

Best Practices: Requirements Flow-down

Whether your corporate goal is to offer a new product, or to improve upon an existing product line, success hinges on the degree to which product development meets market driven requirements. This is a universally known and accepted fact. What has changed, however, is that the product development lifecycle has collapsed while product complexity has increased dramatically. For example, cars deploying advanced hybrid electric, safety, and entertainment technologies are now being designed in a matter of months rather than years. The challenge in this compressed development lifecycle is to work nimbly, maintain costs, and ultimately design products that first meet, and then exceed, customer expectations.

Throughout the iterative planning, concept and design phases of the product lifecycle, requirements must remain comprehensive, clear, well-structured, traceable and verifiable. Requirements Flow-down is a best practice that helps engineers maintain clarity and structure while they perform decomposition of high level system requirements into functional, physical and component design requirements. Requirements Flow-down also establishes traceability between levels of decomposition, helping to control ambiguity or errors that can cause design processes to become less efficient. Well-managed functional and physical decomposition of requirements helps engineering teams identify best components and optimize product design and manufacture.

Mathcad by PTC®, the product development company, PTC Mathcad provides the ideal environment to build mathematical models, perform calculations critical to accurate physical decomposition, and ensure traceability despite design changes. As the industry standard software for engineering calculations,

unique features like standard math notation, unit management, and whiteboard-like worksheets dramatically reduce the “noise” in Requirements Flow-down. Specifically, PTC Mathcad enables:

- Clarification as to how requirements are satisfied by underlying product designs, and which requirements drive which system, product or part designs;
- Understanding of how design changes impact requirements and how requirement changes impact product designs;
- Visibility across all engineering disciplines throughout the product development process;

This software gives engineering teams greater confidence that the solutions they design will optimally meet the market requirements, and achieve strategic company goals such as greater market share, faster time to market, and profitability.

Engineering Challenges in Managing Requirements during Physical Decomposition

Whether engineering is charged with developing a new product or improving existing products, the process starts with analyzing and documenting high level needs, then deriving solution requirements.

There are a variety of factors that introduce “noise” into this process and make it challenging. Some of these factors are:

- Human error and inconsistency in the mathematical analysis and documentation;
- Breaks in traceability between physical requirements as they are mapped back to functional requirements, or forward to the component design phase;
- Miscommunication between teams in different functional areas, for example, between electrical and mechanical engineering teams;
- Inability to keep requirements and test results up-to-date as changes are introduced.

Requirements Flow-down is a best practice that helps engineers derive or decompose functional and physical requirements from system or market level requirements (Figure 1).

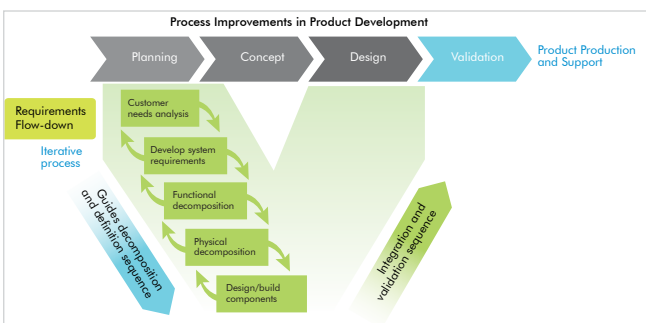


Figure 1: Requirements Flow-down from Initial Requirements through Detailed Design.

Let’s focus on the demands of physical decomposition that involve translating qualitative requirements defined in earlier phases to quantitative ones that are verifiable.

To successfully manage requirements during physical decomposition, engineering teams must be able to:

- Ensure that requirements comprehensively address functional requirements and that they are clearly structured and articulated/documentated;
- Structure decomposition so physical requirements are easily traceable up through higher levels of requirements;
- Ensure the changes in higher level requirements ripple down accurately into physical requirements and stay current – all levels must remain in sync;
- Define and execute the appropriate tests of physical requirements in a timely and accurate fashion;
- Receive test results and pass them back up through levels of requirements to see that they are being met – an iterative process requiring change management synchronized with requirements management.

Mathcad by PTC®, the product development company, PTC Mathcad plays an integral role in physical decomposition:

- Provides the ideal environment to perform decomposition allowing engineers to easily and accurately handle the mathematics used in physical modeling and analysis;
- Enables easy evaluation by teams across geographic locations by using familiar natural math notation with textual annotations;
- Establishes traceability of requirements decomposition, integrating with both the product lifecycle management tools that organize requirements at different levels and with design systems that are driven by requirements.

Let’s take a look at how these capabilities would help a technology company manage the physical decomposition used in semi-conductor wafer production.

Requirements Flow-down Example

Facing ever increasing business growth expectations as well as foreign competition, a manufacturing company wanted to build a new semi-conductor fabrication system capable of generating wafers 20% faster than current methods. If they were capable of meeting this design goal then they would be able to maintain their market share, and sufficiently differentiate their product from lower cost, foreign alternatives. This manufacturer's previous design approach was to start by building a basic wafer throughput estimate. This estimate would be generated by recording the start/stop time for each step on an existing production line. These empirical processing times would be captured on a spreadsheet and totaled depending on the specific layout of the production line. If, for example, a wafer needed to be moved through 5 stations and each station required 10 minutes to process then the overall wafer throughput would be 50 minutes per wafer. Once the rough estimate was prepared the design team would focus on building and refining physical prototypes until the ultimate throughput goal was achieved.

There are several drawbacks to this brute force approach. First, this approach only provides a low fidelity model that does not account for the dynamic interdependencies that could exist in the manufacturing process. Next, this approach relies heavily on physical prototypes which increase the cost and time required to develop the product. Lastly, innovation is stifled because the tendency will be to simply develop a variant product versus a truly original one. Developing state-of-the-art equipment and/or implementing new and unproven processes without analytical back-up increase the risk of a costly failure. Given these drawbacks the research team decided instead to develop a high fidelity mathematical model and leverage this model to further identify, elaborate, and eventually flow down requirements before spending limited resources on prototype development. The research department organized, or decomposed, the model into three elements representing areas of significant

redesign on the new wafer fabrication system. These included the production line layout, the specific wafer handling system, and the deposition process used to impregnate the wafer itself. We will now discuss each of these in turn.

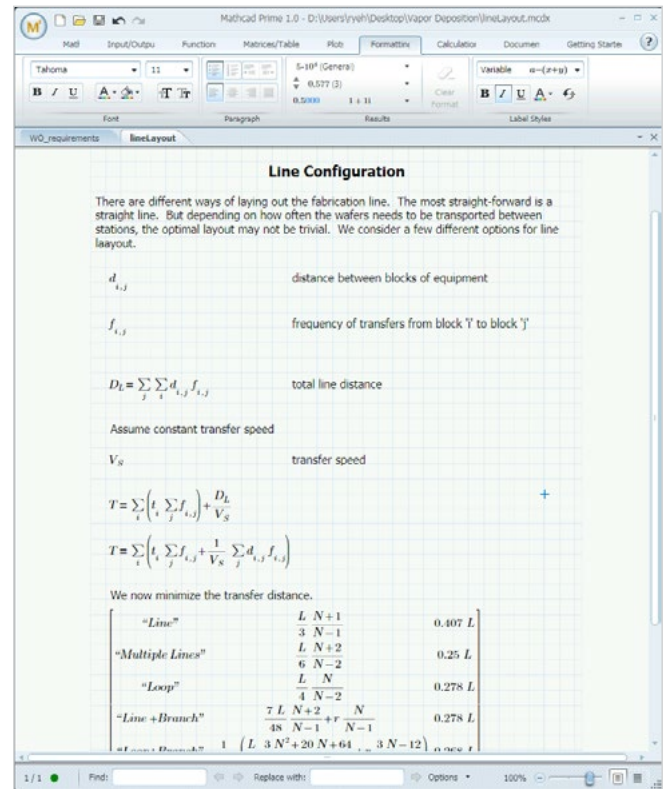


Figure 2: Production Line Layout Model in PTC Mathcad

- a. **Production line layout** – To meet the speed improvement goal various different production line routing options needed to be modeled and analyzed. Each routing option involved various sub-requirements including the distance traveled, the time to travel, the frequency of transfers, and the order of the preparation and production stations. These aspects were modeled as basic distance and velocity equations. In addition tolerances were assigned for movement through each station based on component variation. At the completion of this step a crude time based model was established, allowing engineers to quickly identify potential bottlenecks in their path design process.

b. Wafer Handling System – Once the rough cut production line layout was established, and limitations were explored, the team confidently elaborated additional requirements for the wafer handling system itself. There are several options in moving wafers through the production line. In this case the engineers were examining the efficacy of using a traditional assembly line method whereby the wafer would transfer station to station by a series of robotic arms, and comparing this to a new technique leveraging a magnetic levitation mechanism. Though more expensive, the magnetic levitation system reduced friction and hence component wear, while minimizing any potential dust contamination from contact. At this point the design team involved their controls engineers to further expand the requirements for both handling techniques under review. The controls engineers began by analyzing the time budget, or the time allocated by each station and determining how fast each component would need to respond to meet those requirements. At this stage the team defined the critical motor parameters including response time (T_r), settling time (T_{settle}) and percentage overshoot required for each direct drive motor used on the assembly line, as well as the response time and the position accuracy required of the magnetic levitation based system. Given that magnetic levitation based approach utilized a high speed switching circuit to transport the wafers, an additional transistor modeling domain was required. Fortunately, this multi-domain model can be easily assembled by leveraging the underlining electromagnetic equations. At the conclusion of this step they had a detailed model of the production line pathway as well as the specific requirements for each of two handling systems.

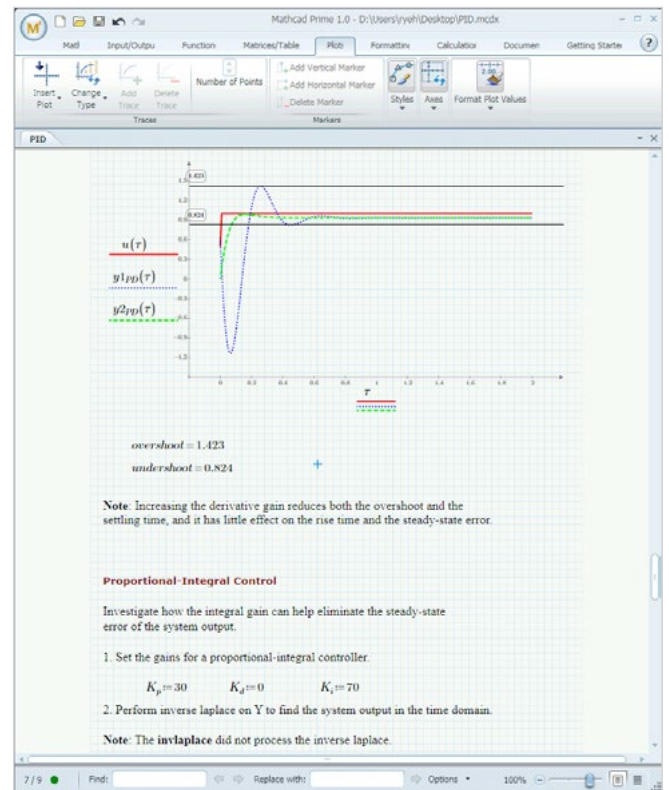


Figure 3: Wafer handling control requirements

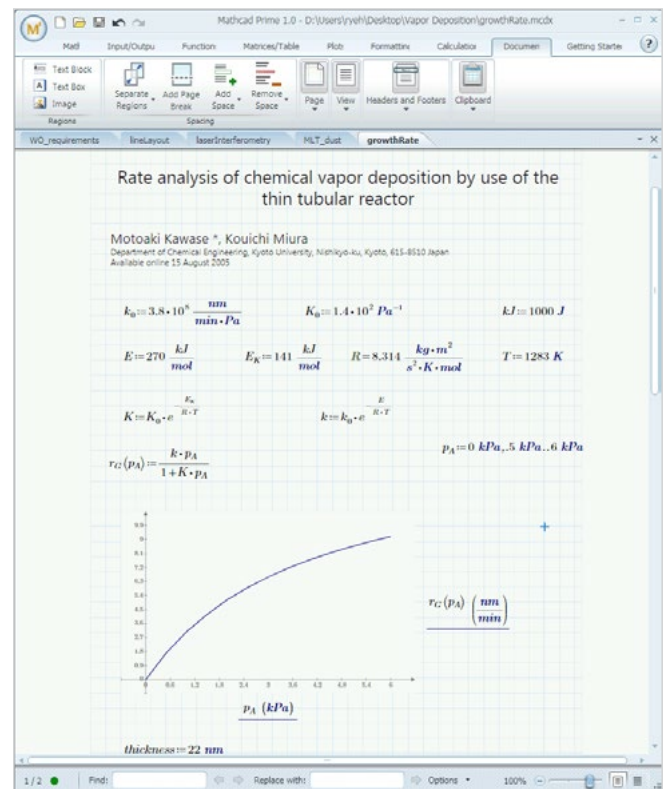


Figure 4: Langmuir Absorption model

c. Chemical Vapor Deposition – Given that a detailed model was developed for production line routing and wafer handling, the next step was to develop a more detailed model for each of the stations on the production line. The most significant of these stations was the chemical vapor deposition process itself. This process was largely governed by the underlining physics [shown in the attached PTC Mathcad sheet]. Growth is largely determined by both the chamber pressure PA and the temperature T. The higher the temperature and pressure the faster the deposition process, however as the temperature increases the stress on the wafer increases as well. Further consideration needs to be taken to assure that the temperature and pressure required can be achieved by the furnace and vacuum pump. This was modeled with the Langmuir adsorption model (with dependency on the reactant partial pressure). Other factors to consider include gases that are added to the chamber, as such additions can increase or decrease the growth rates.

Finally, the design team had a detailed mathematical model describing all major aspects of the production line routing, wafer handling, and deposition processes. They could modify the production line layout, change the wafer handling mechanism, or introduce other chamber dynamics and quickly determine the impact of these changes on their design. This detailed model provided a cascade of requirements from the high level 20% wafer throughput down to individual requirements for each actuator, chamber and sensor used on the production line. This flow down of requirements and the traceability it provided allowed the research team to explore new and innovative designs without having to develop costly physical prototypes. As a result they were able to provide the calculation context behind their design decisions and provide a pathway for future requirements verification and subsequent intelligent reuse of their models. By leveraging these engineering best practices this manufacturer was able to efficiently build their new wafer fabrication system, protect their market share, and fend off lower cost rivals.

Ensure Traceability of Requirements Decomposition

Throughout the iterative planning, concept and design phases described in the previous manufacturing example, requirements must remain comprehensive and clear, well structured, traceable and testable.¹ Product Lifecycle Management (PLM) systems like PTC Windchill organizes requirements at different levels and break tasks into appropriate disciplines (e.g., mechanical and electrical engineering).

Requirements can be reviewed throughout the planning and concept stages, to help manage derived requirements as they emerge and track data, associated with the appropriate components of the project, to provide traceability (Figure 5).

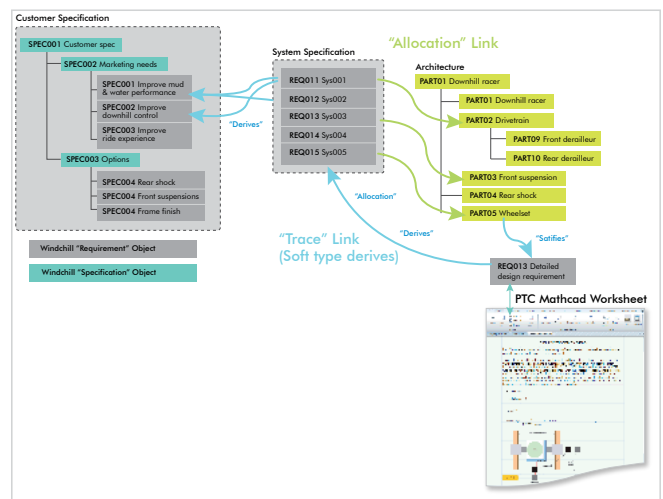


Figure 5: Requirements Flowdown in Wafer Manufacturing

The software's open architecture allows easy integration with PLM systems to provide maximum traceability. Working within a PLM system, PTC Mathcad provides the engine for formulas and calculations that “sit inside” the requirements and help explain the rationale inherent in physical decomposition. The software helps clarify as how requirements are satisfied by underlying product

¹ Visit PTC – PTC Mathcad – Systems Engineering – Engineering Calculations Software to download our White Paper, Best Practice: Design Studies and Trade-Off Analyses

designs as well as which requirements drive system, product or part designs. Engineers can check-in and check-out worksheets from either the PTC Mathcad or PLM user interface – and quickly search attribute labels and contents of stored worksheets. PLMs are able to preserve and access all versions of worksheets. If changes are made to requirements, the product automatically handles the necessary changes in formulas and calculations and iterates them as required, providing synchronized and up-to-date visual traceability maps/matrices. PTC Mathcad also integrates with CAD systems like PTC’s Creo Parametric, so the impact of changes in Requirements Flow-down can be reflected in revised design drawings. An open architecture also enables traceability for engineering groups that are not using PLM systems. In many companies, high-level requirements originate as documents in Microsoft Office and SharePoint. The architecture allows integration with these applications and includes built-in integration with Microsoft Excel. Worksheets can be stored and dynamically updated through Live Math for ad hoc use. Alternatively worksheets can be exported as PDFs to be managed by normal ECM or DMS systems.

Aligning Product Development Processes with Corporate Goals

To achieve greater market share, your company might define an initiative to improve a specific business process: for example the more efficient and flexible manufacture of key product components. PTC Mathcad empowers engineering teams to better perform physical decomposition, articulate and share

their work and establish traceability in Requirements Flow-down. Leveraging dynamic worksheets and unit management provides greater confidence that the designed solutions will optimally meet the market requirements and achieve larger, strategic company goals.

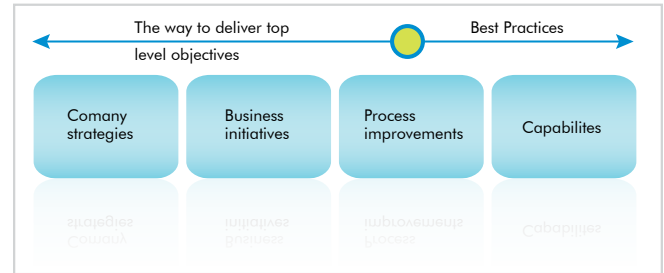


Figure 6: Engineering Process Improvements Support Company Strategic Goals

Best practices applied within engineering help ensure that the solution does indeed address efficiency requirements, and thereby, support achieving greater market share. These best practices include: Design Studies and Trade-Off Analyses (DS/TOA); Requirements Flow-down; Requirements Verification; and Frontloaded Simulation.

Check out our **Best Practices in Product Development** series of whitepapers:

- **Design Studies and Trade – Off Analyses** whitepaper
- **Feasibility Analysis for engineering designs** – achieve better and faster design decisions with confidence

Summary

Employed in best practice planning, concept, and design phases of product development, Requirements Flow-down allows engineers to more closely align product decisions with defined requirements. The software enables this best practice by providing the ideal environment in which to perform decomposition. Engineers can easily and accurately capture and display the math used in physical modeling and analysis. Through dynamically updated worksheets, clarify how requirements are satisfied by proposed system, product or component designs. This also promotes visibility for physical decomposition across all engineering teams throughout the product development process. Enable those performing decomposition to easily document and communicate their logic in familiar natural math notation with textual annotations that enable easy evaluation by teams across geographic locations and timeframes. Finally, PTC Mathcad helps establish traceability of requirements decomposition by integrating with the product lifecycle management tools that organize requirements at different levels – as well as and with CAD systems that are driven by those requirements. Synchronized and up-to-date visual traceability maps/matrices promote understanding of how design changes impact requirements and how requirement changes impact product designs.

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Contact us today and a representative will call you to set up a customized demo with a product expert.

PTC Mathcad is the Industry Standard Software for Engineering Calculations.

Learn more at PTC.com/products/mathcad.

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