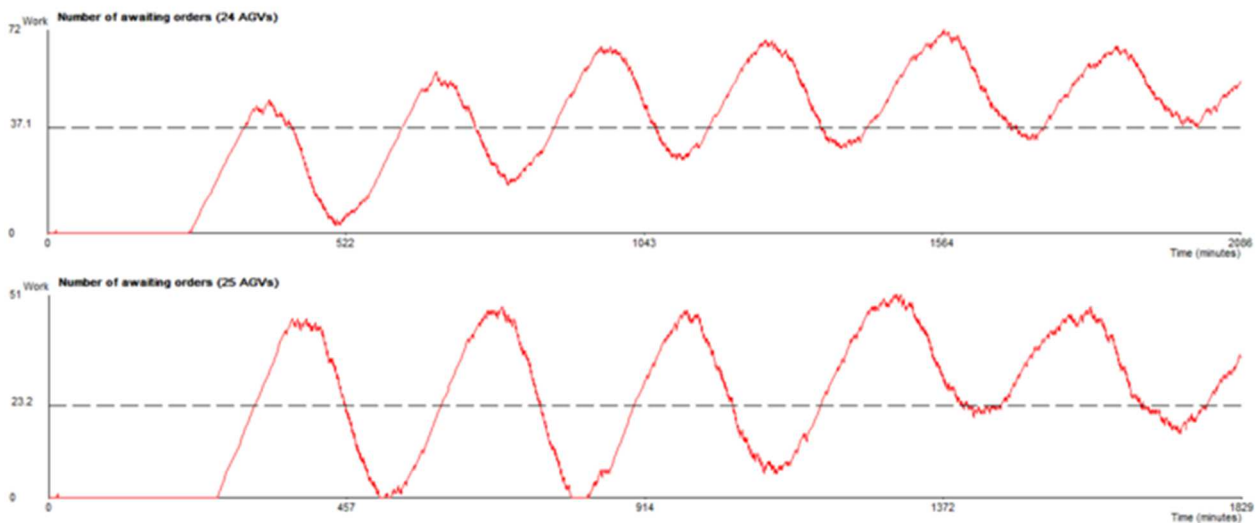


Figure 6 Number of awaiting work items at the input side

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Győrvári; Andreas Kluth

We tested several charging logic, and finally the following one was proved to be most useful: We do not let the AGV run until the batteries were totally (20%) exhausted, but if the charging level of the AGV is below 80%, the AGV will be removed from the system and recharged. This can only be done if there are sufficient amount of AGVs to perform the material handling tasks. The system was sustainable for over a long time when it consisted of at least 25 pc's of AGVs (Fig. 6).

The above results make up the reference values for the inductive power transfer models. The question is therefore,

how large reduction can be achieved regarding the number of AGVs compared to the previously stated 25 pieces.

5.2 Simulation results for the AGV system with additional IPT-loop charging

In this case the AGVs are charged on the tracks, therefore discharging has a lower rate. Additional charging track is, however, cannot be avoided like in the conventional case. The number of necessary AGVs is, however, much lower. Simulation results have shown that the necessary number of AGVs are 15.

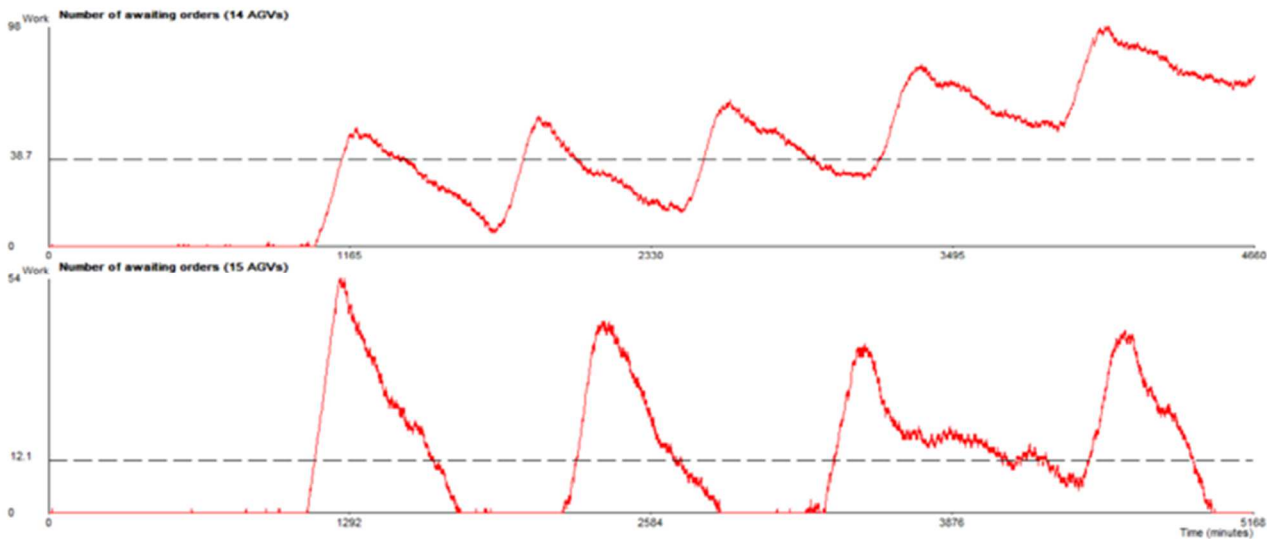


Figure 7 Number of awaiting work items at the input side using IPT tracks

In Figure 7 we can see that the time when the capacity drops under 80% and the AGVs massively depart for extra charging occurs later (around 1202 min instead of approx. 430 min, see Figure 6 for 25 AGVs) using an IPT system, because of the charging along the routes. Figure 7 for the case of 15 machines clearly shows that the system is capable of actively reducing the number of awaiting incoming orders periodically to zero. We remark that the amount of fluctuation can be reduced by a more strictly controlled material flow when not all AGVs are let out for auxiliary charging at the same time.

5.3 Simulation results for the AGV system with additional IPT charging stations

In this case during the movement, the capacity decreases, and the battery is charged at the separate charging stations and at the work centres. The simulation runs have proved that in this case 15 AGVs are necessary

as well. Results can be seen in Figure 8. in which we can observe that 14 machines are still not enough.

These results made us drawing further conclusions because the simulation runs couldn't decide preference of either IPT systems. We found that if the sum of processing times would be significantly more than the time of related AGV motion than the application of charging stations is preferred. In our example these values were chosen approximately and accidentally almost for same.

There are however other factors which should be considered by the decision of which system to apply. The track type IPT system costs more than the charging stations, so a parallel calculation of these costs is also necessary.

Finally, it should also be considered how significant changes can be expected regarding the layout. If it can be matched to the existing IPT track sections then it brings a great advantage, because repositioning of charging stations causes significant costs.

EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zolt Györfvály; Andreas Kluth

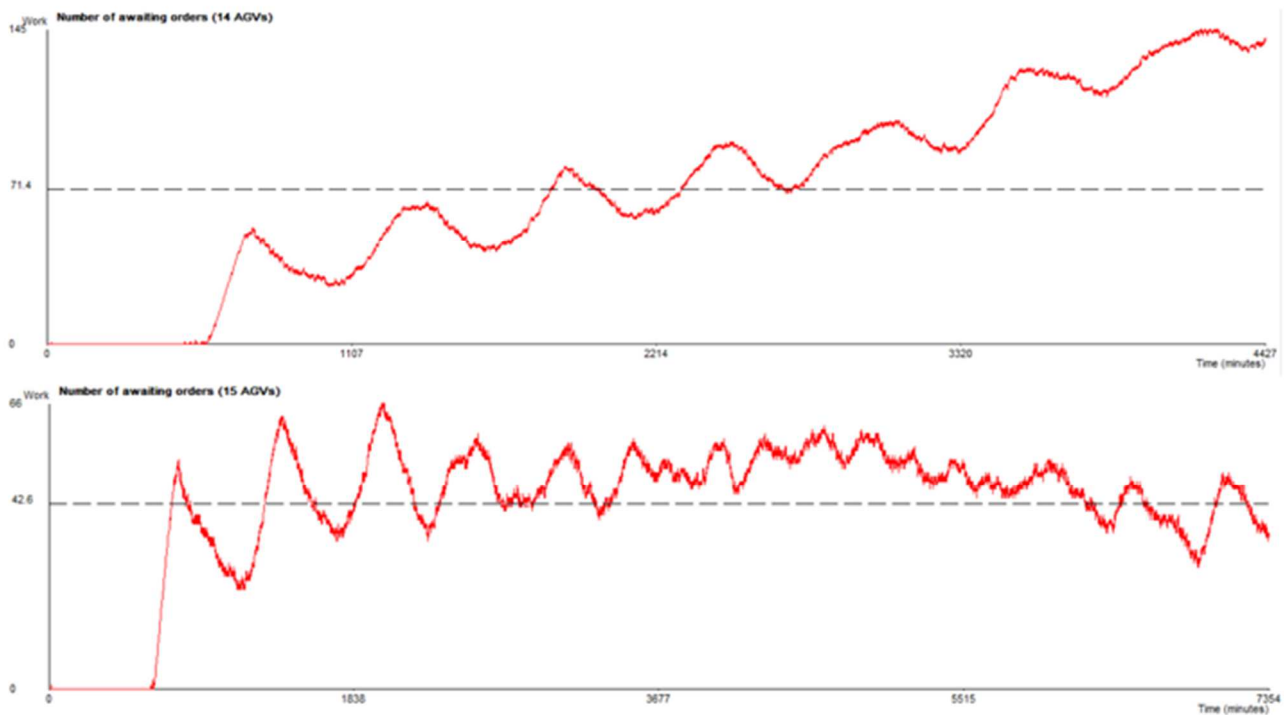


Figure 8 Number of awaiting work items at the input side using additional IPT stations

6 Conclusions

Our simulation proved that first of all, with a well-chosen charging logic, we can achieve serious investment saving, and simulation can effectively support these planning and analysis activities as well. Secondly, using an IPT system for additional charging of AGVs can be used effectively to increase the system capacity. It was also pointed out that both charging stations and tracks can be advantageous depending on the model parameters. This issue can be later an important basis for further examinations. The above scenarios depicted a static scenario that means the incoming material flow is stationer and homogeneous.

Further research concentrates on inhomogeneous and instating material flow which means, the AGVs handle simultaneously multiple different transport tasks, during which the generated path consist of IPT and no charging sections. This requires complex planning to which a theoretical model is needed. Next task of research aims development of this model.

7 Appendix A – Acronyms table

AGV – Automated Guided Vehicle;
 IPT – Inductive Power Transfer;
 DES Simulation – Discrete Event Simulation;
 WIP level – Work in Process.

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EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

Gábor Bohács; Zsolt Györfvály; Andreas Kluth

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Single-blind peer review process.