A planning scheme for Lean Hook-Up in semiconductor fabrication facilities.

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Abstract

This paper examines and presents ways in which tool hook-up at semiconductor fabrication facilities could be improved and streamlined. Significant cost reductions and faster completion times could be gained by companies that deploy such improved approaches in the planning process. To investigate potential avenues for improvement, an experienced team of hook-up managers - with 200mm and 300mm project management experience - identified four key areas of focus for improvement: managing change, managing scarcity, managing variation, and project management and decision making. A failure mode effects analysis FMEA [2] type approach to both change and scarcity was proposed; for managing variation, a return to basics and focus on culture and individual responsibility was proposed as the way to influence behaviours that reduce man-made variation; and for project management and decision-making, the allocation of buffers to eliminate certain behaviours was advised.

Introduction:

Tool hook-up in a semiconductor fabrication facility does not generate revenue and can cost well in excess of $100M. When construction ends, the hook-up and qualification phase begins. Other key drivers include the type of technology, quality of the workforce, policies and methods used. It is also impacted by other key limiters such as space, materials, and resources. The number of tools needed for first Silicon in a 300mm facility is in the order of 150 tools (~100 process tools and 50 metrology/analytical and support tools[1]). This paper explores the underlying issues that constrained hook-up from achieving better, faster, and cheaper results in the past and seeks to develop a series of planning and execution approaches that would help to deliver improvement.

Fig 1

Hook-up happens at phase 3 in the life cycle to production ramp of a semiconductor Fab.

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[1] Support Tools include Parts Clean

Methodology:

We convened a panel of experts drawn from the semiconductor industry with experience in 200mm and 300mm equipment hook-up[2]. We asked them to share their collective experience in order to find the fundamental drivers of the many problems associated with hook-up. A process similar to that used by Theory of Constraints (TOC) practitioners was employed to build a logical picture or reality tree. We began with the negative effects before going on to build the map of causal drivers using the experts' knowledge and experience to validate the relationships.

In the second part of the exercise we examined the set of cause-effect relationships and isolated the common themes associated with the causal drivers. Four recurring themes were identified; most of this paper is devoted to understanding how to predict, eliminate or minimise the problems that can arise when these causal drivers are in play. We try to provide the reader with a structured pre-emptive approach to identifying problems early and reducing the negative effects.

Finding the Fundamental Drivers

Our team conducted an analysis of the major undesirable effects that they have experienced in major-scale hook-up projects. We then began to examine these effects to understand their cause via a process similar to building a current reality tree using the TOC approach. Fig. 2 below shows a small extract from this activity.

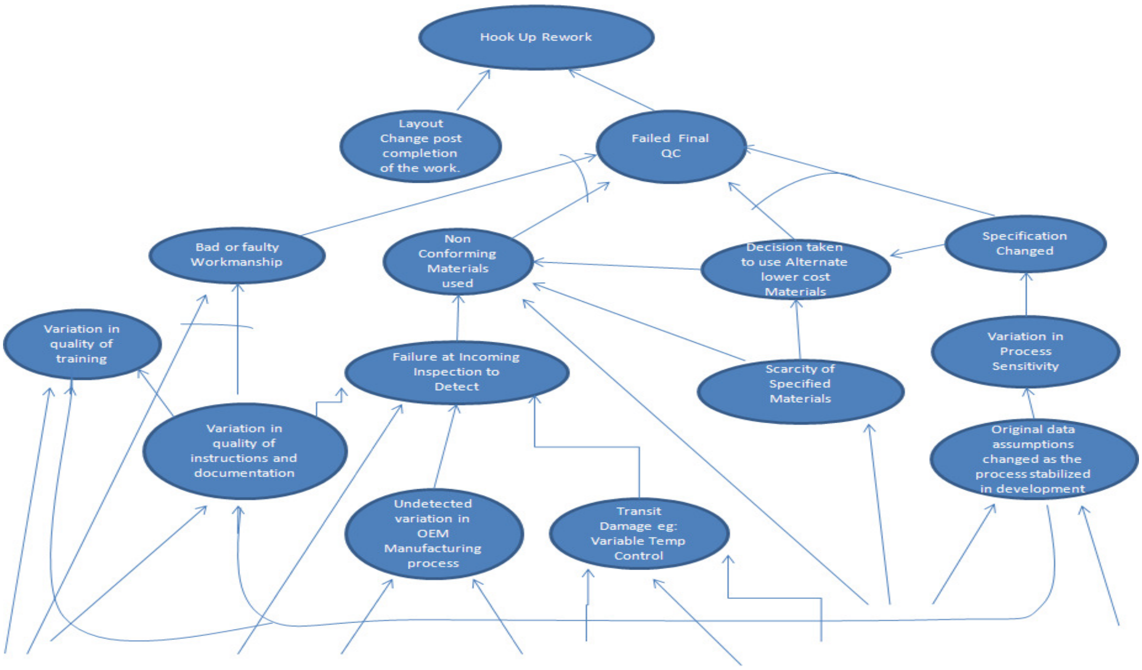

Fig 2

An extract from the current reality tree.

In this particular example, rework is driven by failure to meet Quality Control specification and final test. This can be caused by a number of factors, such as poor workmanship standards, which can be further caused by a lack of understanding of the specification requirement. Other causal drivers include variable quality of materials or delays caused by variation in completion times of key feeder activities.

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[2] Expert panel included members with practical experience in major hook-up projects, 200mm and 300mm.

Our team completed a series of these exercises and found a number of common themes across the spectrum of issues and drivers.

The four key themes identified by the analysis were:

- **Managing Change** at a fundamental level in the project structure that caused domino effects throughout the project. We found that changes to core components happening later in time had the most dramatic negative effects.
- **Managing Scarcity** in equipment, materials, labour (skills and numbers), and information. We found that scarcity issues caused many pinch point type issues that could have been avoided if identified early.
- **Managing Variation** in process technology, conformance of equipment and materials to quality specification and all other forms of variation, such as workmanship quality, delivery times, productivity. We found that man-made variation was a significant causal driver.
- **Project Management Policies and Decision Making** in all areas but particularly in strategic choices, allocation decisions on scarce resources, and risk analysis. We found that many of the problems were driven by behaviours that were driven by policies attempting to protect the schedule from the unknown with time buffering throughout the schedule.

Managing Change

The consequences of change in a semiconductor hook-up project can be significant depending on when and where it happens. For example a new material may be needed in the pipe welding process because the previous material was shown to produce contaminants. A tool may have to be moved and re-installed because an additional tool has to be accommodated in an area. Both these examples can lead to significant re-work and waste in materials, labour and energy. This type of issue is not uncommon; usually the driver or cause of the change is further down the cause effect chain and may relate to incorrect design assumptions around capacity capability of a tool still under development.

This brings us to the core of the problem in leading edge technologies where decisions affecting the future of very expensive facilities such as semiconductor fabrication facilities must be made under uncertain conditions with limited information. Sometimes there is a long delay between the causal decision and its effect see fig 3 below.

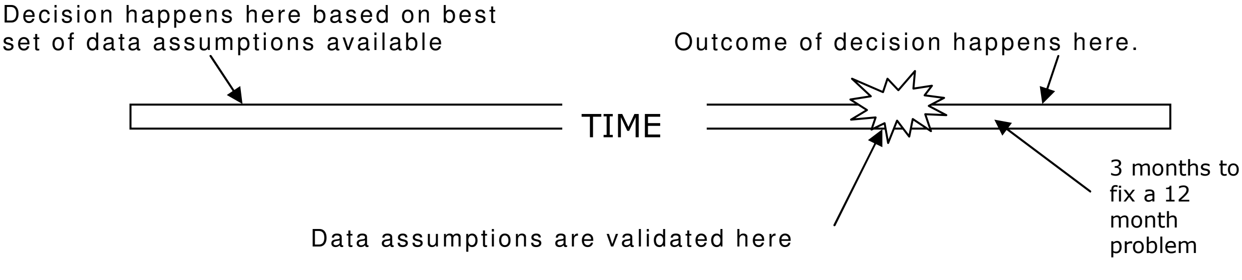

Fig 3

Big decisions made with uncertain or highly variable data and information can result in dramatic change.

In the example above, a decision to order a toolset may have to be taken one year before it is delivered, but the actual performance capability of that tool may not be known until three months before delivery. This is vital information because - among other issues - it affects how many tools need to be ordered. So, how can we anticipate potential negative effects that change will bring?

One possible approach is to rank the items that have the most dramatic impact on the project in terms of severity and uncertainty. This is the sort of risk prioritization approach that would be used in Failure Mode Effects Analysis (FMEA)[2]. Once ranked, it enables decision makers focus on the things that will cause most trouble.

The core of a manufacturing facility is the process equipment that takes the raw or partly processed material and adds form, fit and function. If a fabrication facility is to achieve a particular output level then there is a minimum portfolio of process equipment that must be accommodated. It makes sense therefore that the risk analysis should use this as its starting point.

The problem impact is weighted in terms of its severity, level of occurrence, and number of tools. Finally, it attaches a weighting to reflect the uncertainty associated with the issue at hand. The timing of when the risk will be eliminated can also be factored in to table if desired. The resultant risk prioritization number (RPN) will then rank the risk level of each item listed. See fig 4 below.

Item	Key Area of Activity	Potential Impact	Severity	Number of Tools	Occurrences	Risk Resolution Timing	Uncertainty	RPN	Solutions
1	Precision Scanners	Performance trials show 25% gap to requirements on WPH TPT.	8	6	3	Next DOE due to run in 1 month: Risk Level H	3	432	Not Known
2	A- CVD	Robot arm configuration is unstable.	6	8	2	Technical Workaround possible: However expect performance degradation Risk: M-H	2	192	Workaround Possible – Root cause resolution will happen when resources are available.
3	DNS	Handling issue causing downstream wafer cracking and breakage	5	3	4	DOE currently running expect results in 2 weeks	3	180	Will be resolved post next DOE run.
4	ASML	Controller Issues causing infrequent (1/10000) indexing error.	3	4	1	Debug complete _ revised controller design TBD in 1 month	1	12	1 Month to resolution.
5	TEL TRK	Resist Dispense TPT currently constraining link TPT target level	2	4	1	Understood – redesign in POR	1	8	Will be ready for 1st Si.

Fig 4

A sample data set showing change risk, RPN, and solution approach

Once the significant change drivers are known, the next step is to formulate a coherent strategy to deal with it and to establish the solution path. Semiconductor fabrication facilities are complex and many disciplines must work with each other to be effective. Once the change drivers are known, it becomes a matter of understanding the consequences. The Installation Qualification (IQ) project teams are well positioned to list the potential issues arising and to propose risk reduction strategies such as revising schedules to allow for alternate move-in sequences, adjusting layout plans to accommodate more than one planned approach, and defining latest-possible decision timing[4].

Managing Scarcity

We can define scarcity as any scenario where demand exceeds supply. This can include materials, equipment, labour and any other item or issues that constrain the project. Examples of this include scarce skillsets during critical phases of the project. This can be brought about by peak-load demand or scarcity of skillset supply. High purity pipe-fitting and welding skills was a recurring example. Others to feature prominently included analytical tools for equipment and process qualification, pre-processed test wafers for equipment qualification and speciality gases and chemicals. Movable infrastructure issues such as pedestals and floor adapter plates for rapid tool installations were listed but less frequently.

The challenge of predicting scarcity is one of how to calculate the future demand supply profile for key resources. Our team had a simple approach to this problem. Step one is to perform a similar ranking exercise to that mentioned above under change. Next, identify key resources with risk potential. Step three is to identify the demand arising for each of the key resources needed and then overlay a time-phased supply profile to identify the points of scarcity. Finding these pinch points is a form of first order capacity analysis that identifies critical points which are within our control. Of course, global demand requirements should be factored into the supply profile in order to ensure an accurate prediction but, since these are beyond our control, we regard them as second order, external effects. Many of the resources in question will have global demand requirements; it will be important to understand the extent to which other projects around the world will influence supply and the extent to which we can respond to these external changes.

Once the pinch points were identified, we began to fix them. Some could be solved with workarounds on the schedule; some could be solved with a temporary workforce; some required more dramatic action such as additional investment, or new supply chain initiatives. Other programs may be needed to eliminate the demand drivers. Alternate approaches could include adjusting the timing and location of some of the work to avoid conflict with critical pinch points. This would involve modularising sections of work activity so it could be completed in an external location earlier and dropped into the fabrication facility in a plug-and-play mode at the appropriate time. Adapter plates are an example of this thinking: Suppliers pre-deliver a standardised plate that can be installed and certified prior to tool arrival.

This first pass yielded, the location of likely project constraints and a capacity profile by resource, demonstrating capacity headroom and the regions where buffering is most likely to be required. This is essential for planning with minimum risk; it helps remove emotion from how the schedule is built and enables intelligent buffer use through such approaches as critical chain [1], which seeks to allocate dynamic buffering based on real project needs.

Managing Variation

Variation occurs when the outcome of some action or event is different to what was planned or targeted. In a process, it could be the extent to which a film thickness is different to target or the actual electrical channel width versus its centre target. It could be how many particles were added during a test wafer run versus specification after a chamber clean. It could be how long a machine runs between maintenance cycles versus how long it is supposed to run. (ie: mean time to failure , MTTF)

Variation can sometimes be tolerated and have little negative impact. On the other hand, it can cause significant problems, especially if it occurs at a time and in a place where its knock-on effects are dramatic. Our team examined in detail the major causes of variation in hook up.

These causes fall into two categories: Natural variation and man-made variation. Natural variation occurred in processes as a natural outcome of the process operating under normal conditions. For example, centre line target for particulates added during a chamber process qualification will represent the mean or average number of particles that will be added to a run under normal operating conditions. The actual number added will vary above and below this line. The extent of the variation depends on the parts of the process causing particulate contamination to be added and provided nothing changes it is likely that the variation will be normally distributed around the mean. Much can be done to reduce this type of variation by understanding the root causes or component causes and putting controls in place to manage them

The man-made variation is of more concern and arises as a result of human behaviour, including workplace behaviours, decision making at all levels, and quality of workmanship. It relates to any output from a process dependent on human input that is less than optimal and causes downstream dependencies to suffer negative consequences. Such negative consequences can quickly escalate to cause trouble for further downstream steps, resulting in a domino effect. If the ‘ripple’ can be ironed out at an early stage of the process, negative consequences can be avoided.

Our discussions led us toward two approaches to dealing with this problem. The first was to identify the potential for variation at an early stage and eliminate it by focusing on the issues that ensure and maintain a high quality of human input and decision making. The team felt that human behaviours lay at the core of the issues arising in this area and this was corroborated by the analysis undertaken. The key to reducing variation arising from this source was to focus on the things that drive unwanted or incorrect human behaviours. These include things like clear and unambiguous quality standards and training where quality and workmanship standards are concerned. To the greatest extent possible, standards and quality judgements need to be moved from subjective to objective so that the possibility for human error is reduced. Well engineered documentation that is easy to use but is tight around desired human behaviours is an essential part of what will make it work well. It may sound obvious but these basic and critical activities can often be overlooked or poorly delivered in the heat of the schedule battle. Other key activities include planning and communication, as well as escalation paths and response flows for complex processes.

The second approach was to have effective response mechanisms when things go wrong. The golden rule is not to pass on defective work to downstream operations. This causes re-work and further domino effects such as defect generation, contamination issues and schedule issues. In order to catch defective work one must be able to recognise it. Formal inspection and quality assurance/control systems will prevent and catch some, but not all. One still depends on each individual taking personal responsibility to call it when it's bad and stop the line. It is vital that the company's culture, systems and processes support this type of behaviour.

In summary, while we worry about process variation, we tend to have systematic and effective ways to deal with it. Man-made variation is behavioural in nature and and we need to find ways to prevent it by focusing on the basics such as quality planning and training to reduce or eliminate sources of variation within our control. Having done this, we may still encounter some problems and the response must be to stop and fix the problem once it is identified. It must not be passed downstream. We depend on our systems and processes to achieve this but importantly, we also depend on the culture and sense of individual responsibility toward continuous improvement.

Project Management & Decision Making

We have already referred to the quality of policies and decision-making at all levels as being critical in the reduction of variation. This section deals with the quality of key decision-making at a policy and co-ordination level.

One of the fundamental questions relates to project management policy. Once expectations surrounding the leadership approach have been set, human behaviours - including decision-making – align themselves to these policies. We found the majority of experiences in hook-up projects were implemented using a traditional approach. This involved building an activity network plan using estimated data from project leaders, finding the critical path, and doing appropriate resource levelling with earliest and latest start times issued to each project team. The experiences of this approach were consistent with those articulated by Goldratt E [1] in the critical chain approach. Duration estimates tended to be inflated to protect against variation in feeder activities and against unforeseen issues at the time when the work would be carried out. While instances were identified where earliest finish times were achieved, it was the exception rather than the rule. Work tended to expand to occupy the space allowed and work that could have been passed on at the earliest finish date did not get handed over until the latest finish. Some activities extended beyond the latest finish dates due to further unforeseen issues, including those in previous upstream steps. The net effect was that delays were passed downstream, but little or no advantage came work that could have been completed earlier than planned.

A leaner approach would appear to be one where the buffer or protection is allocated to where it is needed, when it is needed. This replaces negative expectations with a more proactive approach whereby likely problems are dealt with as part of normal processes. The result is that buffers are not spread out evenly at the beginning of a project which can be wasteful because work tends to expand to fill the allowed time. An expectation is set that there is zero buffer available and all activities are run to their earliest finish dates. When problems arise, we allocate the right amount of buffer (with current knowledge) required to recover and, we then re-plan the remainder of the schedule based on this expected outcome. In tandem with this policy is a focus on the critical chain of resources [1] that can cause the reshaping of the traditional critical path. Resource scarcity can cause non-critical path activities to assume critical path status and constrain the overall schedule; it is best to anticipate and eliminate this type of impact before it happens. It is impossible to pre-empt all eventualities however, and an appropriate response is required when the unexpected occurs. The most obvious question for a constraint resource is what is the next priority once it has finished it's current job. A constraint resource should be busy all the time - excluding essential changeover time. Decisions related to job prioritisation should be easily made. Constraint resources should have a pre-defined queue of tasks awaiting them at all times. More importantly, the people responsible for running constraint resources should be aware of, or be able to decide upon, the queue composition without bouncing it up the organisation hierarchy. This is best achieved by using the 'what next ratio' on their task list. The 'what next' ratio is the ratio of the duration of each task on their list over the remaining time available to complete that task to its due date. For example, consider the following table.

Task	**A** Estimated Work Content in Hrs	**B** Number of hours remaining before it is due	**Ratio**
C	13	150	**0.086**
D	30	60	**0.500**
E	**15**	**20**	**0.750**

Fig 5
Constraint Resource 'what next ratio' table example

In order to release the tasks in the right order to preserve the integrity of the network plan and give the overall schedule the best chance of achieving benefit from an improved delivery performance it makes sense to prioritise the tasks as follows: E, D, C.

The next area to explore relates to when decisions are made. The timing of decisions is important: They need to be made when sufficient information is available to ensure the quality of the decision. However, they must also be made within the timeframe required by other parts of the project to meet their due dates. Sometimes a conflict arises between these two requirements and a decision must be made under uncertain conditions

We concluded however that in many projects, decisions were made under uncertainty much sooner than was necessary. The related causes varied but appeared to relate to the individual preferences and local priorities of team leaders and project leaders. The consequences of making a decision under uncertain conditions were either not understood or ignored. It would appear sensible if part of the planning process, especially where change, scarcity and variation exist, was to identify the latest point at which key decisions must be made. One might not always hold to this approach but it would serve to maximise the amount of available information for decisions under uncertainty and act as an important means of communicating risk and consequences to other project team members.

Summary

Tool hook-up in a semiconductor fabrication facility is an expensive and time-consuming activity. Companies can gain significant reduction in costs and faster time to market by adopting leaner approaches. An experienced team of hook-up managers - with 200mm and 300mm project management experience - reviewed their collective experiences for this paper. They examined common problems at the hook-up stage and identified four key areas of focus for improvement during the planning phase of a project. These were:

- Managing Change
- Managing Scarcity
- Managing Variation
- Project Management and Decision Making

They proposed an FMEA type approach toward change and scarcity that prioritises the critical areas for attention. This prioritisation process helps to eliminate waste and achieves better activity flow rates by fixing problems before they arise through judicious resource allocation. This is a key element of the LEAN [5] approach but needless to say the quality of the outcome of the exercise is dependent on the quality of the expert input, and the process itself.

Notwithstanding the technology issues that arise as a result of process variation, we focused on human-induced variation within the project and suggested an emphasis on the basics such as planning and training to eliminate or reduce the sources of human variation. When Murphy strikes it is vital that the cultural and individual response is to stop and fix the issue at root cause level. Defective work should never be passed downstream [3]

We propose a project management approach that seeks to allocate buffers when and where they are needed in order to eliminate the many forms of waste [5] distributed throughout the project network. This aims to eliminate behaviours that result in local optimisation to the detriment of the project as a whole.

Conclusion

The proposed systematic planning approach outlined here and developed from past experience identifies and eliminates sources of delay and waste. The potential benefit arising is that a facility can be brought up to production more quickly and at a lower cost. The return on investment can then be realised in a much shorter time, and at lower cost delivering significant competitive advantage.

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Acknowledgements:

Thank you to the following people who helped with the development and preparation of this paper.

Neil Ardiff, Ardiff Consulting, Ireland
Steve Cox , MSR FSR, USA
Mark Cooney, CTVR, Ireland
Margaret Cuddigan, former Hook Up Project Manager, Intel Ireland
Michael Cunningham, Adaptive HVM, Ireland
Professor Linda Doyle, CTVR, and Trinity College Dublin, Ireland
Ted O'Driscoll, Adaptive HVM, Ireland
Keith Finglas, Innovation Delivery, Ireland
Denis Hickey,former Install/Qual Engineering Mgr Intel Ireland
David Hudson, Greenock, Ireland
Karl Heinz, Koenig, Germany.
John McGowan, Tualatin, Ireland, and former VP & General Manager Intel Ireland
Professor Donal O'Mahony, Computer Science, Trinity College Dublin, Ireland
Dominic O'Meara, Adaptive HVM, Ireland
Charles Nolan, Adaptive HVM Ireland
Padraig Nolan, MSR FSR Ireland
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