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MODELING LOT ROUTING SOFTWARE THROUGH DISCRETE-EVENT SIMULATION

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ABSTRACT

Intel has recently developed lot routing tools that can theoretically minimize local and overall lot movement. These developments were required to maximize the flexibility of existing AMHS and minimize the time needed to retrieve lots for processing.

In order to gain insight of how these lot routing rules impact manufacturing, and how they should be configured, Intel uses two different analysis tools. A static spreadsheet model was used to determine the impact of the new lot routing rules in terms of AMHS lot movement volume. The second level of analysis was to use dynamic discrete-event simulation to determine the impact to AMHS and equipment utilization. Both methods were used to determine how tool policy rules should be set for each operation in the process flow, and minimize impact to AMHS and enhance performance, while meeting manufacturing requirements.

The static model analysis showed that ideal use of the lot routing algorithm had a very significant impact on AMHS transport requirements. The dynamic discrete-event modeling showed that the lot routing policies can be modified to enhance system performance. These modifications resulted in key learnings about configuring the lot routing software.

1 PROBLEM STATEMENT

Due to increasing complexity of Intel's lot routing algorithms, Intel's current material handling simulation models must include new functionality. Intel must develop multiple new simulation techniques to determine the impact of lot routing rules on Automated Material Handling Systems (AMHS) within wafer fabrication factories, and determine how to configure these rules based on tool sets, various operations, and tool layout.

2 BACKGROUND

For several years Intel has employed dynamic discrete-event simulation to model the hardware and software related to Automated Material Handling Systems (AMHS) within semiconductor chip fabrication facilities. AMHS, if used correctly, can increase the accuracy of source to destination WIP movement, maximize process-tool utilization, and provide WIP tracking capabilities, all while maintaining cleanroom standards.

AMHS in semiconductor factories can be separated into two classes - interbay and intrabay. Interbay systems are large, factory wide systems which move materials between bays or functional areas throughout the factory, and are typically monorail-type movement systems, where vehicles move material using the monorail and interface with AS/RS machines (stockers) in areas where materials are processed (manufacturing bays). They are the focus of this paper. At a high level, an automation system typically consists of a shop floor controls system that exchanges information with an AMHS and an automated equipment control system. Figure 1 graphically depicts this automation architecture.

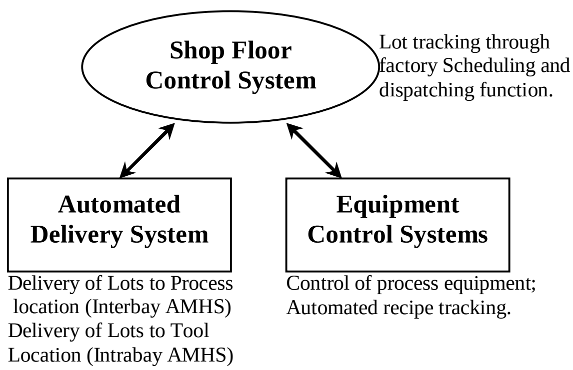

Figure 1: Intrabay Automation Architecture

The shop floor control system provides information on lot availability to a customized user interface, which prioritizes available lots, based on processing priorities. This interface in turn communicates with the Material Control System (MCS), which schedules AMHS actions. Additionally, the shop floor control to MCS interface also stores physical destination information used for lot pickup and delivery by the AMHS (Jefferson, Rangaswami, Stoner 1996).

Until recently, the mapping of individual manufacturing operations to a physical AMHS location (stocker) was limited to a maximum of one destination per operation. Independent of AMHS mappings, process engineering and factory operations requirements also map operations to specific pieces of equipment. When an operation is only processed on a unique piece of equipment only, or when an operation can be processed on multiple pieces of like equipment in the same bay, the 1:1 mapping of operation to destination does not result in operational difficulties. Unfortunately, this is not always the case. Factory layouts often dictate that a particular operation could be processed on a subset of equipment, which may be located in multiple places throughout the factory.

Per the above description of system functionality, the AMHS will only deliver lots to one physical location per operation. Therefore, when an operator at an alternative location needs to process a lot for that operation, the time needed to retrieve the lot is greatly increased. Instead of being located in the local stocker, where retrieval time is at a minimum, the lot must travel from its current location (possibly thousands of feet away!) to the requested location. Obviously, this has implications to constraint and near-constraint processing tools. In severe cases, the time for the lot to arrive could theoretically result in process tool starvation.

To help minimize the impact of the AMHS software shortcomings described in the previous paragraph, Intel has recently developed Lot Routing tools for AMHS which can theoretically minimize local and overall lot movement, decrease batch time, and reduce specific tool setup activities. These developments were required to maximize the flexibility of existing AMHS and minimize the time needed to retrieve lots for processing. In order to gain insight of how these tools impact manufacturing, and how they should be configured and used, Intel uses static and dynamic discrete-event simulation analysis. The focus of this paper is the modeling of these scheduling tools within the AMHS. Specifically, this paper discusses recent lot routing developments at Intel, the use of static simulation in estimating impact to AMHS and manufacturing, and finally, the use of dynamic discrete-event simulation in determining how these rules should be configured.

3 BASICS OF LOT ROUTING ALGORITHM

Intel's new lot routing tool policy rules use relationships between tool sets, operations, WIP, and tool policies to determine how to route WIP dynamically. There can be any number of tool sets and operations, and several tool policy rules are currently used (Refer to Table 1 for a sample of these rules). These rules are combined

Table 1: Examples of Lot Routing Tool Policy Rules Matrix

RULE NAME	RULE DESCRIPTION
WIP Level	Number of lots that are assigned to a tool. This can be used to prevent tool starvation, or create full batches quickly. Sort: Sort tools by ascending/descending WIP level, to ensure tool in bucket with lowest/highest WIP gets next lot Pure: Example, only allow tools with less than or exactly n lots waiting to be considered.
Tool Proximity	Distance between the stocker at which the lot currently resides and the candidate tool/stocker. Sort: Sort tools in ascending/descending order of distance Pure: Ensure that only tools in same or different "zone" are considered.
Like Oper	The number of lots at the same operation number as the candidate lot. This can be used to create full batches. Sort: Sort tools in order of descending/ascending lots with same operation Pure: Qualify tools to a bucket if they have fewer or more than n lots at an operation.
Like Prod/Oper	Same as like Oper, but instead counts lots at the same operation AND of the same product as the candidate lot. This can be used to reduce tool setup activities. Sort: Sort tools in order of descending/ascending lots with same operation and product type. Pure: Qualify tools to a bucket if they have fewer or more than n lots at an operation and product type.
Dedicate Lot to Tool	Passes only tools to which the lot is dedicated as candidates
Reticle on Tool	Passes only tools at which a candidate lot's associated reticles reside.

together in multiple "Policy Buckets", using a variety of priorities, or pure vs. sort assignments, to configure many different effective routing policies. Pure rules dictate that specific tool, operation, and location criteria must be met for the candidate lot to be routed to a location, while sort rules indicate that all possible locations will be prioritized or ranked based on those rules. The high-level logical flow of how tool policies get transformed into tool and storage assignments can be seen in Figure 2. Based on the configured "policy buckets", WIP is assigned to the appropriate tools. Storage locations assigned to those tools are then chosen as AMHS destinations for WIP transport.

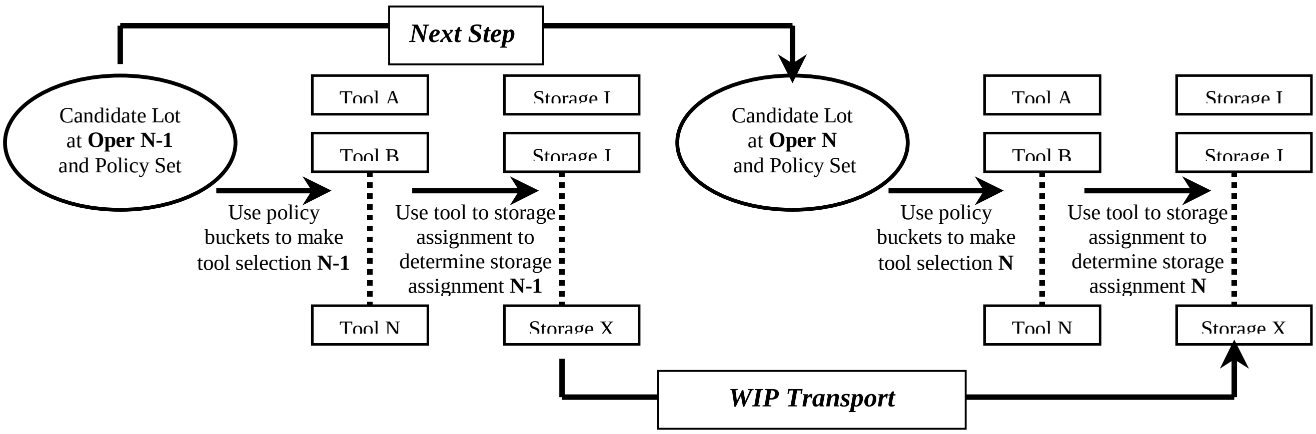

Figure 2: High-Level Lot Router Logical Flow

4 MODELING METHODOLOGY

The modeling methodology used to understand this new functionality involved two separate models. First, a static spreadsheet model was used to determine the impact of the new lot routing rules in terms of AMHS lot movement volume. This first level of analysis was done to determine if there was any impact on AMHS, in terms of throughput requirement, or AMHS volume. The second level of analysis was to use dynamic discrete-event simulation to determine the impact to AMHS performance (move types) and equipment utilization. Both methods were used to determine how tool policy rules should be set for each operation number to minimize impact to AMHS and enhance performance, while meeting manufacturing requirements. Both analyses were done using a high volume Intel fabrication facility with limited product mix, consisting of two buildings, with AMHS within and between the two buildings. However, this analysis can be used with any fabrication plant layout.

Two static spreadsheet models were used to determine lot movement impact to AMHS without (today) and with (future) the lot router. High level inputs to this model were WIP, throughput requirement, operator and tool availability, process cycle time, tool processing time, AMHS equipment specs, batch sizes, non-production lot movement assumptions, mis-processing assumptions, etc.

The fundamental difference between these two models is that the new lot routing rules model incorporates a second tool/storage destination. The logic of the model accounts for WIP level and tool proximity. Based on the proximity of the tools, the WIP that would be expected at both destinations with cycle times and tool run rates, and the WIP required for that step, the model calculates internal and cross-building lot movement rates. The format of the outputs enables the model user to determine the impact of specific tool layout and lot-to-tool dedications.

The dynamic model was created to predict the effect of these moves to delivery times and equipment utilization, and can aid in determining the best configurations of the tool policy rules for each operation number. Figure 3 is a high-level description of the dynamic model inputs and outputs.

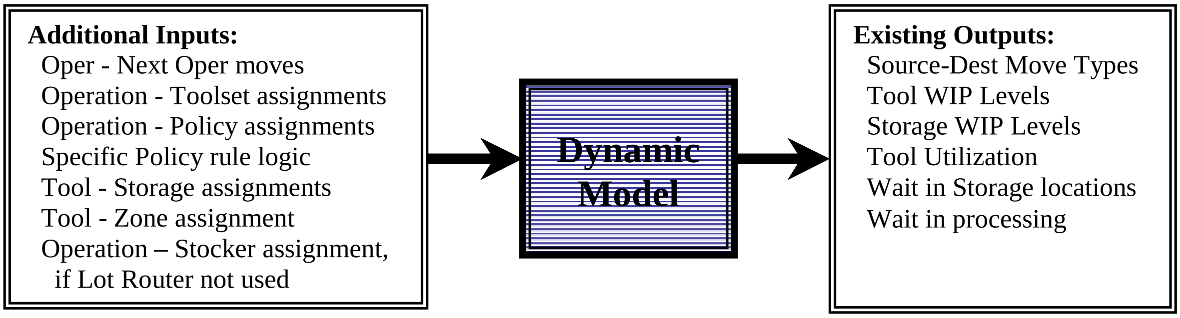

Figure 3: High Level Description of Dynamic Model Inputs and Outputs

The description of the dynamic model logic can be broken down into 7 basic steps (refer to Figure 4 for graphical description of steps 2-3).

1. Based on operation -> next operation move rates and probabilities, the model load is created.
2. Based on the policy rules associated with that oper# (operation/policy assignments), a tool is chosen for the lot for that oper #. Multiple policies may be reviewed if tiebreakers are required until one candidate tool is chosen.
3. After tool is chosen, determine stocker associated with that tool. This is the AMHS destination.
4. The lot is routed from the current location to the storage destination
5. Once the lot reaches its destination, delivery time and move statistics are recorded.
6. The lot must claim and utilize the tool resource for the pre-defined processing time associated with that operation.
7. After processing, additional WIP statistics are maintained, and the model load dies.

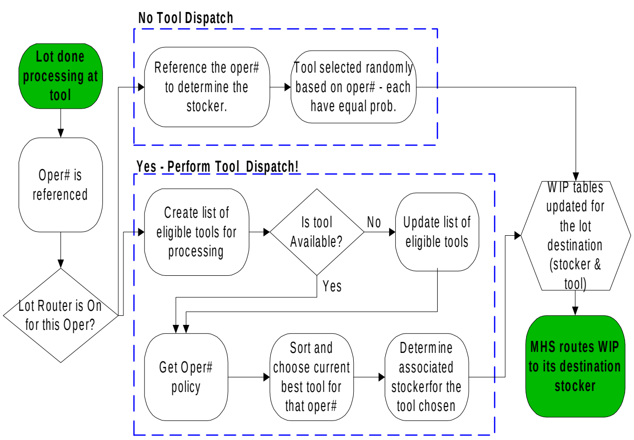

Figure 4: High Level Dynamic Model Lot Routing Logic

With regard to step 2, multiple tool policy rule sets should be considered to determine an "optimal" or near-optimal policy set. This near-optimal configuration will change based on operation flow, lot-to-tool dedications, and tool layout.

5 RESULTS AND IMPLICATIONS

The results of this analysis are categorized by static and dynamic model results. Both show a significant impact of the lot routing algorithms in question.

The static model analysis showed that the Lot Routing algorithm had a very significant impact on AMHS move requirements. All average and peak move rate requirements were increased by 1.8 to 2 times without the lot routing algorithms. Please refer to Table 2. Obviously, this will have a significant impact on AMHS equipment set requirements and performance. Also, 43% of operations in this example did indicate multiple tool assignment possibilities. 57% retained the traditional 1 destination per operation philosophy. Arguments could be made that additional multiple tool dedications could further reduce or increase AMHS requirements, depending on the specific lot-to-tool dedications. The model's user interface and output format of move rates aided in considering many assignment possibilities, and ultimately arriving at the best lot-to-tool dedications to minimize AMHS impact while meeting manufacturing requirements. The most important learning, at least for this fab example and product mix, is to process all lots in the same building for as long as possible, transporting WIP to the other building only when necessary and following the same philosophy once the lot has arrived there. Competing objectives are the existing tool layout, tool relocation costs, and tool utilization goals.

Table 2: Static Model Lot Movement Rate Requirements Results

	With Lot Router		NO Lot Router	
Move per Hour Type	**Avg.**	**Peak**	**Avg.**	**Peak**
Between building MPH	**A**	**X**	**1.89A**	**1.80X**
Building 1 MPH	**B**	**Y**	**1.90B**	**1.83Y**
Building 2 MPH	**C**	**Z**	**1.96C**	**1.97Z**

The dynamic model results can be seen in Table 3, with the intent to analyze various policy sets. Many additional metrics were recorded. Moves within each building and between buildings were recorded. Also, average WIP levels at each tool and stocker were tracked. Delivery times, MHS vehicle utilization, and wait time for vehicle pickup can also be monitored, but are not included here. Obviously, these are just some of the performance metrics that could be analyzed.

Table 3: Dynamic Model Results

Model Metric	Lot Router Configuration 1	Lot Router Partial Config	Lot Router Full Config
Inter-Zone Lot Movement	W	1.15 W	-1.1 W
Intra-Zone Lot Movement	X	-1.15 W	1.1 W
Average Tool WIP level	Y	1.07 Y	0.93 Y
Average Storage WIP level	Z	1.12 Z	0.86 Z

The lot router can have significant impact on tool utilization and AMHS system performance. In fact, meeting all throughput requirements with the old lot router was found to be infeasible with the existing tool layout and AMHS equipment set at the fab. The lot routing rules implemented in the “Full Config” scenario resulted in less movement between the two buildings, which is a primary concern in this example. Several modifications were considered (some with catastrophic failure), resulting in many key learnings about configuring the software.

6 CONCLUSIONS

Both a static spreadsheet and dynamic discrete-event simulation were used to determine if Intel’s recent lot routing algorithms would impact AMHS requirements and performance. The lot router absolutely has a positive impact to AMHS move requirements, as shown by static model analysis. Specifically, the tool proximity and WIP level policy rules were modeled in such a way that long transport moves between and within buildings were minimized. Conversely, these rules could also have been configured inefficiently, so that there would be no impact to or increasing lot movement rates.

The dynamic discrete-event model provides the capability to analyze various lot routing policy sets, and their impact to move rates, tool utilization, and WIP levels across the factory. The main conclusion is that these policies can have both positive and negative impacts to the AMHS system and tool utilization. The impact is dependent on many factors, namely tool layout, processing volume, the capacity of the AMHS system, and most importantly, the lot routing policies themselves. The policies should be continuously monitored and modified to enhance system performance, meeting the dynamic requirements of manufacturing. The ultimate benefit of the lot routing algorithms and the static and dynamic model analysis is that it reduced the amount of AMHS equipment required in the fab, decreasing the cost of AMHS. These benefits are aligned with any organization’s final objective – reducing costs and maximizing profit margins.

7 NEXT STEPS

The scope of this paper was limited, in that it only considered how this lot router could impact a few AMHS performance metrics and some high-level tool impacts. Moreover, it is specific to one fab layout and processing requirements. The obvious next step is to establish a set of best-known policy configurations, for various factory and tool layouts, so that specific rules can be determined as to how the software should be configured for any particular process flow/mix or tool layout.

Another hot topic needing consideration is how these lot routing rules will interact with other existing fab scheduling rules and software. If these policies can be aligned with existing fab scheduling rules and manufacturing priorities, the potential benefits, at least to AMHS requirements, are enormous. The modeling methods presented here should provide the decision support necessary to determine if and how the two functions be implemented as one decision software, or maintained as independent entities. Finally, it is always critical to understand what the cost impacts (savings and expenditures) are, both in terms of AMHS equipment and software, and operations.

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