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A SIMULATION-BASED DESIGN FRAMEWORK FOR AUTOMATED MATERIAL HANDLING SYSTEMS IN 300MM FABRICATION FACILITIES

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ABSTRACT

This paper describes a methodology to tackle the problem of designing Automated Material Handling Systems (AMHS) for 300mm wafer fabrication facilities. The proposed framework divides the design process into two levels: architectural and elaborative. Prior to the design, fab data are preprocessed using simulation of manufacturing operations. The output data and fab requirements data are then profiled to aid in design decision making at the architectural level. Once architectural design decisions are made, lower-level design decisions are made and analyzed using a simulation model that incorporates the AMHS. Due to the potential number of alternatives and time constraints on the design process, we are exploring rapid model generation methods. In this paper, we describe our progress to date in creating this methodology.

1 INTRODUCTION

In the 200mm wafer era, automated wafer handling has limited use in the semiconductor industry. However, with the shift to 300mm wafers, automation is judged inevitable and necessary, to maximize the productivity of capital, and to address the ergonomic considerations of the weight and volume of 300mm wafer lot carriers. As a result, full factory automation is anticipated for the 300mm fab. The wafer fabrication facility design must include the design of the material handling system (MHS), as well as the operational design of the factory. Principally, the design of the MHS addresses movement and storage related issues by specifying the physical and logical MHS components. Hence evolves the need to design methods/tools to facilitate AHMS design, to provide a smooth product flow in the fab with minimal disruption to the production process.

1.1 Automated Material Handling Systems (AMHS) in Wafer Fabrication Facilities

Automating the wafer transport system in wafer fabs involves several levels of automation in the material handling system (MHS). Weiss (1997) and Plata (1997) list the types of automation anticipated in 300mm fabs:

- Tool Automation.
- Intrabay Automation: automating lot transport within the bay.
- Interbay Automation: automating lot transport among the bays.
- Material Control System (MCS): responsible for coordinating the efforts of the various automation systems to move the material to the appropriate bay or tool according to the process requirements.
- Material Storage: Automated storage and retrieval methods, also known as stockers.

Common technologies for transporting lots include:

- Automated Guided Vehicles (AGVs): movement platforms with automatic guidance capability and on-board robots for loading/unloading.
- Rail Guided Vehicles (RGVs): automated vehicles that move in a straight line along a fixed path on an in-floor rail.
- Personnel Guided Vehicles (PGVs): ground based manually moved transporters.
- Overhead Hoist Transport (OHT) where Overhead Hoist vehicles (OHVs) are suspended from ceiling-mounted rail mechanisms and are capable of delivering to/retrieving from stocker ports and process tools from directly overhead.
- Continuous Flow Transport (CFT) through the use of conveyors.

1.2 Automated Material Handling Systems Selection in Wafer Fabrication Facilities

While extensive automation is expected in 300mm fabs, complete automation of transport, storage and handling procedures would lead to high investment costs. Thus, the AMHS must be designed carefully based on the requirements of the fab itself.

The material handling system design problem in 300mm wafer fabrication facility is the problem of selecting the storage and transportation equipment, as well as the network setup for a given fab. The system is responsible for transporting the wafer lots between the tools and the stockers with minimum obstruction to the process flow. A design specifies the mode and layout of the MHS, as well as the physical and behavioral description of the equipment.

In the design problem, the set of equipment is limited as a result of the standards set by semiconductor industry consortia. Strict measures and space limitations in a fabrication facility cleanroom also lead to limited space for material handling and storage equipment.

This design process can be divided into multiple tasks:

1. Fab layout design.
2. Interbay and intrabay AMHS technology selection.
3. AMHS configuration/network design.
4. Elaborative lower-level physical and behavioral design.

The designer may be involved in a subset of the design stages.

Throughout the literature, the importance of AMHS in 300mm wafer fabs has been repeatedly addressed. Most studies present either assessments of various AMHS methods or different AMHS configurations. Therefore, a scientific and comprehensive methodology does not exist, despite the existence of guidelines and analysis methods (i.e., pieces of a design methodology). Such a design methodology would be useful to both semiconductor manufacturers and material handling equipment suppliers, but it must be quick, executable and reusable.

In this paper, we present our work to date in developing such a methodology. We present a conceptualization of the design process that divides it into two stages: the architectural design stage and the elaborative design stage. Each stage is divided into physical and behavioral design. We define the inputs and the outputs for a physical/behavioral stage and we address the iterative aspect of the design procedure. We also address the importance of having a valid simulation model throughout the design process as a result of the iterative nature of the design process and the cost of the MHS.

The paper is organized as follows. Section 2 provides a review of the research addressing the AMHS equipment selection and design for 300mm wafer fabs. In Section 3 we present the problem statement and describe the domain to which our design methodology applies. Section 4 presents the proposed design methodology. In Section 5, the importance of simulation in the design stages of AMHS is discussed and a methodology for simulation models repetitive generation is presented.

2 LITERATURE ON AMHS DESIGN

Research in the area of AMHS selection and design for wafer fabs has been primarily focused on two areas: comparing alternative lot transportation modes (OHT vs. CFT, segregated versus unified interbay and intrabay transports), and describing a methodology for fabs layout design. We present an overview of this literature here.

2.1 Studies on Alternative Intrabay Transports and Configurations

A number of studies in the literature evaluate different configurations and modes of material handling systems in wafer fabrication facilities. Generally, they compare the segregated interbay/intrabay lot delivery system (also known as through stocker (TS) delivery) to the unified (tool-to-tool) delivery system (Pillai et al. 1999, Mackulak and Savory 2001, Kurosaki et al. 1997, Bahri et al. 2001, and Rust et al. 2002). Additionally, some compare the CFT system to the OHT system (Paprotny et al. 2000, Tausch and Hennessey 2002, Rust et al. 2002, Schulz et al. 2000, and Horn and Podgorski 1998). In both cases, the authors build a simulation model for a fab under specific assumptions, test the model under multiple configurations, examine particular performance measures of the system, and then draw conclusions based on their results. While useful, such studies do not lend themselves to a generic design approach.

2.2 Overhead Hoist Transport versus Continuous Flow Transport

Table 1 provides a summary of the literature reviewed for this comparison.

2.3 Segregated vs. Unified Wafer Transport Systems

Table 2 provides a summary of the literature reviewed for this comparison.

2.4 Remarks

- The conclusions in most of the studies depend on the specifications of the fab being modeled, and thus cannot be generalized. For instance, one configuration may exhibit better performance than another, depending on the production volume or on the diversity in products.

Table 1: Summary of Research Comparing OHT vs. CFT Transport Methods

Authors	**Some of the Simulation Model Characteristics**	**Performance Measure(s)**	**Authors' Conclusions**
Paprotny et al. (2000)	- Low-volume 300 mm wafer fab -One Interbay AMHS connecting 6 bays -Modeling the material movement is separate from the process modeling	- Delivery time distribution	-Average delivery time: OHT outperformed the CFT -Delivery time variability: CFT outperformed the OHT
Tausch and Hennessey (2002)	- The AMHS for OHT was Through Stocker (TS). - One diffusion bay and three photo bays were simulated	-Delivery time -Transport - Throughout volume - Throughput variability -Maximum throughput capability	CFT: - Exhibited faster delivery times. - Exhibited tighter distribution of delivery times. - Handled higher throughput levels than OHT
Rust et al. (2002)	- In the CFT model, stockers are included and used only when the conveyor is overflowed with lots otherwise the conveyor provides the storage.	- Average # of moves/hr - Average and standard deviation of transport times - Average and standard deviation of waiting for transport time, - Average # of moves to and from stocker. - Average WIP - Average cycle time	- CFT exhibited the shortest queue time. - CFT had the longest transportation component of overall cycle time - Generally, the presence of loadports for the tools isolated the performance of the process tool from the performance of the AMHS for a majority of lot movements.

Table 2: Summary of Research Comparing Segregated Through Stocker Transport vs. Unified System Transport Systems

Authors	**Some of the Simulation Model Characteristics**	**Performance Measure(s)**	**Authors' Conclusions**
Pillai et al. (1999)	- Through stocker model: one loop serving one bay. - Unified model: one loop serving two bays	- Stocker quantities - Delivery times	For the unified AMHS: - Fewer stockers and controllers are needed. - Shorter delivery times in most bays. - Increased risk if OHT reliability was low.
Mackulak and Savory (2001)	Two intrabay layout designs: - A distributed storage system (DSS) in which one stocker serves one bay of tools. - A centralized storage system (CSS) in which one stocker serves two bays of tools.	- Average delivery time. - Stocker utilization. - Vehicles moves per hour	- Average delivery time for the DSS was strictly less than that of the CSS.
Rust et al. (2002)	- The number of vehicles in the OHT model is fixed for each bay. - 2 stockers per bay for the TS model. - Fewer stockers for the P-P model to provide storage when needed	- Average # of moves/hr - Average and standard deviation of transport times - Average and standard deviation of waiting for transport time, - Average # of moves to and from stocker. - Average WIP - Average cycle time	The TS model exhibited: - The longest average queue time. - The greatest amount of "lot waiting for transportation" time.

- In some studies, simulation models are based on a subset of the bays in the fab and thus are too simplistic to provide solid recommendations.
- Performance measures that have been evaluated are often related to the material handling system. A comprehensive evaluation is expected to investigate the effect of the MHS performance on the overall fab performance measures such as product cycle time, machine utilizations and throughputs.

2.5 Wafer Fabrication Facility Layout Design

Studies addressing the layout design process for semiconductor fabrication facilities point out the importance of concurrent design of operations and material transport for the newly designed fabrication facility. In the case of the 200mm fabs, the fab layout design was separated from the manufacturing objectives of the facility, thereby creating inflexibilities as well as the inability to operate at optimal levels. Successful operations require integration of the scheduling, tracking control and movement of systems (Colvin et al. 1998). It has been estimated that effective facility layouts can reduce manufacturing operating expenses by at least 10% to 30% (Meyersdof and Taghizadeh, 1998).

Padillo et al. (1997) point out the importance of setting and ranking quantitative layout design criteria to provide the design team with the direction needed to generate layout designs that match the manufacturing objectives of the organization. The authors give a listing of design criteria that could be adopted for a fab layout design such as cycle time, quality, safety, flexibility, and WIP management.

Meyersdof and Taghizadeh (1998) organize the design process into three phases:

- Macro layout design: the analysis focuses on functional areas and interactions between them.
- Micro layout design: applies to the design of functional areas and involves a more detailed analysis in which individual equipment sets are analyzed based on process flow and capacity.
- Detailed operational design: involves detailed storage analysis and determination of operational methods.

Weiss (1997) suggests designing the fab to minimize footprint, equipment cost and cycle time, and to increase overall equipment effectiveness (OEE). His proposed methodology for design is:

1. Determine the requirement for layout flexibility.
2. Determine the required transport work of the bay.
3. Select a delivery technology that is compatible with the requirements.
4. Select the least expensive technology that can perform the work.
5. Model or analyze the system to ensure that delivery times are adequate.

Davis and Goel (1997) recommend initiating the design of the material handling system once the process flow and equipment layout are firmed up. The process of the design would be:

1. Map the movement of products.
2. Create a transport layout based on the physical and operational attributes of the transport suppliers under consideration.
3. Simulate the layout to determine travel times and potential traffic jams, number of vehicles, stockers, etc.
4. Consider several variation of the layout until the most efficient design/cost appraisal is achieved.

Essentially, the proposed design methodologies start from high-level design parameters, then address more detailed questions, as is the customary and logical tactic for design problems. However, what is absent from the literature is a thorough description of the design methodology. Guidelines are presented but no actual methods and tools for rapid design generation and evaluation for 300mm wafer fabs.

3 PROBLEM STATEMENT

Our overall goal is to develop a scientific framework for designing automated material handling systems in 300mm semiconductor fabs. This framework will span high-level design decisions, as well as lower-level configuration and optimization. Each component in the framework will be specified in terms of its design decisions, attributes, relationships with other components, and methods by which it can be designed/configured/optimized. This paper concentrates on the structure of the framework and on methods for rapid generation of models to evaluate alternate designs.

3.1 Objective

Select and configure the AMHS for a specific wafer fabrication facility to satisfy MHS requirements (travel times) and fab requirements (cycle times, throughput rates, meeting order due dates, etc.).

3.2 Available/Provided Information

Machine layout, cleanroom specifications, machine information (number, availability, etc.), and product information (release rate, routes, etc.).

3.3 Decision Variables

MHS technology, flow network design, number of vehicles, number and locations of stockers.

3.4 Constraints

- Deliver wafer lots to machines based on move requests.
- Provide storage to lots when machines are not available.

4 300MM FABRICATION FACILITIES DESIGN FRAMEWORK

The design process is tackled through the following stages, which are iterative in nature. These stages are adapted from work in warehousing systems design (Bodner et al. 2001, McGinnis 2003).

4.1 Stage 1

Manufacturing model construction. We assume that the fab requirements and the specification of the fab processing equipment are given. The purpose here is to develop a further understanding of the fab processing characteristics. In this step, a simulation model of the fab is constructed without modeling the material handling system. The general steps are:

1. Relevant data collection.
2. Processing model construction.
3. Report generation and output data collection.

4.2 Stage 2

Profile analysis. Profiling refers to data analysis to provide insight for purposes of design decision-making. This insight may, for example, take the form of useful patterns in the requirements data or manufacturing simulation model output, to aid in design of the material handling system. Example analyses of fab requirements include identification of frequent "hot lot" product types, or characterization of peak order receipts juxtaposed with due dates. Relevant simulation outputs to be analyzed include traffic-congested bays, fab bottlenecks, processing cycle times (excluding material handling), and queue times and lengths. The goal is to map the analysis results into some high-level design parameters for the MHS, such as level of interbay/intrabay segregation and transport technology. Also more detailed design parameters can be derived from the simulation model output using analytic computations, including the stocker requirements, move requirements and vehicle count. It is critical to develop a suite of generic analytic expressions and data queries to support the profiling process.

4.3 Stage 3

Architectural AMHS design. The two main high-level design decisions are:

- The transport technology (OHT/CFT).
- Segregated vs. unified interbay and intrabay systems.

Architectural design focuses primarily on the physical system rather than on behavior, since high-level system behaviors are largely specified by fab standards. For example, most fabs utilize local decision-making rules (i.e., dispatching and lot release policies), rather than global, near-optimal scheduling, due to the highly stochastic nature of fab operations.

4.4 Stage 4

Elaborative physical AMHS design. This involves low-level configuration and optimization of the physical AMHS components:

- Network flow (track) design.
- Vehicle requirements: number and speed and parking locations.
- Stocker requirements: number, location and retrieval speed.

4.5 Stage 5

Elaborative behavioral AMHS design. This involves low-level configuration and optimization of the AMHS behavior:

- Vehicle dispatching rules.
- Idle vehicle behavioral rules.
- Traffic congestion avoidance policies.

4.6 Stage 6

AMHS model construction. Stages 1-5 typically generate a set of alternatives, or a at least a set of initial design decisions that grouped together form alternatives. Due to the dynamic and uncertain nature of fabs, it is critical to use simulation to support the design process. In this stage, simulation models are developed for each alternative. These models must be configurable, so that they can be easily adapted to test different alternatives from the elaborative design stage, since there is strong interplay between this stage and analysis of the simulation models.

4.7 Stage 7

Model evaluation and finalized design. The AMHS simulation models cannot be evaluated on their own, so they must be appended to the manufacturing model to evaluate performance, and to ensure synchronization between the processing the MH systems. Fine-tuning of the design is expected after this stage.

Figure 1 illustrates the proposed design framework and provides further details about each stage.

5 SIMULATION-BASED DESIGN

Since traditional development procedures for simulation models are time-intensive, it is important to develop techniques to automate generation of simulation models. We focus the remainder of the paper on this issue.

5.1 Simulation in AMHS Design

One of the problems faced by the material handling systems designers is the iterative nature of the design process. A design is initially created consistent with the inputs and requirements provided by the customer. The design undergoes several validations, evaluations and adjustments before it is approved and finalized. Given the complex operations in a fab, simulation is the only tool that is usually capable of modeling the details of such environment.

However, building a simulation model that encapsulates the details of the fab is not trivial. Multiple products flow in the fab competing over the same resources, and

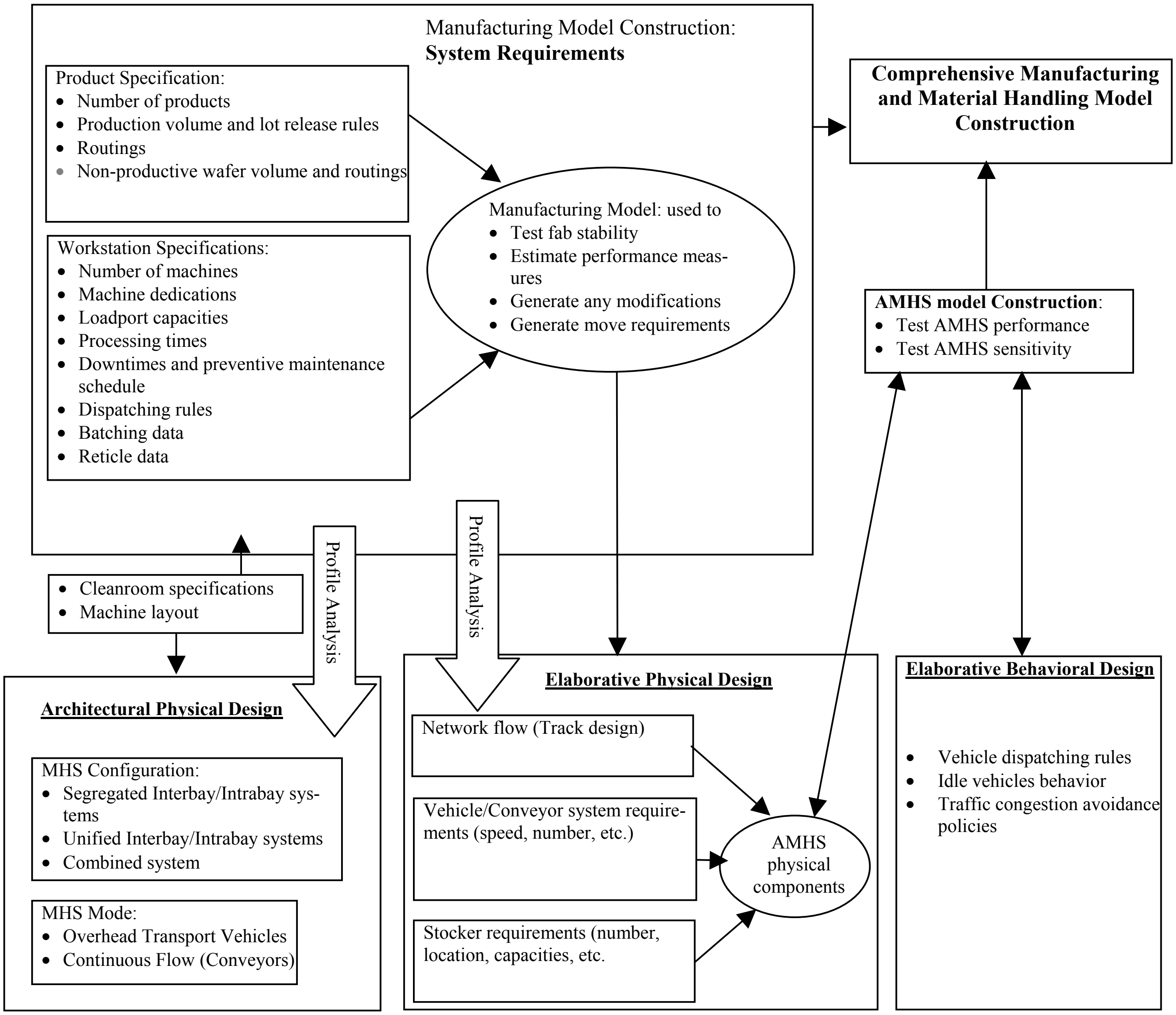

Figure 1: Design Framework

each product requires hundreds of production steps before completion. Products re-enter the same production equipment several times. This leads to the adoption of complicated dispatching rules. Combining this with the material handling process modeling renders the 300mm wafer fabrication facility simulation even more complicated. Such complex models require significant development time.

Several research efforts discuss the problem of using simulation in designing a material handling system for a fabrication facility. Mackulak et al. (1998) suggest developing a generic model that can be reconfigured according to the specific problem at hand, thereby reducing the model building time. Gaxiola and Mackulak (1999) recommend the use of simple deterministic calculations in situations where the process requirements have not yet stabilized.

Steele (2002) proposes an algorithm for quickly estimating the performance of an automated material handling system during the design process. Each AMHS design is modeled as a network of nodes, where nodes may provide transfer capability from/to wafer lot buffers, enable vehicles to move to another branch of track, or enable vehicles to recharge batteries while waiting for a new move task. The author applies the algorithm to a small-scale interbay material handling problem and compare results of the algorithm to results of a discrete event simulation. The conclusions are that while this algorithm is not sufficiently accurate to predict AMHS performance for customers, it did capture sufficient details of the system to reduce the number of simulation experiments for the AMHS design.

5.2 Rapid Simulation Model Generation

Our design methodology includes two simulation models – one of the manufacturing operations, and the other that augments these operations with the material handling system. Here we describe a procedure for generating simulation models, taking advantage of the standard description of a 300mm fab, similar to the standardized manufacturing system representation described in Bodner et al (2003).

1. Domain analysis for 300mm wafer fab operations: The goal here is to organize the knowledge about the system by classifying important system elements, their structure, behavior and inter-relationships.
2. Reference model construction: A reference model for 300mm semiconductor fabs is specified. A reference model is a standard representation of the system, which in this case is aided by standardization efforts in the semiconductor manufacturing industry. Our model classifies the system into two parts: fab vs. control, and processing vs. transportation. Table 3 illustrates the elements of each classification. Elements, attributes and relationships among elements of the reference model are organized in a database. Figure 2 illustrates, for instance, the relationship between machines (physical), routes (logical) and products(physical). Other physical objects include reticles, transporters, and stockers. Logical objects such as downtime and preventive maintenance schedules, and order releases are also included. These elements are stored in a design database, from which they can be extracted by the simulation model generation process.

Table 3: Reference Model

	Fab		Control
Process	Machines, wafers, pods, reticles, machine buffers, processing operations	Updates → ← Requests	Controllers, process routes, machine scheduling rules, products release rules, sampling plans
	Wafer transfer		Information transfer
Transport	Vehicles, conveyors, stockers, movement operations, tracks layout	Updates → ← Requests	Controllers, process routes, vehicle dispatching rules

3. Simulation model generation: Through a user-interface, the fab information is obtained to construct the processing simulation model. An example of entering the photolithography stations data is shown in Table 4. Similarly, the designer enters information about the AMHS through a user interface for the material handling model. A simulation code generator then creates the simulation models, based on user inputs and information in the design database. This simulation code generator is similar in concept to that in Goetschalckx and McGinnis (1989).
4. Validation: Clearly, validity of the resulting simulation models is an important issue. Through careful construction of the reference model, and

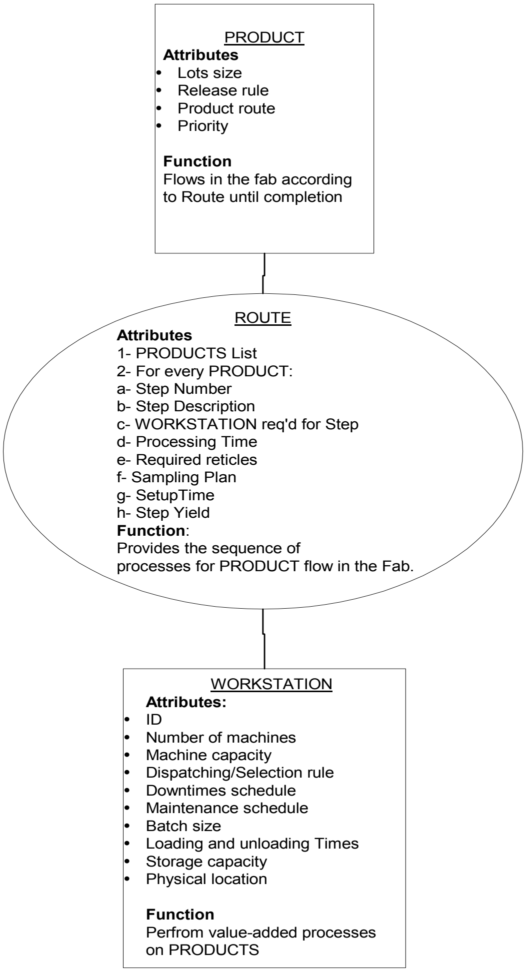

Figure 2: Product-Route-Machine Relationship

Table 4: Generation of Part of the Station File

Input information	**Output**
<u>Photolithography Machines:</u>	Station File
Number of machines:	
Lot selection rules:	
Number of loadports:	
Number of storage buffers:	
Mean time to fail:	
Mean time to repair:	
Batch size:	

through the use of standard data on various equipment, many problems with validity should be avoided. Nevertheless, as part of the design process, the designer must be able to justify the validity of any models used.

6 STATUS AND FUTURE WORK

The proposed design framework is under development at the Keck Virtual Factory Lab at Georgia Tech. An initial reference model has been developed. Current work addresses the following:

- Specifying a generic set of queries and analytic models for profiling.
- Elaborating the reference model to cover all material handling technologies.
- Constructing a design database with relevant equipment data, based on the reference model.
- Continuing work to create the simulation model generation capability, with a focus on the processing model.
- Working with industry partners to ensure validity of the design framework and simulation approach.

The simulation models are being developed with AutoSched AP for the processing model and AutoMod for the material handling model.

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