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ESTIMATING REQUIRED MACHINE COUNTS USING THE BASIC G/G/M QUEUE

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ABSTRACT

In semiconductor manufacturing each silicon wafer is processed through hundreds of sequential steps. At each step manufacturing tools use a specific recipe to process the silicon wafer. Each group of tools has to be able to run dozens if not hundreds of unique recipes needed to process the wafers at all steps for several technologies. The challenge is to determine how many tools within each tool group need to be qualified to run each recipe in order to provide enough processing lanes for product to flow through the toolset so as to not adversely affect cycle time. Queuing theory equations have been successfully used to estimate cycle time using historical factory variability data. This study examines the use of these equations to estimate recipe specific tool counts given the expected utilization driven by each recipe spec and a desired cycle time target.

1 PROBLEM STATEMENT

One of the challenges in semiconductor manufacturing is the need to maintain recipe flexibility within a toolset in order to provide a sufficient number of tools for product to run on so as to not increase cycle time. This is an extremely dynamic and elusive metric to track. Behaviors tend to allow the number of tools qualified to run a specific recipe to drift to the lowest tool count. Managing this is easy to verbalize but hard to implement. It took 6 months to derive a meaningful methodology for a Flexibility KPI. The key component of the methodology is the target value for the required machine count m by recipe. Once m is locked in the flexibility metric can be tracked using an automated reporting system that compares the number of tools qualified for a given recipe against the target machine count.

Without a scientific methodology to determine m a lot of emotion typically enters the discussion of what m should be. Manufacturing wants all tools qualified for all recipes so operators do not have to worry about what to run where and to minimize impacts to cycle time. Engineering wants to qualify the minimum number of tools required for each recipe to keep cost low. Quality wants more tools qualified in order to minimize the impact of potential tool excursions. Especially for lower volume recipes, running all tools is not the optimum solution. The problem is to find just the right number of tools to achieve the best quality, cost, and cycle time (see Figure 1).

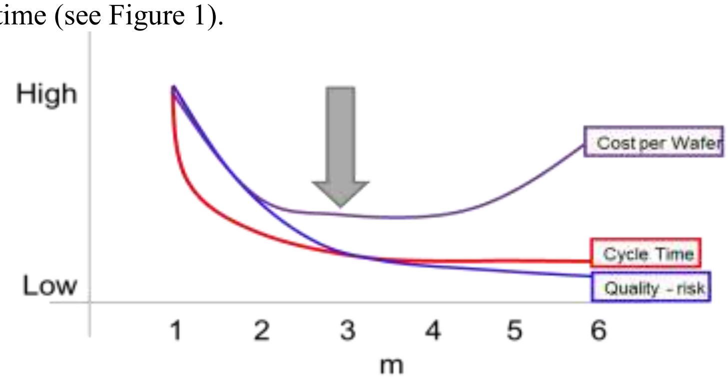

Figure 1: Competing Metrics vs Ideal Machine Count m

2 SOLUTION

The basic G/G/m queue in combination with historical variability data has been effectively used to estimate cycle time. Similarly the same equation can be used to estimate recipe specific machine counts:

$$m = \frac{V}{X_{QT}}\left(\frac{u^{\left(\sqrt{2(m+1)}-1\right)}}{(1-u)}\right)$$

where: V = variability for the recipe spec that m is being estimated for
X_{QT} = queue time x-factor for the equipment set the recipe spec runs on
u = utilization of the number of machines required to run the recipe spec
m = the number of machines required to run the recipe spec given V, XQT, and u

The above can be solved for m, u, and X_{QT} subject to the following constraints. For any given demand mix the product of the recipe specific utilization u and the tool count m estimated using queuing theory has to be the same as the product of utilization and tool count calculated using capacity calculations. The recipe specific utilization u has to be greater than zero and less than or equal to the safe threshold to maintain target cycle time as determined by the factory's performance curve. The variability V used should be the historical recipe specific variability factor from a time period that is representative of expected fab behavior for the given demand mix. The queue time x-factor for the toolset that the recipe spec runs on has to be less than the mean planned queue time x-factor that is required to maintain the desired target cycle time. The resulting tool count m has to be greater than zero.

The programming method used to solve this nonlinear optimization problem is the Generalized Reduced Gradient (GRG2). This method is robust and highly cost effective since it is part of the Basic Excel Solver. The resulting tool count m is rounded up to the nearest integer and quantity one is added to eliminate impacts from single tool prolonged downtime. The final m is subsequently calculated as the greater of 2 (no one-of-a-kind tools/lanes allowed) or the suggested tool count m as calculated (rounded up to the nearest integer, plus 1). However, m cannot be greater than the installed number of tools..

3 APPLICATION EXAMPLES

The methodology was initially tested on two toolsets. The results in Figure 2 show how for recipes with high variability the required tool counts calculated using the queuing theory based methodology (mq) were appropriately larger than tool counts calculated for the same recipes using a purely capacity driven methodology (mc).

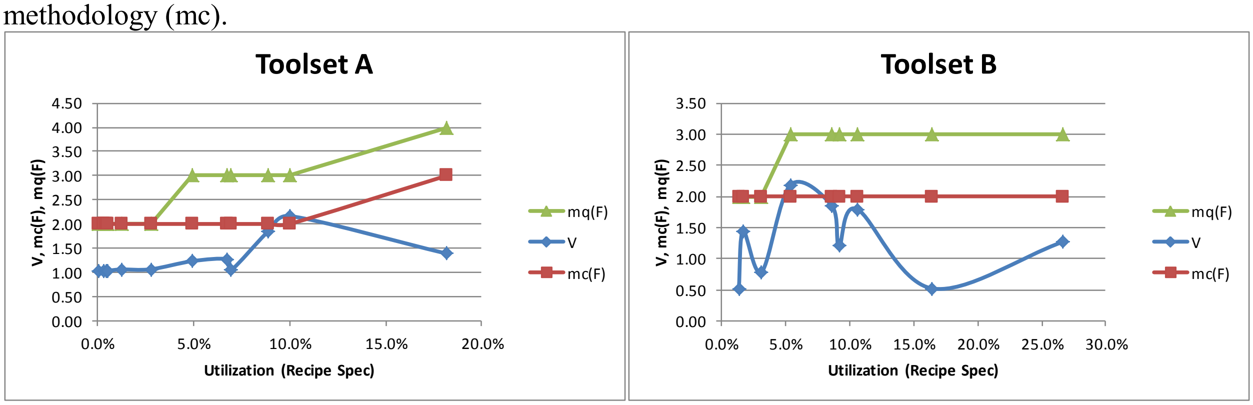

Figure 2: Toolset Application Examples

4 CONCLUSION

Using historical variability the G/G/m queue can be used to estimate the recipe specific machine count required to maintain a target cycle time. While the methodology is still experimental, initial estimates provide appropriately higher machine counts than would be suggested by a purely capacity based calculation especially for recipe specs with low utilization but high variability. Future steps include finding a way to determine how many tools should be qualified for each recipe when many recipes drive small portions of utilization in a large toolset and integrating the methodology into automated reporting.