LEAN DEVELOPMENT: A KNOWLEDGE SYSTEM

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Abstract

Toyota's continued performance has spurred interest beyond its production system in the factory to its development process. According to a NCMS report, Toyota's product design process is far more effective than its main competitors and could be up to twice as fast and four times as productive as the norm at other automakers. In-depth studies of the development process have shown that it differs significantly from current development practices. In this paper, we argue that this process has to be understood in the light of an overall system, as opposed to piecemeal organizational solutions. We suggest a scaffolding to describe this process, underlying its four broad steps with a platform centre organization, a commitment to lean manufacturing, and an underlying investment in knowledge creation.

Toyota Motor Company's continued performance is slowly establishing the firm not just as a benchmark for best practice, but as the inventor of an entirely new model of industrial production, fated to supersede the fordist model on which XXth century industry was built. The "Toyota Production System", or "lean manufacturing" as it is more generally known[1] has been extensively studied since the mid-1980s and many companies are now working hard at adopting "lean" practices on their shop floors.

It turns out, however, that production is only half the manufacturing problem. As a *Fortune* article points out, "*Engineering and component fabrication account for around 85 per cent of the direct cost of the manufacturing process associated with car production*."[2] Not surprisingly, Toyota's Product Development process is just as innovative and counter-intuitive to traditional engineering management as is lean manufacturing is to mass production. Clearly, its performance is impressive. According to a National Center for Manufacturing Sciences report, Toyota product development projects could take half the time of US equivalents, with 4 times their productivity (150 product engineers utilized by Toyota per car program versus 600 for twice as long at Chrysler). Toyota also earns consistently top quality ratings from J. D. Powers or Consumer Reports.[3] Furthermore, it appears that Toyota has succeeded in resolving some of the intractable problems in automotive car development.

TOYOTA'S PRODUCT DEVELOPMENT FOURFOLD EDGE

Firstly, although every manufacturer claims to "listen to the voice of the customer," this is not so clear in practice. Toyota seems to be able to make sure that its engineers actually care about what customers think of their product. This means both creating a strong vision for the future product and communicating this vision across all players in the development process. Once expressed clearly, this early vision serves as a

[1] WOMACK, J. P., D. T. JONES & D. ROOS, *The Machine that Changed the World : the Story of Lean Production*, New York : HarperPerennial, 1991.
[2] VAGHEFI, M., R., L. WOODS & M. N. DAPRILE, "Creating sustainable competitive advantage: The Toyota Philosophy and Its Effects", http://www.toyota.co.jp/en/special/toyota philosophy/
[3] NATIONAL CENTER FOR MANUFACTURING SCIENCES, *Product Development Process – Methodology & Performance measures*, 2000.

reference to arbitrate conflicting constraints within the design process. In some cases, this vision can fundamentally challenge the existing product. For instance, Toyota cars have long been criticized for their rather stodgy appearance, regardless of their quality or performance – a rather cold-headed buy. The Camry, for example, had been America's best selling passenger car for four years running at the time it was scheduled for a successor in 2002. According to its program chief engineer, Kosaku Yamada: "*We now have success because Camry has proved for many years to be an excellent car. The quality is high, the reliability also very high and it has a strong resale value. That part will not change. But even though people like it and recommend it, there are too few who are emotional about it. Our goal is to make people love our car and say, 'wow' when they look at it and drive it*."[4]

Secondly, the Toyota development process somehow limits late engineering changes which plague any industrial development. Late engineering changes feedback into the process and create chaos, both in terms of rework and quality issues. Overall, all automakers are painfully aware of the disruptive power of late engineering changes, but few have learned to limit them in practice. Toyota has perfected a process which mostly avoids such late changes. Indeed, to develop the same example, the Camry project manager at the Toyota Technical Center in Plymouth, Mich., claims that the car's chief engineer, Mr. Yamada, pushed for what he called "perfect drawings", or "Zero EC" in Toyota-speak: no engineering changes would be allowed after production drawings were released. "*It's the ultimate goal*," says Dana Hargitt, the project manager, "*it sounds impossible, but focusing on a Zero EC target really energizes the manufacturing and production people early in the process. If you think you will not have a chance to change it later, you do your homework early and you speak up if there is any doubt. In terms of getting the feedback at the drawing stage before the tooling was cut, this system made a difference*."[5]

The third recurrent issue is to be able to master the flow of drawings and tool elaboration. The aim of any design process is to "industrialize" drawing production to increase overall design effectiveness. This, in turn, is rarely possible because of all

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[4] KOBE, G., "Process of Elimination: analysis of Toyota Camry manufacturing, product development", *Automotive Industries*, Sept, 2001.
[5] *Ibid*.

the on-going changes which cross-impact throughout the development process. Having largely solved key issues upfront in the upstream part of its design process, Toyota can then focus on a precise, tightly scheduled production of the actual drawings downstream – supplemented with efficient use of CAD/CAM technology. In the Camry's case, the number of vehicle prototypes was cut by 65 percent, and the number of crash tests halved by the use of digital assembly software.[6]

Which obviously leads to the final key to an efficient development process: focusing on quality and cost in production itself. Although all constructors are aware that at least 70 percent of the product's manufacturing costs lie in its development, they mostly still focus exclusively on the product's design itself. Drawing on its expertise on lean manufacturing, Toyota doesn't stop at the product design, but also examines all aspects of the car's production to make sure that the product will be build within the targeted cost brackets once the design are released. Toyota's emphasis on lean production and waste reduction starts right at the source in the product design process. In the Camry example, Toyota made many changes to the product to reduce assembly time and improve quality, eliminating operations which were difficult or dangerous for operators in the process. For instance, a 26-pound carpet was redesigned in three parts to avoid back injuries or overhead electrical work was eliminated through the use of pre-wired subassemblies.[7]

These four key factors are the aim of every development process, yet where many try, few succeed. What does Toyota do to succeed in practice where others fail, although all attempt to achieve the same results? Some of the underlying principles of the Toyota Product Development process have been common knowledge in the auto industry since the eighties. Indeed, in the mid 1990's one of the authors, then Industrial Vice-President Manufacturing of the French automotive supplier Valeo was implementing Toyota-inspired notions such as separating research from development projects front-loading the development process, concurrent engineering, and supplier integration.[8] Yet, detailed knowledge on Toyota development practices remained largely anecdotic until two in-depth studies

[6] *Ibid*.
[7] *Ibid*.
[8] *Constant Innovation*, Valeo, internal document, 1997.

specified explicitly many aspects of Toyota's Product Development process, proposing new interpretations of familiar concepts.[9]

A "SYSTEM" VISION

As with implementing the Toyota Production System on the shop floor, a more precise understanding of development practices doesn't necessarily help to improve the efficiency of engineering projects for a number of reasons. First, just as with TPS, it's not just about a collection of "best practices" which can be implemented piecemeal, but a system — one specific practice can rarely hold water without having implemented the others as well. Furthermore, a clearer understanding of the system as a whole also shines a different light on the practices themselves, and, in many cases, changes their intended *purpose*. As such, many of the Toyota practices only make sense in the light of the overall system. Shigeo Shingo, one of the early contributors to the TPS used to say that when asked "What is the Toyota Production System?", eighty percent of people would say "It's a kanban system", another fifteen would know enough of its working in the factory to say "It's a production system," and only a very few five percent would really understand its purpose and answer "It's a system for the absolute elimination of waste":

> "Some people imagine that Toyota has put on a smart new set of clothes, the kanban system, so they go out and purchase the same outfit and try it on. They quickly discover they are much too fat to wear it! They must eliminate waste and make fundamental improvements in their production systems before techniques like kanban can be of any help."[10]

The same can probably be said about Toyota's product development process by replacing "kanban" with "concurrent engineering" which is probably the most well-known (and misinterpreted) design practice in the system.

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[9] SOBEK II, D. K., *Principles that Shape Product Development Systems : A Toyota-Chrysler Comparison*, Ph.D. Dissertation, University of Michigan, 1997; MORGAN, J. M. M., *High Performance Product Development: A Systems Approach to a Lean Development Process*, Ph.D. Dissertation, University of Michigan, 2002.
[10] SHINGO, S., *A Study of the Toyota Production System From and Industrial Engineering Viewpoint*, Cambridge: Productivity Press, 1989.

Secondly, most approaches to product development improvement tend to focus on improving the "product development process", proposing a variety of organizational fixes ranging from full re-engineering to local continuous improvement efforts.[11] However, within a practice-oriented perspective on social learning,[12] we argue that the design process itself is a proximal cause of performance, not an ultimate one. In line with Fujimoto's work on the evolution of the Toyota Production System,[13] we contend that Toyota's current development process is the result of the interaction between a set of practices and situational market conditions. To understand Toyota's lean development process, it is necessary, we believe, to identify the core practices and attitudes which underlie its organizational aspects.

Taking a systems approach,[14] we propose a systemic representation of the Lean Development Process (LDP) which aims to clarify both the different specific practices observed in Toyota's product development process, and the underlying shared attitudes, which make these practices work. In other words, we believe that any of the practices, worthwhile as they may be, taken out of the system will not yield significant efficiency gains in the development process. The system has to be visualized as a whole in order to understand each of its parts:

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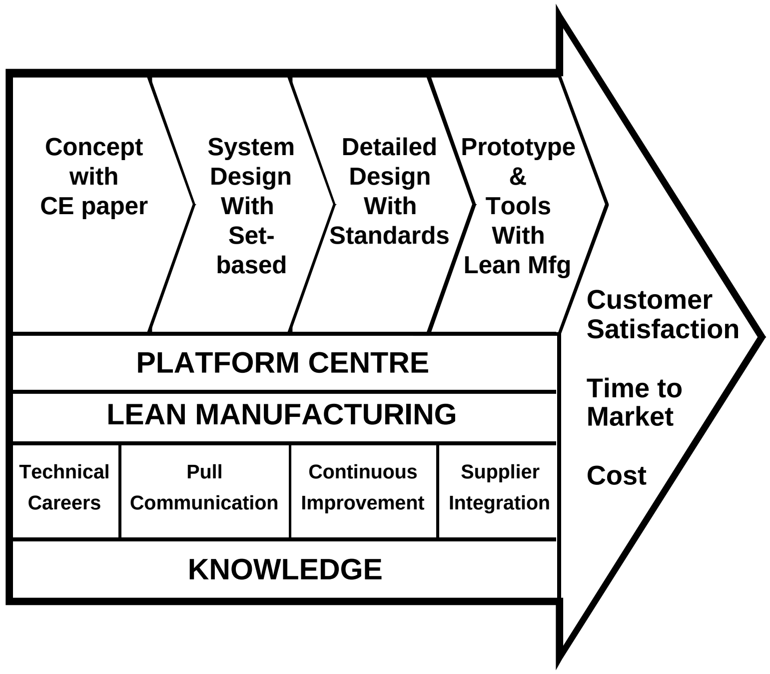
[11] DOOLEY, K. & D. JOHNSON, "Changing the New Product Development Process: Reengineering or continuous Quality Improvement", *Measuring Business Excellence*, 5(4): 32-38, 2001.
[12] WENGER, E., *Communities of Practice*, Cambridge: Cambridge University Press, 1998.
[13] FUJIMOTO, T., *The Evolution of a Manufacturing System at Toyota*, Oxford: Oxford University Press, 1999.
[14] BALLÉ, M., *Managing with Systems Thinking*, Maidenhead :McGraw-Hill, 1994.



To sustain this systemic vision we suggest the following representation, build on four layers:

- Process layer: The product development process
- Organizational layer: platform centres
- Practice layer: lean manufacturing, with the TPS in production and specific practices in product development
- Culture layer: the "knowledge-based" paradigm

We shall address each layer in turn to succinctly describe the key points at each level of the system. In actual fact, we must note that Toyota also takes particular care of the production preparation process between prototyping and start of production, ironing out production kinks through training and intensive problem-solving. This preparation phase contributes to Toyota's ability to quickly ramp-up production after SOP, but we have considered this aspect a feature of "lean production" (a.k.a. the Toyota Production System), and we wish to focus here on the design process proper.

TOYOTA'S PRODUCT DEVELOPMENT PROCESS

Toyota's product development process is represented here in four phases:

- A concept phase leading to the Chief Engineer's (CE) concept paper
- A system-designed phase with concurrent engineering
- A detailed design phase with design standards
- A prototype and tooling phase with lean manufacturing

Although fundamentally, Toyota's development process can be distinguished in two very different stages: an upfront, unstructured phase, and then a planned, very controlled execution phase.[15] The idea that development processes need to be loaded up-front in order to avoid the usual delays and overspending at the tooling and Start Of Production phases has been around for a long time and tried many times, but it is often unclear in traditional development processes exactly how this should be done. The Toyota development process suggests a few key approaches to manage the front-loading in practice.

Chief Engineer concept paper

In their 1991 study of the relationship between organizational structure and project performance, Clark and Fujimoto introduced the notion of "heavy-weight project manager", a practice which has its roots in Toyota in the 1950s.[16] According to Fujimoto, an ideal product manager would have the following roles:

- Coordinate responsibility in wide areas, not just engineering but also production and sales.
- Coordinate responsibility for the entire project period from concept to market.
- Take responsibility for concept creation and concept championing.
- Maintain responsibility for specification, cost target, layout and major component choices, making sure that product concept is accurately translated into technical details of the vehicle.

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[15] MORGAN, J. M., *Op. Cit.*, 2002.

[16] CLARK, K. B. & T. FUJIMOTO, *Product Development Performance*, Boston: Harvard Business School Press, 1991.

- Build direct and frequent communication with designers and engineers at work level, on top of indirect ties through liaisons.
- Establish direct contact with customers (the product manager's office conducts its own market research besides the regular market surveys done by marketing).
- Is multilingual and multi-disciplined so that he can effectively communicate with designers, engineers, testers, plant managers, controllers, and so on.
- Is not just a neutral referee or passive conflict manager. May initiate conflict in order to prevent product designs from deviating from the original product concept.
- Market imagination, or the ability to forecast future customer expectations based on ambiguous and equivocal clues in the present market.
- Walks around and advocates the product concept, rather than doing paperwork and conducting formal meetings.
- Is mostly an engineer by training. Has broad, if not deep, knowledge of total vehicle engineering and process engineering.[17]

Regardless of the many discussions about how "heavy-weight" a chief engineer really is in the Toyota organization (a function which has evolved over time, from the "heavy-weight" product manager to the "chief engineer", the actual architect of the car), Fujimoto's description of the chief engineer fits the portrait Jeffrey Liker draws of the early design of the first Lexus. This author describes how Ichiro Suzuki, the CE for the Lexus first started with a round of limited focus groups and then defined a quantified set of overall performance the new car would have against existing competitors on dimensions such as top speed, fuel consumption, noise, aerodynamics and weight; the he expressed a set of trade-offs which needed to be resolved with a "no-compromise" objective:

- Great high-speed handling and stability *yet* a pleasant ride
- Fast and smooth ride *yet* low fuel consumption
- Super quiet *yet* light weight
- Elegant styling *yet* great aerodynamics
- Warm *yet* functional interior
- Great stability at high speed *yet* low friction[18]

According to Liker, the CE then had great trouble convincing his Toyota colleagues that such a car was possible, let alone feasible. Still, he eventually persuaded some engineers to try their hand on developing some experimental features without being concerned with mass production. Early success with this approach eventually led to

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[17] FUJIMOTO, T., *Op. Cit.*, 1999.
[18] LIKER, J. K., *The Toyota Way*, New York: McGraw-Hill, 2004.

the development of the Lexus which, as of 2002 was the best-selling luxury car in the US.

In a similar vein, Liker also depicts the development process of Toyota's hybrid car, the Prius. Here is how he describes the evolution of the Chief Engineer's function:

> "In Toyota's traditional approach, in the planning phase the chief engineer comes up with a concept, discusses it with the design groups and planning groups, and formulates a concrete plan as a result of joint discussions with those groups. With the Prius, a team of specialists from various design, evaluation and manufacturing functional groups sat in a big room with the chief engineer and made decisions in real time. Joining that group were not only the design engineers, but the production engineers as well so they could have discussions together. To assist these discussions, computer-assisted design (CAD) terminals were put into the room and it became known as "*obeya*" (big room)."[19]

In fact, in recent developments, the "*obeya*" has been generalized to all projects, collocating briefly the core team for a phase at the end of architecture design. Actually, contrarily to many traditional product managers, the chief engineer is first and foremost a technical expert who has a large input in the car's architecture.[20] Although he is responsible for the project from concept to market, he has little formal authority in the matrix, but is mostly recognised by his experience, his technical skills and is communication skills. He has a very small dedicated team of experienced product engineers as well as manufacturing engineers – but all his other resources are in the functional organization. He summarizes his vision for the car in a "concept paper" which leads into the system design phase.[21]

System Design with set-based concurrent engineering

Concurrent engineering has been seen as a source of development performance ever since it was highlighted by Clark and Fujimoto in their 1991 study.[22] However, most companies interpreted this as the need to have more frequent feed-back loops

[19] *Ibid.*
[20] Toyota interviews, 2003.
[21] Morgan, *Op. Cit.*, 2002.
[22] CLARK, K. B. & T. FUJIMOTO, *Op. Cit.*, 1991.

between engineering and production within the traditional process. In many cases this led to disappointing results inasmuch as the amount of rework increased rapidly while at the same time people were trying to reduce deadlines for milestones. In the mid 1990s, Ward *et al*. clarified how concurrent engineering was done at Toyota by introducing the notion of "set-based" concurrent engineering. The authors detail the following approach:

1. The team defines a set of solutions, rather than a single solution, at the system level.
2. They define sets of possible solutions for various sub-systems.
3. They explore these possible sub-systems in parallel, using analysis, design rules, and experiments to characterize those parts of the design space.
4. They use this analysis to gradually narrow the set of solutions, converging slowly towards a single solution. In particular, they analyse the possibilities for the subsystems to determine the appropriate specifications. Both Toyota's engineers and Toyota suppliers described an extensive negotiation process.
5. Once they have established the single solution for any part of the design, it is not changed unless absolutely necessary; In particular, the single solution is not changed to gain improvements (i.e. to climb the optimality hill). [23]

In working this way, Toyota is not only front-loading its development process, but also delaying key decisions, which, paradoxically, results in faster product development.[24] The purpose of the front-loading is to identify all possible problems and to resolve them early on in the process, long before the clay freeze. By nature, it's a messy process, given to ambiguity and negotiation. Ultimately, conflicts tend to be resolved by returning to "customer satisfaction" criteria.[25] As design progresses the sets of solutions gradually narrow according to the information received from all stakeholders (development, testing, customers, etc.) As the design converges, engineers commit to staying within the set so that their colleagues working in parallel can rely on their communication. Consequently, although Toyota considers a broader range of possible designs than most other automakers and actually delays firm decisions, by progressively reducing specifications and resolving ambiguity it

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[23] WARD, A., D. K. SOBEK II, J. J. CRISTIANO & J. K. LIKER, "Toyota, Concurrent Engineering and Set-Based Design", in J. K. LIKER, J. E. ETTLIE & J. C. CAMPBELL, *Engineered in Japan: Japanese Technology-management Practices*, Oxford: Oxford University Press, 1995.
[24] WARD, A., J. K. LIKER, J. J. CRISTIANO & D. K. SOBEK II, "The Second Toyota Paradox: How Delaying Decisions Can Make Better Faster Cars", *Sloan Management Review*, Spring 1995.
[25] Toyota interviews, 2004.

considerably shortens its development cycle.[26] During the critical period of the system design phase, Product Engineering, Manufacturing Engineering, Purchasing, and Quality will have correspondents located in the *obeya* (big room) under the CE's leadership, to develop a team atmosphere with one experienced engineer from each division. After this period, they meet at least every 2 weeks.[27]

Repeated attempts by western automakers at encouraging concurrent engineering have failed in the past. Designers are often blamed for their apparent lack of concern for manufacturing issues, but it turns out that during "concurrent engineering" efforts to get functions to discuss the car concept upstream, manufacturing engineering tends to expect drawings to be able to voice its opinion of the design – something of a catch-22. In Toyota's set-based concurrent engineering approach, manufacturing engineers produce detailed check-lists of what they can, or cannot do, which define the design space in a non-restricting way. Each parameter is obviously opened to debate, but ultimately, this gives designers a loose framework to operate with and the checklists serve as a concrete basis for communication between designers and production engineers.

Detailed design with standards

Morgan reports that after the initial two "noisy" phases of concept and architecture, Toyota's development process moves into a different gear and starts producing detailed designs in a tightly programmed schedule:[28]

> "Early engineering rigor, problem solving and designed-in countermeasures, along with true cross-functional participation, are key to maximizing the effectiveness of the product development process. Further, by effectively segregating this inherently "noisy" phase of the product development process from the execution phase, Toyota is able to minimize downstream process variation that is crucial to both speed and quality."[29]

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[26] SOBEK II, D. K., A. C. WARD, J. K. LIKER, "Toyota's Principles of Set-Based Concurrent Engineering", *Sloan Management Review*, Winter 1999.
[27] Toyota interviews, 2004.
[28] MORGAN, J. M., *Op. Cit.*, 2002.
[29] MORGAN, J. M., http://www.sae.org/topics/leanfeb02.htm

In this second part of the development process, Toyota reduces variability by relying strongly on standardization of skills, processes, and design themselves. This high level of standardization is key to eliminating reworks and waste, and paradoxically again, opens the way for capacity flexibility. In keeping with its emphasis on Standardized Work on the shop floor, in the development process Toyota uses a number of standardization tools, such as:

- Checklists (process checklists and product checklists)
- Standardized process sheets
- Common construction sections.

Sobek and Ward also argue that checklists are a key ingredient to the success of set-based concurrent engineering. According to these authors, every function has its own set of engineering checklists on file. In the early days of the program, functions pass their checklists to update each other on what's possible, what new technologies have become available, what new problems they've managed to solve, etc; When the CE asks a function to participate in a program, the first step is to pull the checklists from the files and customize them for this particular project:

"Engineering checklists contain detailed information concerning any number of areas including: functionality (e.g., piston rings of standard material should have a thickness of at least 1.8 mm to provide proper seal), manufacturability (e.g., bounds on acceptable curvature radii for sheet metal bending), government regulation (e.g., minimum strength characteristics for door side bar member to meet side impact crash test requirements), reliability, etc."[30]

Although the exponential growth of checklists of all sorts can become a bit overwhelming, it is felt at Toyota that this detailed standardization of the design process is a critical factor of its success at maximising learning and continuous improvement in the design process, as well as speeding it up while maintaining its reliability.[31] As major problems are resolved and solutions sets are refined, the *obeya*

[30] SOBEK II, D. K. & A. C. WARD, "Principles from Toyota's Set-Based Concurrent Engineering Process", Proceedings of the 1996 ASME *Design Engineering Technical Conferences and Computers in Engineering Conference*, Irvine, 1996.
[31] Toyota interviews, 2004.

ends and meeting occur less frequently, moving the process towards more formal communication.

Prototype and Tools with Lean Manufacturing

In general, Toyota develops two series of prototypes, which are not used to test solutions, but to choose the different sub-systems and check their integration. The first products of the first wave (1S) are very carefully assembled in a slow build to check all interfaces. All others are assembled using lean manufacturing techniques. In the mean time, simultaneously with the 1S fast build, Manufacturing Engineering will conduct its own slow build to identify manufacturing and assembly issues. Prototyping is a time of intensive work for body engineers, particularly at the first slow builds which is a privileged learning time for junior engineers in body engineering and manufacturing engineering. This is the last stage in which engineering changes will be accepted. They work with system engineers, prototype specialists, quality assurance experts and production assembly team leaders and are expected to respond every quickly, signing off sketches or drawings within 48 hours if not on the spot.[32]

Similarly, die design occurs according to lean manufacturing principles, building the tools just-in-time. Toyota combines die design software with standard manufacturing techniques to obtain high-speed pattern making, and high-precision die machining. Once the dies have been produced, Manufacturing Engineering produces the functional build, makes the necessary changes to the dies and sets final specifications.[33] The main point in die manufacture is that Toyota uses the same lean principles it relies on in the factory, such as die construction cells with check-lists, to reduce the often time consuming die manufacturing lead time. Once the die location has been selected, the entire process is planned in great detail. At the trail production phase, again, considerable value-analysis is conducted to drive the waste out of the

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[32] MORGAN, J. M., *Op. Cit.*, 2002.
[33] *Ibid.*

manufacturing process. Product engineering maintains a small group in the plant to help resolve design issues which might crop up.

Overall, Toyota's lean development process can be characterised by two different stages: a first, front-loaded, "noisy" exploratory stage where the overall concept for the vehicle emerged and many alternatives are explored. The a second "detailed planning" stage where drawings are realized with the objective of attaining "zero EC": no engineering changes once the drawings are released, and then using lean manufacturing techniques to build both prototypes and tools. Toyota has sometimes been portrayed as making more mock-ups than its competitors. In practice, all automakers develop roughly the same number of mock-ups to choose from. Toyota's specificity lies in its detailed discussion of manufacturing issues at the mock-up stage, whereas its competitors are mostly concerned with style and engineering. Toyota is willing to invest time and effort in learning early on in order to make sure that the end solution is truly the best. According to Sobek, Ward and Liker:

"Perhaps the most striking example of multiple (subsystem) alternatives is found in the planning phase [system design] of engineering design that falls between concept design and detail design. In body engineering, the main output of the planning phase [system design] is the *kozokeikaku* document (K4), rougly translated "design structures plan", which is circulated for information and approval to all affected engineering groups. Leading up to the K4 release, body engineers perform many subsystem studies of body structure at a detailed planning level. The pre-K4 studies explore the engineering implications of vehicle styling. By the time body engineering is ready to create the K4 for a given vehicle program, engineers have created two, three, or more designs of the key subsystems of the body structure to support alternatives for the overall structure plan."[34]

This early "open" phase then narrows down rapidly to a very tightly planned detailed drawing phase which then operates according to lean manufacturing principles.

PLATFORM CENTRES

[34] SOBEK II, D. K., A. C. WARD, J. K. LIKER, *Op. Cit.* 1999.

As Sobek *et al.* remark, Toyota is perplexing inasmuch as although its product development process is unusually efficient, the firm does not use many of the recommended techniques for process effectiveness. Its development teams are not collocated and engineers (with the exception of the chief engineer and his small staff) are not dedicated to one program. In fact, cross-functional rotation is unlikely for the first ten years of an engineer's career.[35] By all accounts, Toyota appears to be a rather stodgy, rather conservative company with strong functional silos. Yet Toyota manages to systematically outperform its competitors. What kind of organisation can then sustain its unique product development process? Originally, as described by Clark and Fujimoto, Toyota remained a functional organisation and its development programs were organised around a "heavy-weight" project manager who managed somehow, through authority and charisma, to make the functions responsive to his own project's needs. However, Cusumano and Nobeoka note that as the firm grew this simple organizational model progressively became unsustainable. In 1991, a chief engineer had to coordinate people in 48 departments in 12 divisions to launch a new product program. Furthermore there were too many projects for each functional manager to manage the engineering details of each, as well as coordinate across projects, and, conversely, more junior chief engineers found it harder to fight the authority of functional managers and were no longer such "heavy-weight" project managers.[36] As a result, in the early 1990s, Toyota fundamentally reorganised its product development organisation and moved towards platform centres, splitting it into four distinct development centres around platforms organized to develop product families:

- Centre 1: rear-wheel-drive platforms and vehicles.
- Centre 2: front-wheel-drive platforms and vehicles.
- Centre 3: utility vehicle/van platforms and vehicles
- Centre 4 (1993): components and systems for all vehicles.

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[35] *Ibid.*

[36] NOBEOKA, K., "Reorganizing for multi-project development: Toyota's new structure of product development centers", Research Institute for Economics and Business Administration communication, Kobe University, 1995.

Each centre has a General Manager in charge of the functional managers, the chief engineers and its own planning division. The planning division is in charge of human resources, long-term product planning, preliminary studies before a CE is appointed and cost management. In practice, each development centre has an incentive to minimize its costs by transferring resources and components between projects. Each centre also defines its own vision for product development. For instance, Cusumano and Nobeoka describe the mid-1990s themes as:

- Centre 1: development of luxury and high-quality vehicles
- Centre 2: development of innovative low-cost vehicles
- Centre 3: development of recreational vehicles that create new markets,

This organization has been evolving over time and as of early 2004, there is a further centre devoted to the Lexus platform.

In many ways, the platform organisation is key to the performance of a lean product development process. Firstly, it encourages coordination within projects, secondly it helps to optimise human resources utilization, particularly in the precise scheduling for the detailed design phase, and thirdly it encourages product standardization by the exchange and re-use of components across a platform. This does not only apply to major modules such as engines or gear-boxes, but also to a list of specific components which offers a limited choice for designers to choose from. [37]

LEAN PRACTICES

Organization alone can hardly explain the success of Toyota's product development process. Several of its competitors have tried similar organizational designs with disputed results. Platform centres may be, in many ways, a proximal cause for Toyota's peculiar development process, by encouraging certain behaviours but it can hardly be its ultimate explanation. In fact, we believe that, underlying the organizational structure, one should never loose track of how deeply imbedded "lean manufacturing" is in Toyota's "DNA". To a large extend, the Toyota's philosophy could be described as "customer satisfaction with lean manufacturing". For instance,

[37] CUSUMANO, M. A. & K. NOBEOKA, *Thinking Beyond Lean*, New York: The Free Press, 1998.

it appears very clearly from Morgan's research that Toyota's product development is strongly manufacturing driven. It's objective is to design parts *for* lean production in the plants. This appears elsewhere as the unusually strong role of Manufacturing Engineering within the company, where the balance is carefully maintained between Product Engineering and Manufacturing Engineering but, unusually for a automaker, with a slight advantage towards manufacturing. The rationale is that Produce engineers have a bias towards trying something new. Since one of Toyota's guidelines is that only proven technology should be introduced in a new product development, the onus is on ME to maintain the control of the development, and, in actual fact, it seems that Toyota's best engineers can be found in Manufacturing Engineering.[38] For instance, No product decisions can be taken without manufacturing Engineering's consent. A position of chief manufacturing engineer with a small staff of simultaneous engineers (charged with coordinating simultaneous engineering) mirrors the chief product engineer. In the development process, manufacturing engineering is charged with updating and communicating design standards, performing design reviews, monitoring prototype builds and designing process equipment and tools from part drawings.[39]

Overall, the influence of Toyota's lean approach to manufacturing can be felt in every aspects of its product development process. In this respect, Toyota engineers follow a number of practices which would not appear in any organizational charts, but which are essential to the process steps highlighted earlier. Many of these practices reflect the core principles of the Toyota Production System in the plants, applied to a product development environment. For instance, the "*genchi genbutsu*" principle of "go and see for yourself"[40] can be found throughout the design process – in the early concept phases, the core team around the chief engineer is supposed to tour plants and dealerships to have a hands on understanding of the car they're trying to imagine. At the prototype build stage, the core team meets daily at the end of the day to discuss the progress of the build, and so on.

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[38] Toyota interviews, 2004.

[39] MORGAN, J. M. *Op. Cit.*, 2002.

[40] LIKER, J. K., *Op. Cit.*, 2004.

Technical careers

One of the strongest features of the TPS is its insistence on developing people's skills. As researchers Steven Spear and H. Kent Bowen phrase it:

"All the organizations we studied that are managed according to the Toyota production System share an overarching belief that people are the most significant corporate asset and that investment in their knowledge and skills are necessary to build competitiveness. That's why at these organizations all managers are expected to be able to do the jobs of everyone they supervise and also teach their workers how to solved problems according to the scientific method."[41]

Accordingly, the same emphasis on individual competence can be found in the product development area. A striking feature of Toyota's engineers as opposed to most other industrial engineers in western companies, is their highly technical profile. Although many engineers tend to have technical careers, this is specifically emphasized in Toyota's engineering tracks. As Sobek highlights, an engineer is likely to spend most of his career within the same technical department, specialising in a function. For instance, this author describes a typical engineering career:

- Start: initiation cycle with a hands on project
- 5 years: second assignment in the same or related department
- 10 years: supervisor of five engineers in the same or a related department
- 15 years: department manager of 25 engineers in the same function
- 20 years: director in charge of more than 100 engineers[42]

Each engineer also has a mentor who is not his immediate manager to coach him on problem-solving. Furthermore, learning is further emphasized by the supervisor's role definition which involves training engineers under him in technical design, engineering skills, problem-solving skills, producing reports, procedures, communication and so on. To all practical purposes, the supervisor appears to have a very similar role to that of team leader on the shop floor.

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[41] SPEAR, S. & H. K. BOWEN, "Decoding the DNA of the Toyota Production System", *Harvard Business Review*, September-October 1999.
[42] SOBEK II, D. K., *Toyota's Chief Engineer*, LEI Aeronautics conference Los Angeles

Pull communication

Durward K. Sobek points out another application of lean principles in product development in what he describes as "pull communication":

> "Like the famous *kanban* just-in-time system in its factories, Toyota seems to believe that design participants should obtain (i.e., "pull") the information they need when they need it and in the right amounts."[43]

In the factory, it's up do the downstream process to get parts from upstream. Similarly, the responsibility for finding information lies with the one who needs it. This, in turn supposes that anyone can talk to anyone else in the company and that people know *where* to find the relevant information. Not surprisingly, this also involves a great deal of standardisation of communication, favouring written communication over verbal debate. Toyota has indeed developed a number of communication standards in "A3" sheets which are used to summarize technical points by having standard outlines, such as problem situation, target, root cause analysis, countermeasures, implementation and verification/follow-up. Several such formats exist for various topics such as proposing a new plan or initiative, giving the current status of an activity, problem solving etc.[44]

According to Sobek's observation, decisions which involve a large number of people in various functions must also be consistent, and Toyota achieves this by roughly following a three stage process:

1. Initiate one or more rounds of written exchanges.
2. If the problem persists, hold a face-to-face meeting.
3. If there is still a problem, meet with the CE[45]

A practical implication of this "pull communication" principle is that part drawings are released as they are completed rather than in one "batch" release once the entire

[43] SOBEK II, D. K, *Op. Cit.,* 1997.
[44] DENNIS, P., *Lean Production Simplified*, New York: Productivity Press, 2002.
[45] SOBEK II, D. K, *Op. Cit.,* 1997.

product design is finished. This enables manufacturing engineering to work on the process early and level its workload rather than receive all of it at the same time and start from there.

Continuous improvement

A further instance of the application of lean manufacturing principles to development can be found in the emphasis on continuous improvement in the development process. As with production *kaizen*, continuous improvement in design functions is largely possible because the high degree of standardization from standard processes, check-lists, etc. we discussed earlier in the design process. Indeed, organizational researchers Adler and Goldoftas studied the model change process at the NUMMI Toyota-GM joint venture in Fremont, California, and highlighted the ability to challenge what has been done and improve upon it as a fundamental contributor to the speed of product change in the plant.[46] Contrasting the product change in the NUMMI plant with current practice in General Motors, the authors describe how all functions collaborate to the plant's product change right from the start. For instance, manufacturing involvement for the 1993 model change began as early as 1989, just after the previous product change had been completed. Toyota design engineers began by collecting problems and suggestions from NUMMI, as well as Toyota's other plants in Japan and in Canada. A year before the change, the sister plant in Takaoka had detached engineers to work with the development team in reviewing the emerging product designs and identifying production issues. This and rigorous "certification" prior to operations dramatically reduced the number of changes required after the start of production.

Although the 1993 NUMMI changeover performed almost to Toyota standard, the plant encountered many difficulties (reaching full production in 77 days as opposed to the planned 60 days), and specifically resulting in a high rate of worker injury. The conflict over ergonomics affected labour relations and NUMMI

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[46] ADLER, P. S. & B. GOLDOFTAS, "Flexibility Versus Efficiency? A case study of model changeovers in the Toyota Production System", *Organization Science*, 10, 1:43-69, 1999.

experienced its first work stoppage the following year. Two years later, NUMMI made its next major product change reaching full production in only 48 days and with far superior health and safety conditions. The researchers attribute this spectacular change to the Toyota practice of "reflection-review", or *hansei*: the systematic challenging of the activities which have just been done and on-going search for better solution.

The *hansei* process starts by reviewing the checklists and other standard documents and then refining these procedures. One of the interviewees describes the process:

> "The binders give us best-practice procedures for managing model changes – just like standardized work sheets give the workers best practice procedures in regular production. And the learning process is the same. In manufacturing, anomalies show up as differences between takt time and the worker's actual cycle time, and these anomalies lead to problem-solving, which then leads to defining countermeasures, which in turn leads to new standardized work procedures. Anomalies in the changeover process are the differences between our target changeover time and our actual time. The hansei process is simply the problem-solving procedure we use to improve our model change."[47]

Morgan reports that such *hansei* meetings occur at various levels of the learning cycle. An engineer can be handed a *hansei* assignment by his supervisor who will ask him to reflect on some aspect of their performance and to come up with a plan for improvement. *Hansei* will also occur at team level within a specific project and take place at major milestones, right after the activity has been completed to keep the experience fresh in the minds of the participants. Finally, *hansei* also occur in the form of post-mortems to surface "what went right" and "what went wrong" lessons for future use. According to this author, *hansei* sessions not only serves as an opportunity to learn and improve, but are also a key factor to focus the group on common outcomes and build a sense of shared destiny and being part of the same team.[48]

Supplier integration

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[47] *Ibid.*

[48] MORGAN, J. M., *Op. Cit.*, 2002.

Supplier integration is another key practice which strongly structures Toyota's lean development process. This aspect of the TPS has been extensively researched, and is a practice common to several Japanese automakers, and which has been increasingly adopted by their western competitors.[49] Takahiro Fujimoto describes four broad types of supplier involvement:

1. *Supplier Proprietary Parts*: the supplier develops a component entirely, from concept to manufacturing as its standard product (*shihanhin*). Some highly standardized components, such as batteries, may belong to this category.
2. *Black Box Parts*: developmental work for the component is split between the assembler and the supplier. In a typical case, the former creates basic design information such as cost/performance requirements, exterior shapes, and interface details based on the total vehicle planning and layout, while parts suppliers do detailed engineering. There are two sub-categories of black box parts: approved drawings (*shoninzu*) and consigned drawings (*itakuzu*).
    a. *Approved drawings*: in this case, the drawings are eventually owned by the supplier, which assures design quality and patent rights over the parts in question. That is, the supplier has to make engineering actions in response to field claims related to the parts. In exchange for this responsibility for quality, the supplier enjoys a greater degree of design discretion for better manufacturability and cost reduction.
    b. *Consigned drawings*: unlike approved drawings, final drawings are owned by the carmaker, but detailed engineering work is subcontracted out to the supplier. The former pays the design fee to the latter as a separate contract, and is free to switch suppliers at the manufacturing stage. It is the carmakers that take responsibility for quality assurance, though.
3. *Detail-Controlled parts*: The third category is the case in which most of the component engineering work, including parts drawing, is done in-house. In this way not only basic engineering but also detailed engineering is concentrated in the hands of the carmaker, although the suppliers can make requests for design changes for better manufacturability and cost reduction. It is called the 'provided drawings (*taiyozu* or *shikyuzu* system' in Japan.[50]

Fujimoto tells about how much of the black-box parts procedures originated with the establishment of Nippondenso as an independent supplier when Toyota's founder Kiichiro Toyoda decided to change Toyota's procurement policy after WWII and emphasize outsourcing. The author suggests that a supplier will progress in status of

[49] CUSUMANO, M. A. & A. TAKEISHI, "Supplier Relations and Management: a survey of Japanese Transplant, and US Auto Plants", *Strategic Management Journal*, 12: 563-88, 1991. CLARK, K. B. & T. FUJIMOTO, *Op. Cit.*, 1991.
[50] FUJIMOTO, T., "Note on the Origin of the 'Black-Box Parts' Practice in the Japanese Motor Vehicle Industry", in H. SHIOMI & K. WADA (eds.) *Fordism Transformed: the development of production methods in the automotive industry*, Oxford: Oxford University Press, 1995.

parts as its relationship with Toyota expands and its design competence increases in line with Toyota expectations. In actual fact, Nippondenso has become proficient in the use of these methods, and particularly as regards set-based concurrent engineering.

The degree in which Toyota shares knowledge with its supplier, and, in return benefits from the supplier's own innovation efforts has increasingly been seen as a fundamental source of competitive advantage, which makes Toyota such a "moving target" in terms of continued performance improvement. Indeed, Toyota has also organized some of its suppliers in knowledge-sharing networks to increase the learning effects[51]. However, as Kennedy points out, such efforts are fruitful only with a great level of maturity in terms both of modularity of the product and definition of functional performance for each module.[52]

KNOWLEDGE

In trying to explain Toyota's superior performance (for instance, four times its US competitor's productivity), the authors of the NCMS report faced a quandary. Toyota does not seem to follow any of the fashionable trends in the industry, such as team co-location, design automation, 6-sigma initiatives, reengineering programs, and so forth. On the contrary, their research highlighted that, for example:

- Toyota engineers are matrix, not team organized.
- Engineers are not dedicated to programs and are functionally aligned.
- Product and manufacturing engineers are separated.
- Simple, non-standard processes are used for product development.
- Limited use of formal tools like QFD, DFM and design automation.
- Relatively few and brief meetings.[53]

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[51] DYER, J. H. & K. NOBEOKA, "Creating and Managing a High-Performance Knowledge-Sharing Network: The Toyota Case", *Strategic Management Journal*, p271-291, 2000.
[52] KENNEDY, M. N., *Product Development for the Lean Entreprise: Why Toyota's System is Four Times more Productive and How You Can Implement It*, Richmond: Oaklea Press, 2003.
[53] NCMS, *Op. Cit.,* 2000.

In the end, the authors conclude that Toyota operates on a different "paradigm": rather than being structure-based, it is "knowledge-based". Although the concept of "paradigm" is notoriously tricky to define (NCMS defines it as the "*model of reality or systems of facts, theories and philosophies that is widely accepted and becomes the framework for thinking*") this interpretation converges with Nonaka and Takeuchi's work in explaining of Japanese firms such as Toyota, which, they argue, rests on these firms' ability for knowledge creation. They propose that knowledge creation is the result of two simultaneous processes. Firstly, knowledge is created through the social interaction between its two fundamental components: tacit knowledge and explicit knowledge, a distinction originally drawn by Michael Polyani to draw attention to the fact that we "*can know more than we can tell*."[54] Secondly, Nonaka and Takeuchi describe how knowledge created at the individual level is progressively transformed into organizational knowledge. They argue that innovation is caused by the interaction between these two "knowledge spirals".[55] Indeed, Spear and Bowen make the case for the TPS as an extension of the scientific method to the factory.[56] Certainly, the "set-based" application of concurrent engineering attacks one of the fundamental issues of decision-making. As has been established by an abundant literature on "bounded rationality", rational choice in decision-making broadly fails in two ways: either decision-makers narrow down to one option very quickly and avoid considering any alternative options for fear of weakening their resolve, either, on the contrary, they fall into pusillanimous exploration of endless possibilities, never actually committing to one practical action[57]. In this respect, the set-based approach appear singularly successful in encouraging the exploration of options *as well as* making sure decisions are taken in time to respect milestones – an exercise in rationality.

The practices we have highlighted also indicate a commitment to knowledge creation. First, the technical career path of the engineers encourages the development of specific expertise. According to Morgan, the first assignment of a young engineer

[54] POLANYI, M., *The Tacit Dimension*, Gloucester: Peter Smith, 1966.
[55] NONAKA, I. & H. TAKEUCHI, *The Knowledge-Creating Company*, Oxford: Oxford University Press, 1995.
[56] SPEAR, S. & H. K. BOWEN, *Op. Cit.*, 1999.
[57] JANIS, I. L., *Crucial Decisions: Leadership in Policy-Making and Crisis Management*, New York: Free Press, 1989.

is an improvement project.[58] Secondly, the emphasis on "pull communication" supports the exchange of information amongst functional specialists. Continuous improvement through *hansei*, obviously constantly challenges *status quo* and opens the way for new knowledge creation. Finally, Toyota's collaborative work with it's suppliers is another source of practical innovation, as is apparent from Daniel Whitney's study of product design at Nippondenso.[59]

Furthermore, there are reasons to think that Toyota's focus on knowledge creation is more than simply an "emergent" property of its organizational process, and more of a deliberate management approach. As Dyer and Nobeoka have shown, Toyota's investment in coaching its supplier is considerable. For instance, Toyota set up the Toyota Supplier Support Center in the US in 1992 to echo its internal Operations Management Consulting Division in Japan (established in the mid 1960s by Taiichi Ohno) and assist North American suppliers to implement their own version of TPS. The number of TSSC projects has increased rapidly and Toyota neither charges for the consultations, nor asks for immediate price decreases or a portion of the savings from the improvement (although suppliers do eventually pass on some of the savings)[60] In fact, signs of Toyota's management recognition of the importance of knowledge can be found from very early on. In 1953, after an in-house contest, Toyota adopted "*Good Thinking, Good Product*" as its motto.[61] Similarly, a Toyota internal document describing the evolution of "*JIT production through the entire process from parts supply to the customers*" states "reform of manager's mind" as the ultimate goal of the progress of kaizen activities from the 1970s to 1995.[62] Finally, in 2003 interview, Michel Gardel, VP of Toyota France explains the "Toyota Way" document internally distributed in Toyota in 2001[63] in the following terms:

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[58] MORGAN, J. M., *Op. Cit.,* 2002.
[59] WHITNEY, D., "Nippondenso Co. Ltd.: A Case Study of Strategic Product Design", *Research in Engineering Design*, 5:1-20, 1993.
[60] DYER, J. H. & K. NOBEOKA, *Op. Cit.,* 2000.
[61] NONAKA, I., "The Development of Company-Wide Quality Control and Quality Circles at Toyota Motor Corporation and Nissan Motor Co. Ltd." in H. SHIOMI & K. WADA, *Fordism Transformed: The Development of production Methods in the Automobile Industry*, Oxford: Oxford University Press, 1995.
[62] Internal document, Toyota, Takaoka Plant.
[63] The "Toyota Way" states four high level principles: *hoshin kanri* (strategy deployment), *genchi-gembustu* ("go and see"), *kaizen* (continuous improvement) and respect and teamwork.

"The "Toyota Way" is not just a sum of procedures. More than a corporate culture, it is a state of mind (état d'esprit)."[64]

Conclusion

"*Human development is at the very core of TPS*," warns Gary Convis, President of Toyota Motor Manufacturing Kentucky. "*It is often overlooked, as people seize on the more tangible aspects of TPS. Engineers are particularly likely to latch on to tools like kanban, heijunka, and jidoka, and think they have captured the essence of TPS.*" [65]

It would be tempting to assume that the key to Toyota's product development remarkable speed and productivity lies in its design process. Certainly, many of the Toyota techniques make sense on their own and would be beneficial anywhere. But on their own, they are unlikely to deliver the kind of benefits people would expect.

"*For TPS to work effectively*," says Convis, "*it needs to be adopted in its entirety, not piecemeal. Each element of TPS will only fully blossom if grown in an environment that contains and nourishes the philosophies and managerial practices needed to support it*."

We have argued that, like the TPS in production, Toyota's lean development process is sustained by a system-wide scaffolding of organization, practices and, ultimately, an explicit attitude towards knowledge creation through systematic problem-solving and challenge-setting. If our assessment is correct, it would have far-reaching implications for managers trying to emulate Toyota like performance in their own product design organisations. The odds are that applying lean "best practices" will not deliver the wished for results unless managers question themselves seriously on their tacit approaches to knowledge creation. At the end of the day, if you have the right experts, if they communicate effectively and they are given challenging goals, not surprisingly, they'll deliver splendid products. Yet, for each new managerial initiative, organizational change or simple on the spot decisions, managers can ask themselves these simple questions: "*Are we developing better engineers?*", "*Are we helping them to share their knowledge across functions?*", "*Are*

[64] CASTELET, C., "Toyota: la formule magique", *Le Nouvel Economiste*, pp: 87-93, 2003.
[65] CONVIS, G., "Role of Management in a Lean Manufacturing Environment", SAE, 2004.

we giving them the proper challenges?" If the answers are uncertain, it's probably our attitude we need to challenge before we even start looking at our processes.

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