

# THE CYCLE TIME OF FRONT END IC MANUFACTURING AND AMHS VARIABILITY

*George W Horn, William Podgorski PHD*  
Middlesex Industries SA, Switzerland  
Email: [gwhorn@midsx.ch](mailto:gwhorn@midsx.ch)

## ABSTRACT

Semiconductor manufacturing is a race for cycle time. Variability in the manufacturing process causes factory cycle times 2-3 times longer than the true front end processing time for an IC. Reducing variability is the key to efficient Fab operations. This two part study examines variability contributions of the inter process logistics. Manufacturing variability at the individual tool levels is amplified by the variability in the linking of process steps with AMHS. A stochastic simulation model of abstract substrate flow is constructed for: a) based on the current paradigm of inter process logistics, and b) based on that of a new hybrid AMHS concept. Fab OC curves are developed, highlighting differences in operating curves, which show the manipulating power of the AMHS on manufacturing process variability, and gains in cycle time via Hybrid AMHS.

## BACKGROUND

### The axiomatic over view

Substrate lots are hopping around the factory, according to a recipe, to receive value add in around 1,400 steps. As soon as a lot is released from one tool-step it needs instantly be transferred to the next step. Cycle times in excess of true process times arise, because this cannot be accomplished synchronized amongst all the tools. To counter this asynchronous order, buffers (and stockers) are set up, primarily enroute and at the destination point of each step. In this universe than, the best strategy becomes to remove the substrate lot from the source tool and to move it to the destination tool as fast as possible, making the work available in the destination process queue. Given this task an AMHS system is a failure when destination buffers have no work content. Yet, the lean destination buffer content is exactly the one which gives the factory its best cycle time. Conversely, if destination buffers are filled, in excess, cycle times become long and the AMHS has no effect on factory cycle time. So, how to design an AMHS which delivers WIP Just in time? Thus, there is no doubt about the significance of logistics for factory cycle times. In that perspective, most of today's AMHS are irrelevant, since factory cycle times are 2.5 to 3 times longer than true process, indicating a lot of idling work in stockers. The reason for this is the inability of the current AMHS design to accommodate variance at the tool to tool move level, so it needs to create accumulation of Work in stockers.

Therefore, the current manufacturing paradigm is, characterized by process time/cycle time ratios of around 1/3. In most other industries, inter process product moves are rationalized via transport links, using continuous flow technology (conveyor like). In IC manufacturing our imagination short changed us and conceived the task as merely automating the manual product movements, with robot vehicles, lot by lot, in a discrete fashion. The question is, would it matter if we considered a new material flow logistic? This study is the first phase of that question, making comparisons between the AMHS technologies of today and that of a new hybrid one.

## NONLINEAR AMHS VARIABILITY

The budget of time exceeding pure process times, the AMHS time, is composed of 1) waiting in queue for carrier pick up at end of process steps, 2) transport time to the next tool, 3) waiting in buffer for processing at the next tool, 4) Additionally, there are some off-line storage times in stockers which increase average cycle time. All of the above times are variable, and are contributors to overall manufacturing variability. Arrival times embody variability occurring at or upstream of the preceding tool process, the variability of the pickup-wait, and variability of the pure delivery to the next tool itself. Each being independent of the other, contributing to the overall probabilities via multiplication between each process step. This non linearity may be a key influence the AMHS has on overall manufacturing variability. Destabilizing manufacturing flow, amplifying upsets and so creating the need for more stabilizing buffer and storage time.

## THE VIEW BY QUEUEING THEORY

### The global substrate queue

A thousand or more independent solid state physical processes, are executed by a number of independent tools which are conveniently arranged on the factory floor. Product substrates then step through these tools in a recursive flow sequence, each step demanding a buffer stage of the substrate in front of it. The state of the system is than viewed as an enormous matrix of queues, managed via the logistics infrastructure linking the queues (Fig 1). The matrix of queues is statistically varying, acting as shock absorber for upsets in the semiconductor processes, and thus stabilizing the manufacturing flow. During 2/3 of the manufacturing cycle time, the AMHS is the owner of the product, interconnecting and organizing the buffers.

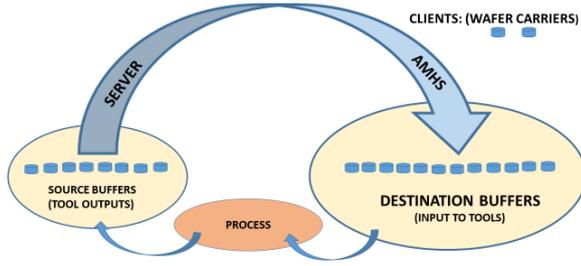


Figure 1: The Global Fab model of queuing. A single server AMHS

The efficiency of this infrastructure partially determines the content of the queue matrix. The AMHS assignment is to deliver substrates just in time, and to reduce the instability caused by the upsets at the physical tool processes level.

### Probabilities

If we consider all the tools in the fab, evolving carriers as a global stochastic system, than the combined rate of evolution may be characterized statistically, and by a mean rate,  $\lambda$ , where the overall process of evolution can be approximated as being a Poisson process. Thus, we are filling the global pick-up-queue (after process) of the fab at the mean rate of  $\lambda$ . There will be two kinds of material transport systems considered. One is a discrete vehicle type, as used in most current 300 mm wafer fabs. The other is a hybrid transport using network conveyors and local tool interface devices to tools (EDi). The pickup events by the server AMHS, for case a), the vehicle type AMHS, will occur randomly, creating varying wait times in the global buffer distributed throughout the Fab. Overall, the process is an M/M/1 Markov sequence with mean service time of  $\mu$ . For pick up events in case b) the conveyor/hybrid AMHS, pick up times have negligible variance, available intime D. Therefore, the process approximation will be M/D/1. The above descriptions are then repeated for the arrival process. Differentiating case a) from case b). The delivery segment of moving a carrier towards destination, once picked up, will be a large set of time (distance-speed) values, different for each carrier move. Considering the AMHS standalone, the steady state (stationary distribution) analytical solution for the above two cases are basically identical, differentiating them in the variability parameter:

Kingman's formula for average waiting times in the queue:

$$E(W_q) = (\rho/1-\rho) [(V^2+v^2)/2] t \quad (1)$$

Where  $[(V^2+v^2)/2]$  is the overall variability coefficient ( $V$  for arrivals,  $v$  for service time by the AMHS);  $\rho = \lambda/\mu$  utilization of the server);  $t = 1/\mu$

And the Pollaczek-Khinchine formula for expected wait times in queue and service variance:

$$E(W) = [\rho + \lambda\mu \text{Var}(s)]/2(\mu - \lambda) \quad (2)$$

Where  $\text{Var}(s)$  is the variance of AMHS service time.

While the approximate analytical solution of these queue systems is instructional, the solutions' drawback is the assumption of stationary distributions. In fact, some have likened the process to a chaotic mathematical model, riddled with the uncertainty in outcome depending on if, and when, a single carrier arrives to a tool. And with those uncertainties the system evolving in a nonlinear fashion. A further issue with the Kingman and the Pollaczek-Khinchine formulae is the unknown variability coefficient. In this AMHS study it is not a goal to solve such formulae for specific fabs, for specific AMHS performance, under steady conditions. Instead, we turn our focus to find the role of AMHS in contributing to overall manufacturing variability, by assuming fixed tool processes in a fab, and imposing on this the stochastic AMHS process. This way, we can plot fab OC curves and find differences in coefficients of manufacturing variability due solely to different AMHS-s.

### THE FAB OC BY SIMULATION

In 1997, the IBM Consulting Group introduced the concept of an Operating Characteristic Curve for semiconductor manufacturing, which relates Fab cycle time to Fab throughput. Today, the generalized Operating Characteristics curves (OC) of a factory are approximated with the following formula:

$$FF = \alpha \frac{U}{1-U} + 1 \quad (3)$$

Where FF is the normalized cycle time, plotted on the vertical axis: Cycle time/raw process time;  $U$  is the normalized fab throughput: throughput/capacity;  $\alpha$  is the coefficient of overall variability, containing the factors  $V$  for arrivals, and  $v$  for the manufacturing process,  $\alpha = (V^2+v^2)/2$ .

Contributor to the variability of arrivals,  $V$ , is the Poisson arrivals. On the other hand, process variability,  $v$  (value add + WIP moves + WIP storage/buffering variability) is determined by what happens between two tool-value add steps, when making the tool value add component invariable. The tool-value add to tool-value add move variability (fig 1), is the subject of this study. Extensive data exists on specific fab simulations with various AMHS. The current study is made so as to achieve data, unbiased for specific fabs. Therefore the global fab model is based on random substrate flow recipes between process tools.

#### a) The discrete vehicle simulation model.

Inter bay capable OHT-s, (or alternately, intra bay OHT-s) pick up carriers from tools, which have randomly spawned substrate carriers at the overall mean fab rate of

λ. The carriers are then delivered to an off line storage shelf in the target bay, or inserted directly into a tool if there is a tool port opening. As the process tool FIFO input buffers in the bay open up some free space, the carriers are moved from the bay stocker into these FIFO buffers. Tool buffers are set to have a capacity of three substrate carriers. Two ports are reserved for tool input, and one for output. At the tool, the logistics process ends in constant in-process residence of the carrier for 20 min. As carriers are spawned at a tool output buffer, the tool input FIFO buffers are consumed accordingly.

#### Determining the number of vehicles employed.

According to the Poisson process, the evolution of client wafer carriers creates a demand rate for carrier delivery which follows a uniform distribution. The number of vehicles to be used is calculated to instantly respond to approximately 96% of the probable demand rate with a mean delivery time of 1.3 min.

#### b) The Hybrid conveyor simulation model.

A substrate is picked up by a robotic tool interface device EDi (or hoist vehicle) which is dedicated to the tool, or to an immediate tool group, and placed directly on the intra bay section of a continuous conveyor network throughout the fab. The carrier will then travel to the target bay where the conveyor move terminates in one of many conveyor I/O ports (output buffers) dedicated to specific tools. There, the tool's dedicated interface robot, will place the carrier into the Tool's FIFO input buffer, space allowing. If no space is open on the tool, the carrier stays on the conveyor's I/O port. Again the fab logistics is terminated at the tool's input buffer.

#### Determining the number of tool interface robots.

Hybrid AMHS I/O ports are interfaced with the tool ports via robotics (EDi), at each tool, or immediate tool groups. The number of such devices is determined to provide move times from tool port to conveyor port, in 14 seconds (96% demand rate distribution).

## RESULTS

The OC curves as output of the simulation model are shown in Fig. 2. The curves show differences, having a lower cycle time for the Hybrid AMHS, in all fab throughput regions (utilization). It is also noted that at operation close to fab design-throughput the discrete vehicle model decays significantly faster toward higher cycle time values, or loss of throughput. Stated in another way, the variability contribution of the AMHS, in a fab, operating near 90% throughput capacity, results in increasing cycle time in the case of pure vehicle AMHS, as compared to a hybrid AMHS.

While examining the curves, it is important to note that major manufacturing process variabilities are omitted

from the model in order to evaluate the variabilities due only to AMHS. Having different operating curves for the same stochastic Fab, with non-variant tool-value add steps, is an indication of the direct manipulative power of the AMHS on over all process variability.

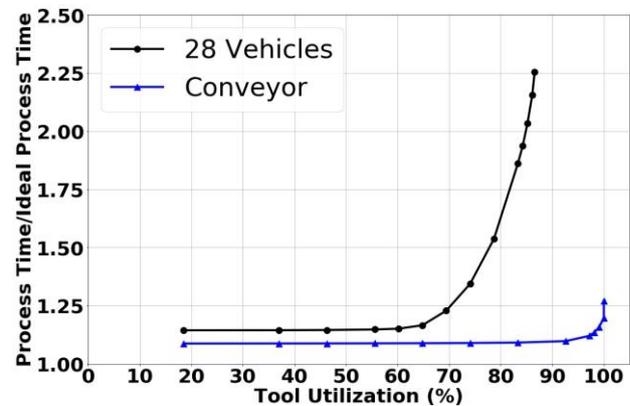


Figure 2: Effect of sole AMHS variability on the Fab process. Lower Hybrid, Upper curve vehicle AMHS

## REFERENCES

- [1] S.S. Aurand, P.J. Miller, *The Operating Curve: A method to Measure and Benchmark Manufacturing Line Productivity*. 1997 ASMC Conference, Cambridge, Ma.
- [2] Roland Schelasin, National Semiconductor, *Using Static Capacity Modeling and Queueing Theory Equations to predict Factory Cycle time*, Proceedings of the 2011 Winter Simulation Conference. [3] R. P. Feynman, *Lectures on Physics*, Addison Wesley, 1989.
- [3] Steve C. H. Lu at all, *Efficient Scheduling Policies to Reduce Mean and Variance of Cycle Time*. Department of Electrical and Computer Engineering, University of Illinois, NSF Grant ECS-90-2007.
- [4] Da-Yin Liao, *Vehicle Clustering Phenomenon in AMHS*, Material Science Forum, Vols. 505-507 (2006).
- [5] International Sematech, *300 mm Factory Layout and AMHS Phase I, II, and III Reports*, Tech Transfer #99113848-Eng.
- [6] Middlesex General Industries Report, *Simulation of the Sematech Generic Fab Model*, 4/5/2004. Reference: Tech Transfer #99113848-Eng.
- [7] Muh Cheng, *Hit Rate Based Dispatching Rule For Semiconductor Manufacturing*, International Journal of Industrial Engineering 15(1) 73-82, 2008.
- [8] Sematech Technology Transfer #05074662A-TR, *Integrated Middlesex Industries Conveyor and OHT AMHS*.
- [9] Hiroshi Nagamochi, *Approximating a Vehicle Scheduling Problem with Time Windows*. Technical Computer Science 393 (2008).