

# **Structuring a Manufacturing Process Technology Development Program for Success**

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The objective of a process technology development program is to develop and deploy a high performance, low cost and manufacturable technology that meets (or exceeds) the market's demands for availability (timing, capacity), cost, performance and quality. The same forces that are driving shrinking product lifecycles also drive shrinking technology development cycles. 50% of products sold today are less than two years old so technology development is central to maintaining competitiveness.

Further compounding the challenge of shrinking technology cycles is the increased technical complexity and the capital intensive nature of today's technology development activities. As with any development program, the rate at which you can achieve time-to-money (TTM) must always be improved upon. You need to get it right the first time since neither time nor resources will be available for rework.

The scope of most technology development programs usually includes multiple development activities. Successfully introducing a complex manufacturing technology such as a wafer fabrication process requires developments in areas that are both directly and indirectly involved with the actual manufacturing process. Areas of direct involvement are equipment, materials, process flow and metrology. In order to effectively utilize this new process, additional developments in areas such as design tools, IP, test and simulations will also be required.

Ultimately, the core challenge that the technology development organization faces is how to integrate a series of interdependent development efforts being pursued by internal development teams, external suppliers & development partners and customers. Successfully managing this broad range of development activities requires the following:

- A technology development & certification methodology that enables concurrent development activities
- An organization structure that integrates all parties (internal & external) and facilitates communication
- A process collateral & documentation system that captures and disseminates critical information to all affected parties
- A risk management process to identify issues and minimize their impact
- A technology transfer and transfer certification strategy that enables timely and effective transition from development into production
- A comprehensive program management strategy to monitor and coordinate activities across the entire development network

## **Technology Development & Certification Methodology**

The development organization can only get so far into experimenting and developing detailed schedules complete with spending plans, Gantt charts and MS Project files without having a documented and structured development methodology. While ultimately necessary, these steps should not be taken until the team has agreed upon a development methodology that provides a clear articulation and framework of phases, decision points, deliverables and interdependencies into which specific project details such as resources, deadlines, priorities, etc. are added in order to arrive at an overall project strategy and schedule.

Having a well defined development methodology enables a much higher level of team awareness and alignment on deliverables, interdependencies, priorities and risks. Use of standardized development methodologies and project models facilitates the management of priorities and resources in the multi-project environment. This is particularly true when there is a high degree of both technical and schedule interdependency between the various development activities. It is these interdependencies that most frequently determine project schedule constraints. Understanding where these constraints are and how they arise is central to successfully managing a complex development program.

The final reason to develop and apply well defined and documented development methodologies is continuous improvement and cycle time reduction. Lessons learned are much more readily applied when using the same model as opposed to attempting to apply learning when you are defining subsequent project plans from scratch.

As mentioned above, technology development activities face a number of management challenges. Chief among them:

- Concurrent development of technically interdependent sub-projects
- Coordination of activities across organizational and company boundaries
- Transferring the technology from development into production

There has been a great deal written about product lifecycles and product lifecycle management (PLM). Technologies have lifecycles just as products do and the development methodology must address these cycles. At a high level, there are three distinct technology phases: Discovery, Development and Deployment. Each stage has its own specific set of activities, risk tolerance, capital/expense demands, technical focus and management focus.

A summary of the focus and key outputs by phase is shown below.

### Technology Development Chronology

	Discovery	Development	Deployment
<b>Focus</b>	Evaluate technology, material options & equipment capability vs. program needs	Baseline process defined. Enhance stability, capability, quality and reliability to meet technology goals	Begin revenue production. Ramp into high volume and/or transfer to high volume site.
<b>Key Outputs</b>	Technology Target Specs Functional Area Specs Mutual Expectation Doc's Draft Process Specs Certification Strategy	Process Specs Quality Operating Systems Baseline Data (Mfg, Q&R, \$) Process Collateral Technology Certification Tech. Transfer Strategy	Transfer Certification Revenue Generation Cost Reduction Continuous Improvement

As the name implies, the objective of the Discovery phase is to evaluate market needs and opportunities. Based on an assessment of the market's needs the next step is to identify and evaluate tentative solution options (e.g. equipment, materials, processes). Risk tolerance is high during this stage whereas capital/expense outlay is relatively low. The technical focus is on evaluation and the management focus is on planning.

The transition from Discovery to Development occurs when a specific solution has been selected from among the range of tentative solutions. During the Development phase the objective is to develop the technology to meet specified yield, cost and performance targets. The technical focus is on integration and characterization. This phase culminates with certification of the technology and preparation for transfer and ramp-up. Frequently, risk revenue production will start just before the end of the Development phase on the basis of acceptable performance and market opportunity. Risk tolerance decreases from high to moderate at the beginning of the Development phase and continues to decrease to as Deployment nears. Capital/expense outlays increase from low to moderate. The management focus is now on execution.

Once certification has been achieved the technology moves into the Deployment phase. During this phase revenue production begins and the organization is now focused on ramping and transferring the new technology into a high volume production environment. The technical focus shifts from technology development into continuous improvement (defect/cost reduction). Risk tolerance is low. Capital/expense outlays now move into high gear to accommodate volume production.

Because technology development programs frequently involve the integration of multiple parallel development activities the methodology must provide for concurrent development efforts within a development network. The development network can be quite broad and frequently includes suppliers, development partners and customers in addition to the organization's internal development efforts.

When multiple interdependent development activities are simultaneously underway it is important to define a series of synchronization points. Each

synchronization point (or sync point) represents an intermediate project milestone that is defined in order to achieve increased integration of the various technology elements. Specific targets for integrated performance are defined for each sync point in terms of key technology performance metrics such as quality, functional performance, yield, cost, and reliability.

Depending on the technology being developed and the experience of the organization developing it each of the three high level phases can be broken out into a series of intermediate steps. Each phase will have specified activities, deliverables and gating criteria. There will be well-defined review processes and collateral such as checklists and decision matrices available in order to facilitate communication and decision making.

In the case of a manufacturing technology the development organization should be performing most of their development work on a development line. Ideally, this will be an integrated line that is operated in a fashion and an environment similar to those of the target production environment. As mentioned above, risk revenue and first production material are frequently produced on the development line. The issue of “Copy Exact”, often raised in conjunction with the subject of technology development lines, will be discussed in the subsequent section on Technology Transfer.

### **Certification Strategy**

The final aspect of the technology development methodology that must be discussed is certification strategy. Technology certification means that the process meets its technology goals, all products falling within the technology’s process envelope can be expected to experience low risk qualifications, and that volume can be ramped.

In order to satisfy these conditions a certification strategy must address the following three areas: Technology Assessment, Quality Operating Systems, and Success Indicators. A related topic, Transfer Certification will be addressed in the Technology Transfer section.

Central to technology assessment and certification is the concept of the process envelope. When a new technology is developed it is done so with the expectation that any and all products to be processed by the technology will exhibit a specific set of attributes. These attributes are expressed in terms of key parameters with allowable ranges for each. The full range of allowable product attributes is called the process envelope. The objective of the technology assessment activities is to evaluate functional performance, yield, manufacturability, quality and reliability across the full range of the process envelope.

Once the process envelope has been defined a set of development vehicles must be identified (or developed). These development vehicles can be either real products or simplified test vehicles.

Care must be taken when selecting development vehicles; they must be sufficiently representative of the real products in order to yield an accurate picture of process performance yet they must also be simple enough to analyze. Cost is another important consideration; the less expensive they are the greater the volume that can be built.

Capturing process manufacturability, yield and quality data as well as stress test data on a regular basis enables a much higher level of statistical confidence in the technology assessment data. Ideally the development line would process these development vehicles on a continuous basis.

As the technology development effort progresses and material is processed through the flow the development organization will need to develop a set of Quality Operating Systems that will be used to monitor process performance for both certification and production. Statistical process control and response flow checklists must be developed for each step in the process flow.

A Manufacturing Process Change Control system must be implemented to manage and coordinate the process changes and improvements being implemented across the full process flow. Finally, a Disposition Control System to manage discrepant and excursionary material must also be implemented.

Depending on the nature of the technology being developed there will be a set of specific success indicators that must be satisfied in order to achieve certification. These criteria typically fall into one of the following categories: Technical Performance; Quality & Reliability; Yield & Manufacturability; and Cost.

Development vehicles are used to generate the bulk of data required for certification. As confidence builds in the new technology's performance and key success criteria are met processing of actual products can begin. Ultimately, the Technology Certification dataset will contain data from both development vehicles and actual product.

### **Organizational Structure**

When defining the organization structure to pursue the development of a complex manufacturing process technology it is important to remember three critical points:

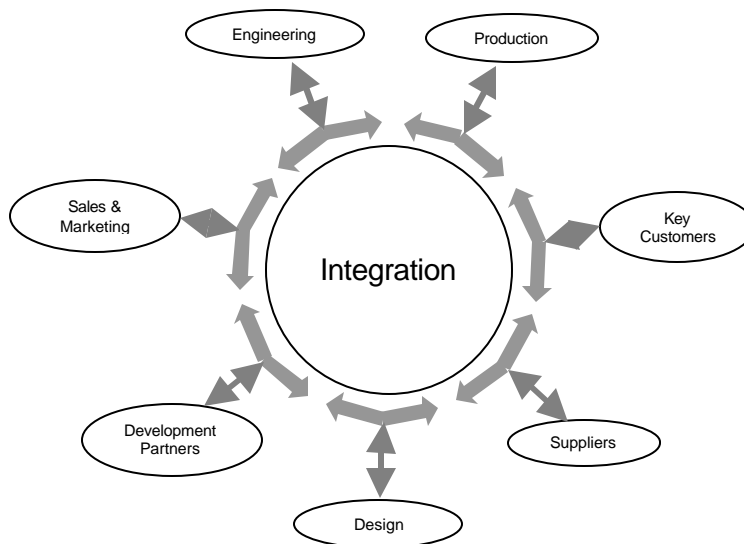
- A high degree of cross-functional and inter-organizational collaboration will be required in order to coordinate the efforts of internal development teams, suppliers, development partners and customers

- A high degree of technical interdependency exists among a series of concurrently executing development activities
- Complex technology development programs evolve through a series of distinct lifecycle phases

For the purposes of this discussion the scope of “organization structure” has been extended to include the meeting and review structures necessary to manage communication within the organization.

Because of the high degree of technical interdependency and the need to coordinate the efforts of multiple groups, it is essential that a cross functional team structure be implemented as soon as is practical. By creating a functionally integrated project team upfront the amount of time lost to rework cycles is minimized. The functions involved will include Engineering, Production, Sales & Marketing, Design, Development Partners, Suppliers, and Key Customers.

The best way to effectively and efficiently manage the myriad communication channels of such a complex cross-functional arrangement is to create a centralized and fully resourced Integration function. The integrated cross-functional team structure is shown in the figure below.

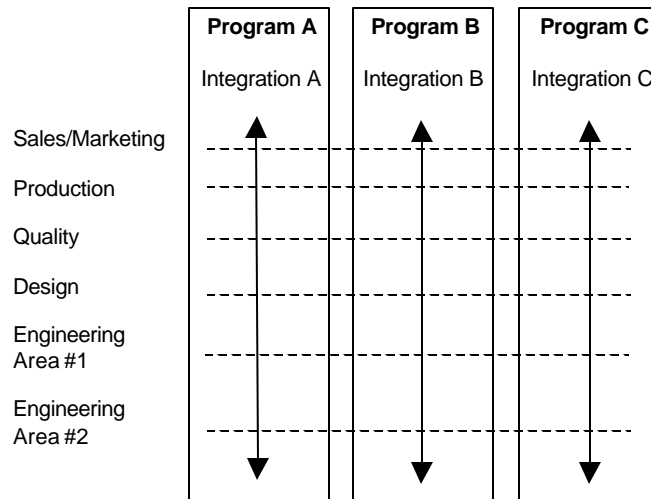


The role of Integrator must not be confused with that of Program Manager. To be effective, the Integration function must have full responsibility from program success. That means having the authority to set technical program direction, establish priorities, define resource allocations, and resolve inter-functional conflicts in addition to the responsibility for providing program management coordination and support. To make this work, the individual chosen to lead the integration function (a.k.a. the “Integrator”) must have in-depth technical knowledge as well as excellent team building and program management skills.

The size of the Integration team, as well as the other various teams, depends on several considerations including the nature of the development program and the size and maturity of the organization.

The larger and more mature the organization, the more likely it is that there will be several programs underway at varying stages of development. In this case each functional group will likely be supporting multiple development programs. This is accomplished by assigning a dedicated individual from each functional area to each development program. Allocating full program responsibility and authority to the Integration function necessitates the matrix organization structure described in the diagram below.

**Matrix Structure for an Organization Supporting Multiple Development Programs**



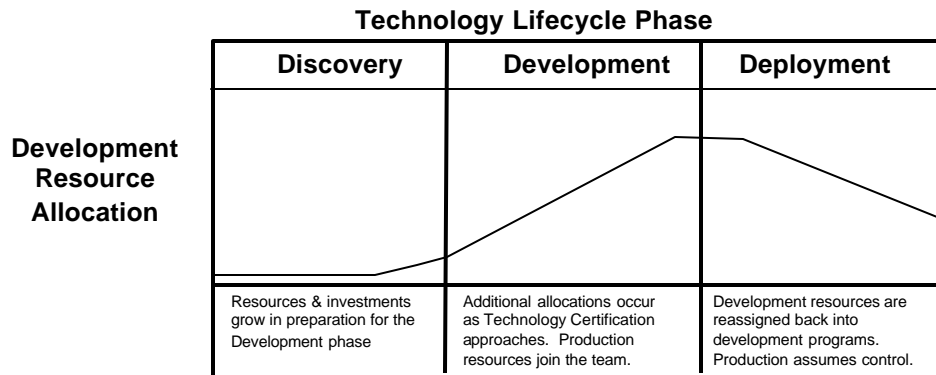
When there are multiple development programs underway additional attention must be paid to managing cross-program issues within each of the functional areas. In particular, organizations pursuing multiple development programs often do so with expectations of synergy and technology reuse between programs (e.g. .13um, .90um & .65um silicon process technology generations). This will place additional demands on Integration to ensure the appropriate level of coordination exists with the other development programs.

Larger organizations will also have a range of support functions such as Q&R, IT and Supplier Management that may be called on to participate. The functional group representatives are then responsible for managing execution, raising issues and driving solutions within their respective areas.

Large organization or small, multiple development programs or just one; a strong, centralized Integration function is absolutely critical to successfully managing complex concurrent development activities.

Resource levels will vary as the program evolves through the technology development lifecycle. During the Discovery phase the focus is on evaluating market needs and identifying technical alternatives. Resource levels are modest and overall organizational complexity is low. The primary functions involved in this phase are Marketing, Engineering plus 1-2 Key Suppliers & Partners. There may also be secondary involvement from Design and Production depending on the technology development objectives.

The Development phase involves active participation from all functional areas. As the Development phase nears completion and the transition to Deployment begins responsibility for the technology will shift from Engineering to Production. There is also a shift in representation from the other functional areas as the revenue shipments begin and the emphasis moves from technology development to continuous improvement. The figure below illustrates how resource demands on the development organization vary as a function of technology lifecycle phase.



In order to establish and maintain clear channels of communication throughout the development organization a three-tiered meeting structure (program, functional area & company levels) should be implemented. The specifics of the development program and the organization driving it will dictate actual duration and frequency.

Regular program-level Coordination Meetings are held on a bi-weekly basis and will run for one to two hours. These are process meetings whose focus is on monitoring performance, information sharing, identifying and tracking issues and maintaining cross-functional coordination. They are chaired by the Integrator and are attended by all of the functional team leads. This is the key forum for reviewing status, managing risk, implementing change and decision making.

Functional Area Meetings should also be held on a regular basis; approximately 30 minutes to an hour each week. These, too, are process meetings focused specifically on execution and status within the functional area. This meeting is run by the functional area lead and is attended by the entire functional area team.

In addition to the weekly Functional Area Meetings there may also be Working Group meetings which operate in a similar manner to the Functional Area Meetings. A Working Group is formally chartered to address a strategic development concern, usually a significant cross-functional interdependency, and operates at the same level as a functional area team. It is comprised of representatives from each of the affected functional areas. Working Groups meet at the same frequency as the functional area meetings. These meetings are a combination of process and mission types. The duration of a Working Group activity can range from just a portion of the development process up to the entire development period.

A Task Force is similar to a Working Group in that it is comprised of representatives from multiple functional areas. The difference is that it is a tactical response to a specific issue that is uncovered during development. Once convened the Task Force meets and operates in basically the same fashion as a Working Group until the issue is resolved. As soon as the issue is resolved the Task Force is dissolved. Duration and frequency are entirely dependent on the specifics of the issue being addressed.

Care must be taken when considering the formation of a Task Force. Because it is a tactical response to an unforeseen issue it places in additional demands on development team resources. Task forces must be the exception. Excessive use of task forces will move the organization into a perpetual firefighting mode where execution and quality suffer as risk increases.

Regular program-level Operations Reviews should be held quarterly. In addition to having the same attendees as the bi-weekly Program Coordination Meetings the Ops Reviews are attended by senior management as well as senior representatives from Customers, Partners and Suppliers. These are in-depth technical and program review meetings and will take from 4-8 hours. A comprehensive Ops Review is held at the end of each lifecycle stage to ensure that all required activities have been completed and that all requirements have been met so that the program can proceed into the next stage.

### **Process Collateral & Documentation**

In support of the technology development and deployment efforts a considerable amount of work will be required to develop the process collateral and documentation necessary to actually execute and implement the technology. These deliverables can be broken down into three main categories: Technology Specifications & Documentation, User Collateral, and Archival Documentation.

During the Discovery phase the development organization works to identify capabilities that can be developed in a timely and cost effective manner that will meet anticipated market needs and/or opportunities. These needs are defined in terms of a set of key technology requirements. Once the key technology

requirements have been defined the feasibility of technical options is established and refined into a single set of key technology attributes; a set of features that are unique to the technology and distinguish it from existing technologies. These key technology attributes form the basis of the Technology Target Specification (TTS). The TTS is the guiding document for the development of the new technology.

Once the technology has been defined by the Technology Target Spec it must be analyzed to determine the specific development activities that must be pursued, which, when integrated together, result in a process that satisfies the TTS. Once each of these development activities is identified a Functional Target Specification (FTS) that specifies the key attributes (with targets) must be defined. Accurately translating top level technology requirements into functional area or sub-team requirements is critical.

Effectively managing high degrees of technical interdependency between concurrent development activities in multiple functional areas requires the definition of additional supporting documentation such as the Mutual Expectations Document (MED). As the name implies, the purpose of the MED is to document technical and procedural expectations between interdependent functional areas (e.g. defining input requirements to upstream process steps and output commitments to downstream process steps). Each functional area development team should document its functional expectations in an MED and then review their MED's with the functional teams with whom they are interdependent. The objective of having MED's is to reduce time lost due to development rework by minimizing the risk of cross-functional mismatch.

Process Specifications describe the manufacturing parameters, equipment set, and procedures required to implement the process. These specs are owned by the functional area teams. Process specs will evolve, sometimes frequently, as development proceeds. Process specs are a key deliverable for both technology certification and technology transfer.

A set of Process Collateral is required by Suppliers, Partners and Customers in order to use properly support and use the new technology.

Design Rules translate the functional attribute targets of the technology into standardized dimensional, material and applications parameters for the products that will be manufactured on the new process. Developing Design Rule specifications will frequently involve balancing supplier and manufacturing capabilities with the overall technology requirements to enable execution to the TTS (e.g. dimensional parameters for incoming materials).

Design Rules represent the dimensional and performance details of the process envelope. A product that satisfies all DR's can be expected to experience a low

risk qualification and new product introduction since technology certification is defined in terms of this process envelope.

Application of the new technology may require the use of new or customized tooling, jigs and fixtures. Depending on the magnitude of the differences between the new and existing technologies tooling development (design, materials, etc.) may be required as part of the overall technology development activity. Metrology development efforts are often required as well.

Designers developing product that will be manufactured on the new technology will need collateral that guides them on how to develop their products to take advantage of the features offered by the technology. In the case of wafer fabrication processes this type of collateral includes IP libraries, functional models, performance simulations and quality & reliability models.

Given the levels of complexity and interdependency involved in today's technology development efforts a disciplined and robust approach change control is absolutely essential.

Maintaining (& improving) process performance in the post-transfer production environment requires the development and transfer of a full compliment of support systems and methods. At the top of this list are the Quality Operating Systems (with the appropriate baseline process data). Failure analysis techniques, if new, must also be developed and made available to production sites and customers.

Finally, care must be taken to compile and maintain a comprehensive record of the development activities, issues, decisions and results at both the program (Integration) level and the Functional Area level. Sometimes referred to as "White Books" or "Blue Books", these records are the complete source of information about the technology. They chronicle the development of the technology, experiments, process stability & capability data, and the history of process changes.

There are two separate and distinct audiences for these archives. If the technology is transferred, either internally or externally, these archives will enable the receiving site to get the technology up and running more quickly and cost effectively. They will also be used as a guideline for troubleshooting and continuous improvement. The second audience for these records is the development organization itself. These records represent an extremely valuable source of lessons learned and knowledge that can be used by next generation development activities and teams.

## Risk Management

Risk is defined as a factor, course or element involving uncertainty or hazard. It can take many forms; technical, schedule, financial, competitive, market. When developing new and complex manufacturing technologies the reality is there is always some degree of risk that cannot be avoided so it must be managed. Managing risk effectively involves four steps: Identification, Assessment, Mitigation/Contingency Planning, and Monitoring.

Working from the development and certification strategies all relevant risks should be identified and then characterized according to degree of risk (high, medium, low). Early identification of issues (or potential issues) enables the development team to define and implement the necessary plans to minimize schedule impact. Archives of previous development programs are an extremely valuable source of information regarding risk and risk management strategies.

Determining the magnitude of risk for any given issue requires assessing both the likelihood of occurrence and the severity of occurrence. An overall risk level is then assigned using the Risk Matrix below.

**Risk Matrix**

		High	Medium	Low
<b>Severity</b>	High	Med	High	High
	Medium	Low	Med	High
	Low	Low	Low	Med
		Low	Medium	High
		<b>Likelihood</b>		

Once risk assessment is complete contingency plans and triggers (conditions under which the contingency plan is activated) must be defined. The objective is to make dealing with risk as proactive and process driven as possible rather than ad hoc and reactive. Defining triggers for the contingency plans is a key to enabling monitoring and proactive decision making. Taking the time up front to think through options for what might happen is a lot easier than having to figure out what to do next after they have happened.

Finally, risk management is an ongoing process. As the program progresses, risks must be monitored to ensure they are either on the way to being resolved or to determine if activation of a contingency plan is required. Risks must also be

re-assessed on a regular basis (at a minimum, in conjunction with quarterly program-level Ops Reviews; more frequently if necessary).

Remember, risk tolerance decreases as the program moves from Discovery, through Development, and into Deployment. Risk tolerance is high during the Discovery phase since multiple options are being explored. However, once the decision has been made to pursue Development of a specific alternative then the degree of risk that is acceptable drops significantly, and keeps on dropping. As the program nears completion risk levels must be low so as not to jeopardize Certification and Deployment.

### **Technology Transfer Strategy**

Requiring a formal Transfer Certification addresses two objectives. First, both sides must agree that the technology, as transferred, meets the TTS goals and that all aspects of the receiving site's expectations have been addressed and satisfied. Second, both organizations must be sure that the receiving site is able to own and operate the process without the need for ongoing support from the development organization.

Even though technology transfer does not occur until after the technology is certified planning for a successful transfer starts during the Discovery Phase! Why? Because the technology must be developed so that it is transferable, i.e. compatible with operating constraints and expectations that will exist in the target production environment. Consequently, the Technology Target Spec and the Functional Target Specs must include well defined production requirements. Typical examples include uptime, cost, staffing, and facility requirements.

The receiving organization will be required to prepare their site for startup of the new technology. The phrase "Copy Exact" is often used to summarize the strategy whereby the receiving site duplicates the operating environment (process, material, metrology, and operating conditions) in order to guarantee compatibility for the new process. The objective of Copy Exact (CE) is to reduce risks during volume ramp and product proliferation.

CE is an extremely powerful tool. As with all powerful tools, the challenge lies in determining how and where it is required. Care must be taken during process development to understand the critical variables required for operation of the process. Equipment settings, materials, process flow, facilitation of equipment, environmental parameters and operational procedures can all influence the performance of the process. The (non-trivial) challenge is to identify only those critical elements that require exact replication.

The development and receiving organizations are jointly responsible for developing the Technology Transfer Plan. The scope of the plan includes equipment procurement, resource planning (hiring, training), site preparation (if

required), process startup and transfer certification. The magnitude and complexity of the transfer plan will be in direct proportion to the magnitude of the differences between the new technology and those already in production at the receiving site. The receiving organization should document its expectations for the transfer in the form of a Transfer Mutual Expectations Document as soon as possible so as to minimize the risk of miscommunication.

Primary process training for all key personnel from the receiving organization will occur at the development site. Content experts from the development organization travel to the receiving site to oversee advanced training and to monitor the transfer certification activities as soon as equipment installation and process startup begins. Regular Transfer Meetings will be held and are similar to the program Coordination Meeting in structure and content. These meetings are chaired by the receiving site program leader and are attended by all key development representatives, suppliers, and partners.

Successful Transfer Certification is based on demonstrating equivalent process performance as measured by each of the Quality Operating Systems. Process performance at the receiving site is must be statistically equivalent to current process performance at the developing site. When these conditions have been met the receiving site can then start shipping revenue and ramping volume.

### **Program Management Strategy**

The Program Management strategy must support and facilitate the following:

- Concise communication and effective decision making
- Efficient resource allocation and utilization
- Clear direction on priorities and deliverables
- Timely identification of issues and responses
- Maintain a clear picture of the current program status

As mentioned previously, a strong, centralized Integration function is essential for establishing and maintaining alignment and collaboration between the various groups working on the development program. The organization and meeting structures discussed above, coupled with a well defined development and certification methodology provide the basis for the program management structure.

The use of a documented development and certification methodology ensures that there will be well defined roles & responsibilities, clearly defined deliverables and a structured framework within which to monitor progress and enable effective decision making. Once again, program management is part of the Integration function's responsibilities.

The regular Program Coordination Meeting, chaired by Integration, is the key forum for setting & maintaining priorities, reviewing status, managing risk,

implementing change and making decisions. Including representatives from the supplier network, development partners and key customers in this process provides increased visibility which leads to increased confidence.

Major program decisions such as the transition from Discovery to Development and the granting of Technology Certification are driven through the Program Coordination Meeting and then brought to the Operations Reviews for formal ratification.

A formal change control process is also required so that the team can systematically communicate, evaluate and manage change.

An efficient and effective PM strategy allows the team to focus on program exceptions like changes and unforeseen risks. At all times the development team needs to understand where the priorities and constraints are and the team must be managed accordingly. By managing to the program-level objectives, priorities and constraints rather than to individual functional area priorities resource allocation can be optimized. The result is improved overall schedule performance and minimization of risk.

### **About the Author**

Philippe Vaney is President of Vaney Partners, L.L.C., a management consulting firm that assists high tech companies and startups in managing their technology development and new product introduction activities. Philippe has 18 years experience in the development and introduction of new technologies and products in the semiconductor & electronics industry in both corporate and pre-IPO startup environments.