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NETWORK OPTIMIZATION PRIOR TO DYNAMIC SIMULATION OF AMHS

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ABSTRACT

The method presented in this paper is based on deducing a network graph from an automated material handling system in order to utilize algorithms from graph theory. An optimization process is built on this network structure enabling an improvement of AMHS system performance prior to employment of dynamic simulations. Run time in a static simulation is significantly shorter than that of dynamic simulations, thus this approach provides improvements not previously achievable. These may then later be analyzed and validated in dynamic simulations. The achievements of this method are demonstrated in a case study of a running semiconductor Fab. The throughput limit of the AMHS was able to be increased by nearly 20 % without negative impact on delivery times.

1 INTRODUCTION

Modern automated material handling systems, like those of semiconductor Fabs, have become large and complex. State-of-the-Art systems consist of several thousand meters of track, hundreds of intersections, and thousands of tool ports and buffer places. Newer facilities tend to be even larger and more complex. Despite this complexity, the routing of transports is still fairly simple. Most systems are based on a shortest-distance path routing, i.e. either length or some weight (cost) is assigned to each piece of track. The shortest path between source and destination is then used for routing. Each transport from a source to a destination takes the same path, regardless of current traffic or of track load. This lack of global-balancing limits the throughput of the entire system in cases where portions of track are congested. The key factor prohibiting a more sophisticated approach is the limited global availability of local traffic information.

In attempts to correct this traffic balance problem primarily dynamic simulations are used. This is both costly and time consuming. This paper therefore entails a new method for optimization prior to simulation, which allows faster and better results, as well as a better insight into system behavior.

The method is based on a network-model representation of the AMHS (Hammel et al. 2008), which allows improvement of system throughput and efficiency through the application of methods from Graph Theory. Highly sophisticated algorithms for network analysis enable system optimization in a way not practicable through dynamic simulation. Although this approach does not account for dynamic behavior, it enables a distinct improvement of system performance, which can be demonstrated when applied to a running system.

The AMHS of semiconductor Fabs will be employed to illustrate this approach. This can, nonetheless, be applied to any other transport system with similar features. Section 2 describes the basic model. Section 3 gives insight into the developed method and theoretic background. Section 4 demonstrates its functionality in a specific case study.

2 MODEL

For pre-simulation optimization, a network graph must be deduced from the layout of the AMHS.

2.1 Network Model

Each intersection and each tool port location, both as source and destination (to be called sink in network context), is represented as a node in the network. The connecting track forms the links (Figure 1, step 1). Thus, a network graph *G(V,E)* is generated with vertices *V* and edges *E*. For simplification, all vertices with only one inbound and one outbound link are eliminated, and the associated links are combined (Figure 1, step 2). Transports using such a node as source or sink are assigned to the corresponding link. This makes the number of links and nodes much smaller, thus increasing algorithm performance.

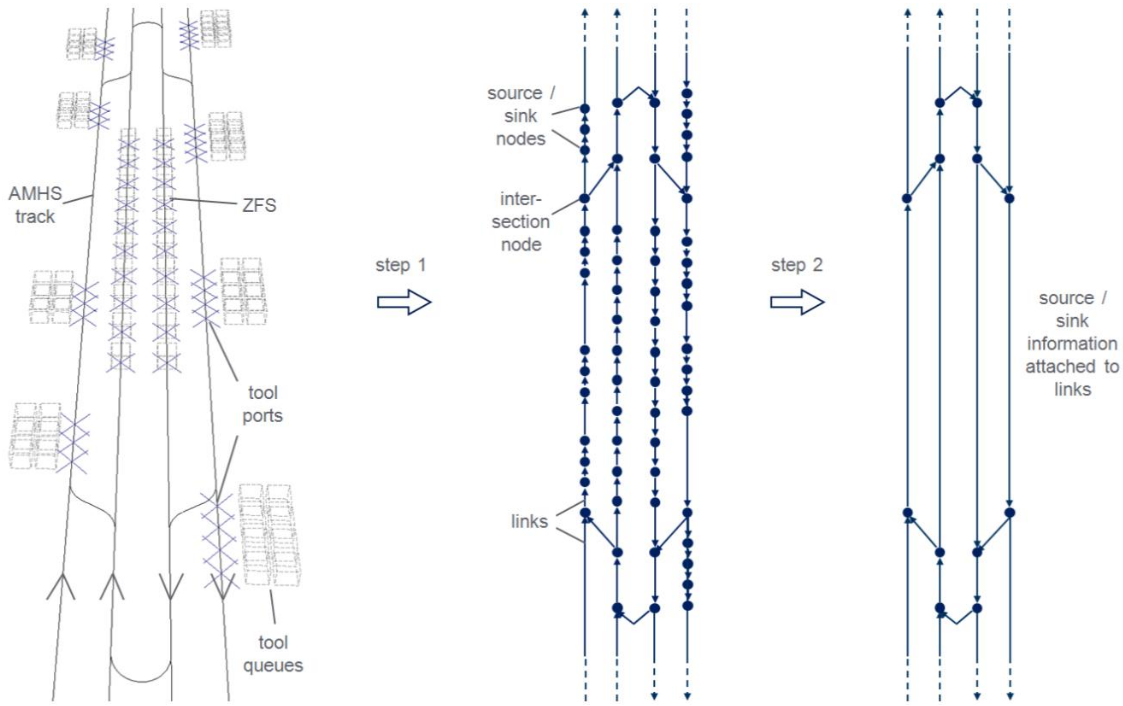

Figure 1: Deduction of network graph from AMHS (step 1, from AutoMod simulation model) and simplification of graph (step 2)

2.1 Track Utilization

Track utilization is calculated based on an approach derived from calculating betweenness centrality measures (Newman 2003, Bocaletti et al. 2006) from the Theory of Complex Networks. A list of single transports is used to represent the typical transport structure / load scenario for a certain time period *T*. Shortest-distance paths (lowest priced) are identified for each appearing source-to-sink relation $p_i(e_{i_a}, e_{i_b})$, where e_{i_a} and $e_{i_b}$are the source and sink links of relation i. n_i is the number of transports for this relation. Average track utilization $u_h$of link e_h is determined by adding up the number of transports for each relation to the used links and division by time period:

$$u_h = \sum_{i:e_h \in p_i} \frac{n_i}{T}$$

Common algorithms of graph theory are used to search for shortest / lowest-price paths. While Dijkstra's algorithm (Dijkstra 1959) performs well when looking for single shortest paths ($O(|V|^2)$ in its basic version for each path), others like the Floyd-Warshall-Algorithm (Floyd 1962 and Warshall 1962) provide a better approach for cases in which a high number of shortest paths from any given node to another is sought ($O(|V|^3)$ for all paths). To handle even larger systems than the ones tested to date (see section 4), it might be beneficial to use more specialized algorithms for the specific network structure. To keep things simple, only basic algorithms have been used: primarily the Floyd-Warshall-algorithm. The result of this algorithm is a matrix, which provides the next desired node from the present node, dependent upon the final destination. The specific path has to be constructed by looking up the next node, one after the other, until arriving at the sink.

Certain specific features of the investigated systems can be exploited in order to improve performance without changing the algorithm. Many AMHS have mainly simple divergences and mergings as intersections, rather than combinations of them. Accordingly, shortest paths may be identified starting at links before divergences and ending at links after mergings. If the actual origin, for example, is a link followed by a merging, there is no free choice for the next link. This simplification decreases significantly the number of shortest paths which can be constructed in the resulting matrix, and hence improves run time of the algorithm.

2.2 Differences between Real System, Simulation, and Network Approach

The degree of similarity between dynamic simulation and real system depends on the level of detail of the simulation model. No matter how much effort is invested, there is always a certain discrepancy between the two. A simulation expert is therefore needed to interpret the results. The same holds true for the network approach as well. The main differences between the presented method and reality (and dynamic simulation) are:

- Only transports are considered
  Empty (idle) vehicles are ignored; no track utilization is created by empty vehicle dispatching; no retrieval moves are considered. In systems with vehicle utilization by transports of 70-80% bottlenecks are defined mainly by real transports. For these systems, the approach is reasonably accurate. However, for systems with transports primarily directed in a single direction (e.g. baggage handling systems in airports), empty vehicle dispatching must be taken into account.
- No dynamic behavior
  Track utilization is calculated by average transports per period of time. Hence, the maximum throughput of each piece of track must be assumed to be considerably lower than it would actually be (i.e. with a constant transport flow) to allow a buffer for dynamic deviation. Furthermore, the network approach is not meant to substitute for dynamic simulations, but rather provides new improvement possibilities which should be tested in further simulations.

3 NETWORK OPTIMIZATION

The essential part of the presented approach is using the network model to improve system performance with regards to transport time or throughput by distributing traffic more evenly among different routes, and hence avoiding bottlenecks.

Less traffic on bottlenecks results in less traffic jams and an improved flow. However, this typically leads to longer transport routes. For optimum transport times, a balance must be achieved between transport distance and a broader distribution of traffic. A track utilization chart with link costs resembling link lengths identifies the distribution of transports across all links, if each transport takes the shortest path. Clearly, the links with the highest utilization will be the first to emerge as bottlenecks, if the overall demand on the system is high enough.

3.1 Basic Idea

To avoid traffic jams, all link utilizations must be below the maximum limit which the link can support. Technically, such a maximum number might be easy to derive for constant transport flows. The challenge is to define a limit that gives a large enough buffer to account for dynamic variation. One way to do this is the analysis of an existing system. The average track utilization from the network analysis of links with occasional traffic jams in real / simulated behavior should be taken as an approximate limit. It should not be exceeded on any link with the same settings. This limit may be assumed to be the same for all systems based on the same hard- and software. It can also be used for facilities still in the design phase.

The intention is to get all link utilizations below the respective link's limit. This way major traffic jams caused by normal transport load should be avoidable. The goal is to find cost parameters for the links which make sure all link utilization limits are held when 'shortest'-path routing is employed (meaning lowest-price-path routing), yet also keep the travel distance as short as possible. If the dynamic variance in the transport load is relatively high, it would be advisable to keep the average travel distance shorter, thus permitting a few traffic jams due to variance. This can be achieved by a smaller buffer for dynamic variance in the chosen utilization limit for links, thus setting the theoretical limit closer to the technical limit for constant transport flows. This allows the same approach, but with a different limit. Accordingly, the method presented in the following sections can be used for both scenarios, although it is illustrated only for the approach which tries to avoid any major traffic jams. As the method itself has illustrated good performance, it is also feasible to try different limit levels, and compare the effect of their final results in dynamic simulation.

3.2 Theoretic Background

Optimizing flows in a network where links have a definite capacity is a common problem in graph theory. Simple problems (e.g. maximum flow problem, see Ford-Fulkerson algorithm, Ford and Fulkerson 1956) consider only one kind of transport good, and fit if handling, for example, a pipe system where the only interesting measure is how much liquid can pass through for a given period of time. It needs a set of sources, a set of sinks, and maximizes the flow between both sets.

3.2.1 Multi-Commodity Flow Problems

There are also several problems related to network throughput of different commodities (multi-commodity flow problems, MCFP, see Bazaraa, Jarvis and Sherali 2011 for examples). Each commodity may have its own individual transport relations and demands. Algorithms for problems of this kind are far more complex and time-consuming. There are three main kinds of the MCFP:

- Minimum cost MCFP: Each link is associated with a certain cost for each passing of a transport. The goal is to minimize total transport costs. Setting a cost for passing a link which is equivalent to its travel distance on a given piece of track is essentially a matter of finding the balance between throughput and total travel distance, as mentioned in 3.1.
- Maximum MCFP: Transport relations are fixed, but there is no excessive demand on any given relation. The goal is to maximize total throughput, regardless of the value of each individual relation or commodity throughput.
- Maximum concurrent flow problem: Each relation has a certain demand. The goal is to maximize the minimum relative fulfillment of any demand. This means the maximization of total throughput of the transport system, assuming that the relationships between transport volumes of the source-sink-relations remain constant.

Algorithms to solve these problems would give a theoretical optimum for travel distance or throughput of the technical transport system, if they were able to handle networks of the required size and the respective number of different commodities within a given period of time. However, in order to achieve their optimum, they all depend on a certain freedom in routing which most transport systems do not provide. Different transports of one source-sink-relation would have to be allowed to take different paths. In our case of the static shortest-path routing (by whichever length / cost parameter), all transports of a single relation would take the same path. If there is no more optimal or load-dependent dynamic routing, this would mean the above-mentioned algorithms will not provide useful results.

3.2.2 Shortest-Path Routing Allocation Problem

Another problem is the actual attempt to find a set of link costs which will cause the shortest-path routing to take paths that assume that capacities of links are held. It is common in communication networks, but even harder to solve as it is *NP*-complete (Pioro and Medhi 2004). Although there are varying prerequisites, it is the run time that hinders the ability of the application of algorithms in finding an exact solution. For networks of the desired size, this is assumed to take too long to make this approach feasible. Hence, a heuristic approach will be chosen.

3.3 Optimization Goal

To maximize throughput of the transport network, an adjustment of network lengths (link costs) is needed in order to assure that transports are better distributed. The result should be as close as possible to that of shortest-distance paths so as to keep the transport times low. To achieve a practical result, an iterative approach starting with a scenario which has costs set equivalent to the links' length seems promising. In this case, all transports take the shortest path by distance. Step-by-step, all over-utilized links are increased in cost, resulting in increased avoidance of them. Eventually, this should lead to a scenario where utilization of any given link is below the target limit. There is no guarantee that this approach will find a solution, if one exists in the first place. Nevertheless, in all tested examples, this led to a result that would not have been found by mere dynamic simulation.

3.4 Procedure

A basic decision before attempting any optimization is which load scenario the system should be fitted to. Each load scenario will have different results in network parameters (just as they do in dynamic simulations). It is therefore advisable to choose a scenario which is as representative as possible. It is also possible to fit the system to one certain load scenario, and test the result with other scenarios, also adjusting it to their specifications. The goal is then to find a set of link-cost parameters based on a load scenario which assures holding the throughput limit for each link, while keeping the transport routes which are used as close as possible to the shortest-distance paths. The larger the buffer between actual throughput limit and target limit for optimization, the greater the chances are that the load scenarios will not result in traffic jams in the real system.

As discussed, starting with a system where all link costs are set proportional to their respective lengths, all transports would use the shortest-distance paths. Depending on the particular situation (how many links are over-burdened at the beginning, and by which amount), there are a few different strategies available to manipulate the cost parameters.

3.4.1 Increase Cost of Highest-Utilized Link One by One

After evaluating track utilization of all links, the one with the highest utilization has the cost raised to bring it just below the target limit. This amount can be deduced by evaluating utilization with a nearly infinite cost of this link, and comparing how much more expensive a path would be if moved away from this link. Sorting these route changes by their ascending differences in path costs, the new link cost can be set as needed in order to change as many routes as necessary to maintain the throughput limit (Figure 2). Track utilization then has to be re-evaluated and the next link similarly manipulated.

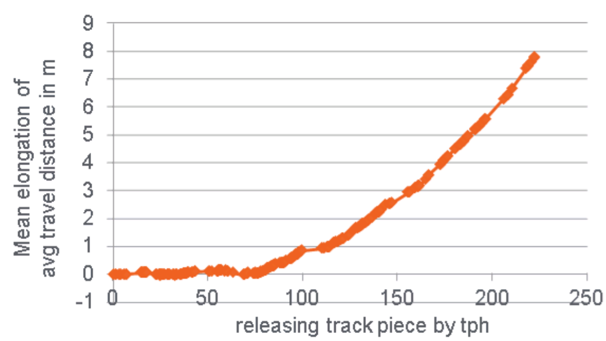

Figure 2: Diagram of impact of cost increase for one link. Increasing cost leads to decrease in track utilization (shown as transports per hour, tph), and thus impacts average travel distance. Each point shows track utilization release (in ascending order) and average travel distance change for any given cost increase

Each step of this approach changes only one link at a time, and requires the analysis of route changes for all routes which include the link in question. This approach is most effective if there are only a few links with utilization exceeding the target limit. It may also be used if a manually supported optimization method is the one of choice: It is possible to evaluate route changes, and the probable impact thereof on average travel distance with each step. In this case, the selection of the link to be changed may also be done manually, given the aim of the change and the possible resulting disadvantages.

3.4.2 Increase Costs of All Over-Utilized Links at Once

If the number of over-utilized links is relatively high, it might be necessary to manipulate more than one link at a time, due to run time. One approach, which proved efficient when testing in real systems, is to make all over-utilized links more expensive either linearly or quadratically in proportion to the level of their over-utilization. The "right" proportion factor must be defined by trial and error attempts. In the tested examples, this method led to far less steps in the elimination of all over-utilizations.

Depending on the actual network structure, the potential problem with this approach is that consecutive links over their throughput limit would all be increased in cost. They might all be used by the same paths so increasing the cost of one link might be sufficient in itself. Increasing all of the consecutive links at once might result in certain paths becoming excessively, and unnecessarily, expensive.

After eliminating the majority of links from the set of over-utilized links, a sound strategy might be to change to the strategy mentioned above (3.4.1). If dealing only with few over-burdened links, this approach is more targeted, and might thus require less steps.

3.4.3 Genetic Approach

Genetic algorithms are frequently chosen for problems without a feasible analytic solution. Compared to the approaches mentioned above, they have some stochastic influence on the parameter changes. Additionally, they evaluate the improvement in each step and accept the changes with a certain probability, depending on the advancement. This could result in the acceptance of changes that might negatively impact the situation. This theoretically enables finding a global optimum, rather than getting fixated on a local one.

In the network optimization described here, this could mean making the proportion factor from 3.4.2 a random number within a certain range for each link that is to be changed in cost. Additionally, costs of links with utilization under, but close to, the limit might also be changed with stochastic influence. The result of these changes could then be evaluated in terms of number of links with utilization above their limit and total sum of over-utilizations before and after application of the algorithm. Depending on this evaluation, the changes would then be either accepted with a certain probability or discarded. This approach, however, has not been tested yet, because the combination of the two approaches mentioned above (3.4.1 and 3.4.2) always found a suitable solution in a limited number of steps.

3.5 Validation

The result of any of these approaches is a set of cost parameters for the network links, which leads to all link utilizations being below their respective limits. Depending on which limit has been chosen, this may mean that transferring these parameters into the simulation, or real system, will result in the occurrence of rare major traffic jams. In order to test and validate the outcome, only a few runs in the dynamic simulation are needed. Depending on the simulation results, it might be necessary to rerun the network optimization with different link utilization limits.

Also, sensitivity analysis is advisable at this stage. This involves testing different load scenarios or subsets of the used time period in network analysis and simulation.

4 CASE STUDY

The presented network optimization approach has been tested in a producing semiconductor Fab. GLOBALFOUNDRIES runs three facilities called modules at their Dresden campus. Module 1 has the oldest AMHS. Since it tends to be over-utilized, it was decided that this system needed to be improved so that it will be able to handle the production load it currently faces, as well as future production loads.

4.1 Fab Introduction

The Module 1 AMHS was installed in 2004. It consists of 6,500 meters of track, 280 vehicles serving 750 tools, Zero-Footprint Storage groups (tool delivery buffer bins under the track controlled in groups, ZFG) located in all 17 intra bays and additionally 60 stockers. Tools are located in intra bays, but most stockers are connected to inter bays

(Figure 3). The inter bays are potential bottlenecks, due to the fact that nearly all stocker transports and transportations between different intra bays must pass the inter bays. Wafers are stored in so-called FOUPs which are transported either directly from one tool to the next or get buffered in some storage area in between.

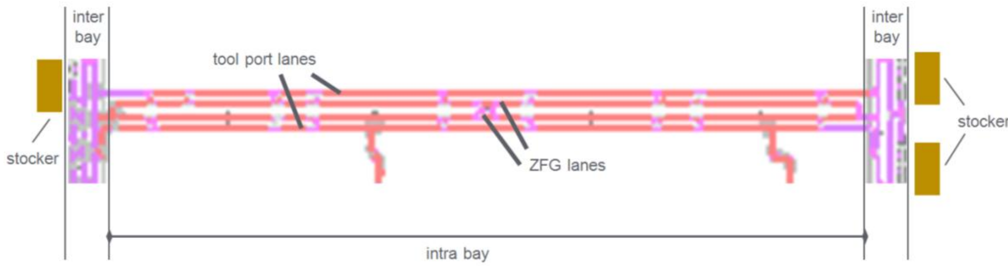

Figure 3: Basic bay layout

The interesting feature of this Fab, from the point of view of testing the network approach, is that the transport demands were to rising because of updated tools with higher throughput and an overall rising production rate. Since the AMHS was already running close to its limits, it was necessary to find any optimization means that could be quickly and easily implemented. Adjustment of cost parameters for the transport network had already been performed in the past, but mainly for local changes if a bottleneck was readily evident in the real system, and without investigating broader consequences of these changes to the system, in advance. The need to optimize traffic flow across all critical areas became urgent. A well-founded overall approach was therefore sought.

4.2 Approach

A software tool has been developed to deduce the layout information (track, tool ports, etc.) automatically from both dynamic simulation and the real system into a network. It was used for both this purpose and to map both systems to each other according to their network structure; the latter, due to inconsistent geometric information. Transports from both systems were automatically transferred into the network model in order to allow dealing with them in the network environment. Besides enabling further optimization, this allowed a comparison between real and simulation-generated transports, as well as their impacts on the transport system. The simulation generates transports based on a subset of all used process flows, and assumes certain simplifications. Therefore, discrepancy between the simulation and real transports is expected. Simulation neglects any transport of test wafers, empty FOUPs, etc. or events like line holds. This comparison also gave good insight into possible differing locations and degrees of bottlenecks based on the respective transport structure.

The high resemblance of expected bottlenecks from a first network analysis (track utilization) to those of the running system, as well as to simulations executed with transports from the producing system, made the model very promising. The primary goal was to enable the AMHS to raise throughput. Assuming that the structure of the transport load would stay the same, this would lead to a relative increase in all link utilizations. The idea was, therefore, to bring all link utilizations below a certain limit, thus enabling an increase in transport numbers. Transport times were considered of minor importance in comparison with throughput. However, reducing traffic jam situations occurring in highly utilized areas was expected to lead to better delivery performance, although the required distances for FOUP transport from source to destination would increase.

A track utilization of 200 transports per hour (tph) was chosen as a limit for each piece of track in order for the network optimization to avoid major traffic jams. This limit was defined by identifying locations in the existing system where minor jams periodically occurred. The track utilization of these points was around 220 tph. Expectations were that holding a limit of 200 tph on all links would give a buffer of around 10 % in throughput for the current state and still keep all traffic flowing to a high degree if this buffer was fully utilized.

The starting point of the optimization was the current setting of cost parameters, which was mainly based on length of respective pieces of track, but also had a few manually adjusted points. All costs of over-utilized links were simultaneously changed as a starting point (3.4.2). In each step, all costs of links with utilization above 200 tph were increased by a factor proportional to their over-utilization. In later steps, manual reviews and adjustments were undertaken, due to the fact that, although some information about potential changes in transport structure was available, they were not to be included in the transport scenario which was used. The manual reviews and adjustments were also necessitated, because the approach was still in development.

Since the software tool was able to export the cost parameters directly to the simulation model, the following validations were easily achieved. The dynamic simulation was executed with the same real transports as used for the network approach, but also with simulation-generated transports involving a reasonably different transport structure.

4.3 Results

The original system had more than 20 over-utilized links with a maximum utilization of 280 tph. This analysis implies regular traffic jams, which could actually be identified and observed in the real system at the expected points. By adjusting cost parameters in the network approach, all link utilizations could be reduced below the chosen limit of 200 tph (Figure 4). The drawback of this improvement in track utilization was an increase in average travel distances by nearly 5 %.

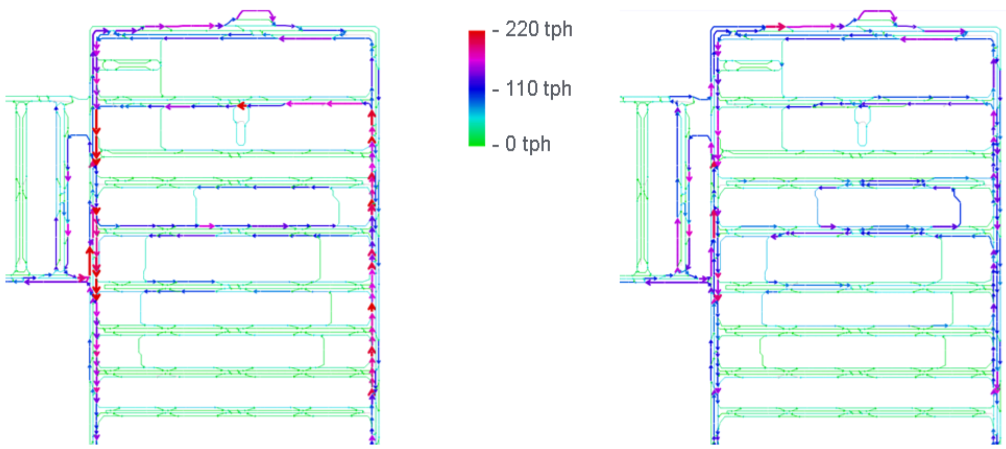

Figure 4: Track utilization chart of a portion of the AMHS layout, left: original state, right: optimized by network approach

Transferring the found cost parameters into the existing dynamic simulation model (built in AutoMod simulation software) showed an impressive result (Figure 5). Runs generally consist of 12 hours of transports including a 2-hour warm-up period. The stability of the results was tested by consecutive runs with a slight step-by-step increased load factor. Not only could the expected throughput increase be realized, but the 95-percentile of delivery times did not worsen in any test case, regardless of whether real transports or generated transports based on process flows were simulated. Even with a low load scenario, the on average longer travel distance was compensated for by shorter waiting times, due to a lack of traffic jams. For the highest achievable load level with original settings (before optimization), i.e. the highest load with delivery times still considered acceptable in the simulation (5 mins average and 10 mins for 95-percentile) a reduction of delivery times by up to 20 % was achieved. Also different load scenarios, like the simulation-generated ones, showed an improved performance. Another feature of the new settings was that, when exceeding maximum acceptable delivery times due to high load factor simulation, traffic continued to flow. With the original configuration, it quickly developed deadlocks.

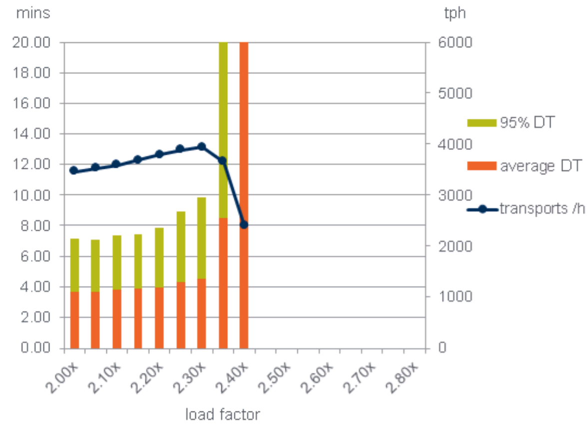

Figure 5: Simulation results in terms of average and 95-percentile delivery times with original (left) and optimized (right) cost parameters

There were concerns about implementation of simultaneously adjusted cost parameters in the whole system without performing a test run in a well-defined, limited area. The impact of changes to and on the system are never completely predictable, especially since the simulation cannot reproduce the running system in every detail. The AMHS team, and management, were convinced to proceed with implementing this model into the running AMHS, because of the fact that the developed parameters may only work for the entire system simultaneously. This is due to the high correlations of all transports. The clear confirmation of the network optimization results by dynamic simulation played a large role in receiving permissions for a real whole system trial.

The changed cost parameters were rolled out on March 14th, 2011. Although the system was running close to its throughput limit, a significant increase in transports of ~20%, or 400 tph, occurred in subsequent weeks without considerable impact on delivery times (Figure 6). Worsening delivery times were noted upon further increase in transports, but in a smoother way than anticipated.

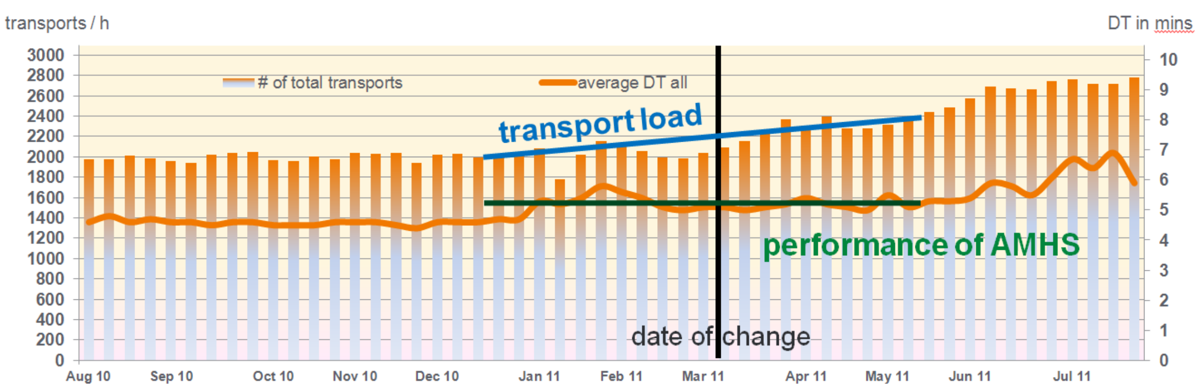

Figure 6: Performance of the running system before and after changes of the cost parameters

Without manual intercession, one complete network optimization, providing a set of cost parameters for all links simultaneously, took about the same time as a simulation run of 12 hours simulated time to test one specific scenario. After the optimization software tool had been developed, the whole-network optimization and validation in dynamic simulation took approximately four weeks, but the latter one was still the most time-consuming portion. An increase in system throughput of that magnitude by other means would have been much more expensive, and would have taken significantly more time.

5 CONCLUSION

In this paper, a new approach for AMHS optimization is presented based on a network model of the transport system, and using methods from graph theory. It analyzes and optimizes track utilization without focusing on dynamic behavior, thus showing a run time for each run which is only a fraction of that of dynamic simulation runs. It can be used to improve system performance prior to, but not substituting for, dynamic simulation. It helps access optimization potential not efficiently available through simulation alone.

As mentioned, the network approach is, by design, lacking any dynamic behavior. On one side, this makes it less accurate than simulation. On the other side, this increases the performance significantly, and hence allows investigations that would not be possible solely using dynamic simulation.

Even though the travel distances of all transports can be calculated exactly, conclusions about travel times are harder to make based solely on network analysis. As long as the assumption of ‘no larger traffic jams’ holds, the travel time in most systems can be estimated from travel distance and the number of intersections to be crossed. As soon as traffic jams become significant, this becomes more complex. As this approach is meant mainly to improve the system before simulation, it helps primarily to deduce travel times for well distributed cases, or to focus on travel distances first and foremost, using simulation for more detailed transport time analyses.

The function and impact of the proposed optimization are demonstrated using a running system in a semiconductor Fab, thus showing an impressive throughput increase, while keeping delivery times at a comparable level. Because of changing transport structure of the manufacturing areas, this optimization has been reapplied after the first optimization showed the initial results. With each anticipated change of transport pattern, for instance due to the connection of new tracks with the existing AMHS system, this optimization was rerun, and proved its applicability each time. Because most routings of AMHS are based on some kind of shortest-distance paths, the same approach can be used for other systems, being especially promising for large and complex ones, such as baggage handling systems in airports.

Besides improving performance of systems already running close to their limit, the method may also be used for robustness improvements of systems with higher throughput buffers, as introduced in Hammel and Wustmann, 2011. In this case, the goal would also be the distribution of traffic to different tracks. This is not to avoid jams due to high traffic volume, but to decrease impacts of vehicle failures. Postulating that two congestions involving a certain number of vehicles have a smaller impact on system performance than one congestion involving double the number of vehicles, the evenly distributed use of two parallel tracks should be more robust than one. This has already been validated in simulations in another module of GLOBALFOUNDRIES’ Dresden campus with a more modern AMHS, and is about to be rolled-out to the running system as well.

Additionally, this approach is not only suitable for optimization of existing systems, but also for fast analyses of layout changes and in the design phase of new systems. Especially in the planning phase when the information level is often inadequate for a highly detailed dynamic simulation or data is changing faster than simulation models can be created and adjusted, the network analysis and optimization can quickly generate a prediction of system performance accurate enough for this stage, as indicated in Schmidt, 2010. While building a high level dynamic simulation takes up to months, the presented approach can give insight into bottlenecks, their impact level and the ability to resolve it by changing the routing within days. At the same time, comparison of different layout options is a very simple matter once a running network model exists.

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