Design Principles for Highly Adaptable Business Systems, With Tangible Manufacturing Examples

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Abstract

Highly adaptable (agile) production systems and business practices are enabled by an engineering design which facilitates the reconfiguration and reuse of common modules across a scalable framework. Examples of agile fixtures, machines, cells, assembly lines, plants, and production organizations are presented; and a common set of ten underlying design principles are shown to be responsible for the high adaptability in each. The principles are system generic, and can be applied to any business practice or process, not just manufacturing and production processes. Finally, a method for capturing and displaying these principles in action is shown which facilitates learning, knowledge transfer, and business-engineering competency development.

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1. Introducing Principles for Agile Systems

In 1991 the author co-led an intense four-month-long collaborative workshop at Lehigh University that gave birth to the concept of the agile manufacturing enterprise. This workshop was funded by the US government, and engaged fifteen representatives from a cross-section of US industry plus one person from government and four people as contributing facilitators. The Japanese had just rewritten the rules of competition with the introduction of lean manufacturing. Our intent was to identify the competitive focus that would be the successor to lean - believing that there would be value in building competency for the next wave rather than simply playing catch up on the last.

The group converged on the fact that each of their organizations was feeling increasingly whipsawed by more frequent change in their business environments. The evidence was everywhere that the pace of change was accelerating - and already outpacing the abilities of many established organizations. With even faster changes expected it became evident that survivors would be self-selected for their ability to keep up with continuous and unexpected change.

We dubbed this characteristic agility and loosely defined it as "the ability of an organization to thrive in a continuously changing, unpredictable business environment."

Being agile means being a master of change, and allows one to seize opportunity as well as initiate innovations. How agile your company or any of its constituent elements is, is a function of both opportunity management and innovation management - one brings robust viability and the other brings preemptive leadership. Having one without the other is not sufficient in these times of quickening unpredictable change. Having neither is a time bomb with a short fuse today.

How much of each is needed at any time is a relative question - relative to the dynamics of the competitive operating environment. Though it is only necessary to be as agile as the competition, it can be extremely advantageous to be more agile.

All of this talk about “how agile” and “more agile” implies we can quantify the concept, and compare similar elements for their degrees of agility. However, as Figure 1 shows, there is some question about value tradeoffs between an increment of leadership and an increment of viability.

Leadership wins if the leader always chooses the most optimal path to advance - but one false step allows a competitor to seize the advantage; putting the previous leader in reaction mode. A competitor with excellent viability can track the leader, waiting for that sure-to-come mistake. Poor viability may then keep the fallen-from-grace ex-leader spending scarce resources on catch-up thereafter.

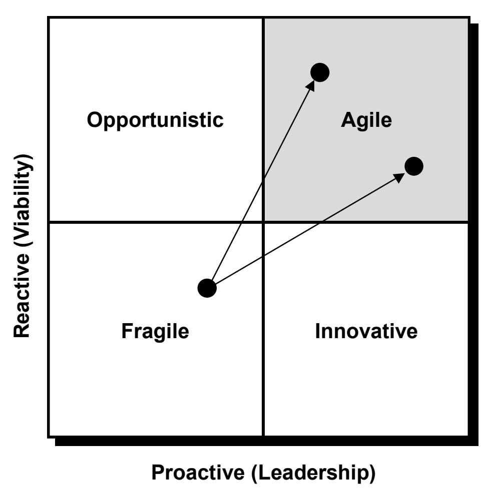
Choosing a desired spot in the agile quadrant is one of the important ways to strategically differentiate yourself from your competitors. Getting to your chosen spot is another issue entirely - and a job for masters at business engineering, not business administration.

How innovative/ opportunistic are you - relative to your competitive needs and

Figure 1 - Agility Space

- **Viability:** Seeks and responds to the voice of the customer, says yes to opportunity, reactive, resilient, staying power, robustness.
- **Leadership:** Introduces new approaches, makes existing approaches obsolete, changes the rules, out-of-box thinking, disrupts the market.
- **Plot* any business element:** Enterprise competitive position, plant operation, supply-chain strategy, specific shop-floor process, teaming strategy, product development, etc.

* See *Change Proficiency Maturity Model* at www.parshift.com for plotting techniques.



If You Could Move, Which Is The Better Move?

business environment? How fast are the rules changing in your market? Are you able to respond fast enough, can you introduce a few changes of your own? Importantly - what allows you to do that? We will look shortly at some promising design principles to answer this question.

The search for metrics and analytical techniques that can pinpoint an enterprise in the agility space has received a lot of attention. Self analysis tests that ask lists of questions are one form, house-of-quality QFD-like templates are another. These have a certain appeal in that they deal with familiar concepts that enjoy intuitive association with agility: teaming, empowerment, partnering, short-cycles, integrated process and product development, and so forth.

But experience shows us that simply saying yes to these questions will not tell us anything useful - too many people, for instance, will say yes to having empowered teams when the yes-ness has nothing to do with the quality of the implementation, or if the implementation promotes agility.

Better to ask how well we respond to critical types of unexpected situations, how often we lead with a meaningful innovation, how proficient we are at a variety of identified change we feel to be strategically important. For sure, empowered teams embody an organizational structure and business practice that can help us be more agile, but only when they are designed and supported with that end in mind.

There are tools that can identify the location of a company in agile space relative to its business environment and competitive realities [1]. When a company decides it is time to change its viability/leadership position it must select and design strategies that will move it to where it wants to be. The selection of appropriate strategies changes with the times and differs from market to market. In the late '90s appropriate strategies might include concepts like mass customization, virtual enterprise relationships, employee empowerment, outsourcing, supply chain management, commonizing production, listening to your customer, and other such.

Table 1 - Key Definitions	
System:	A group of interacting modules sharing a common framework and serving a common purpose.
Framework:	A set of standards constraining and enabling the interactions of compatible system modules.
Module:	A system sub-unit with a defined and self-contained capability/purpose/identity, and capable of interaction with other modules.

Strategic concepts by themselves are open to a wide range of interpretation, however, and are often interpreted incorrectly. Commonization in shop-floor controls, for instance, does not pay agility dividends if it is interpreted as buying controls from one vendor; empowerment does not pay without an information and support infrastructure; and customer listening does not pay when competitors change the rules.

Business strategists recognize the imperative of the agile enterprise, with virtually all popular business writers extolling the need for change proficiency of one kind or another. Of particular note is Richard D'Aveni's excellent Hypercompetition [2], which focuses on wielding change proficiency as a preemptive business strategy, and Kevin Kelly's Out of Control [3], which provides fundamental examples for the business engineer who would design and build agile enterprises and production systems.

Regardless of the strategies chosen, effective implementation employs a common set of fundamental design principles that promote proficiency at change.

Designing agile systems, whether they be entire enterprises or any of their critical elements like business practices, operating procedures, supply-chain strategies, and production processes, means designing a sustainable proficiency at change into the very nature of the system. A business engineer is interested in both the statics and the dynamics of these systems - where the static part is the fundamental system architecture and the dynamic part is the day-to-day reengineering that reconfigures these systems as needed.

Sustaining a desired opportunistic/innovative profile is dependant upon the agility of these systems, which in turn is impeded or enabled by their underlying architectures. In the next section we discuss Reusable/Reconfigurable/Scalable (Rrs) system strategies. Figure 2 provides a set of design principles for these Rrs systems. These principles have emerged from observations of both natural and man-made systems that exhibit Rrs characteristics, with contributions from the Agility Forum's 80-case Agile Practice Reference

Figure 2 - Rrs (Reusable-Reconfigurable-Scalable) System Principles

Any organization of interacting units is a "system": an enterprise of business resources, a team of people, a cell of workstations, a contract of clauses, or a network of suppliers.

Self Contained Units
System composed of distinct, separable, self-sufficient units not intimately integrated.

Plug Compatibility
System units share common interaction and interface standards, and are easily inserted or removed.

Facilitated Re-Use
Unit inventory management, modification tools, and designated maintenance responsibilities.

Non-Hierarchical Interaction
Non-hierarchical direct negotiation, communication, and interaction among system units.

Deferred Commitment
Relationships are transient when possible; fixed binding is postponed until immediately necessary.

Distributed Control & Information
Units respond to objectives; decisions made at point of knowledge; data retained locally but accessible globally.

Self Organizing Relationships
Dynamic unit alliances and scheduling; open bidding; and other self adapting behaviors.

Flexible Capacity
Unrestricted unit populations that permit large increases and decreases in total unit population.

Unit Redundancy
Duplicate unit types or capabilities to provide capacity fluctuation options and fault tolerance.

Evolving Standards
Evolving open system framework capable of accommodating legacy, common, or completely new units.

Base [4], Kevin Kelly's thought-provoking book [3], and the sizable body of knowledge and experience growing out of object oriented systems design.

We will explore the application of these principles next, tying them into various production strategies useful to the agile enterprise.

2. Agile Machines and Agile Production

Agile production operations thrive under conditions that drive others out of business. When forecasts prove too optimistic or markets turn down, they throttle back on production rate with no effect on product margins. If product life ends prematurely, they are quickly reconfigured and retooled for new or different products. Instead of loosing market opportunity when product demand soars beyond capacity, they expand to meet the market. Rather than postpone or shut down periodically for major process change, they evolve incrementally with continuous incorporation of new process technologies. In support of new product programs, they freely take prototypes in the workflow. For niche markets and special orders, they accommodate small runs at large run margins. Irrespective of all of these changes, they maintain superior quality and a steady loyal workforce.

They also accommodate work flows of intermixed custom configured products -- the mass customization concept frequently misunderstood as the defining characteristic of agile production. Mass customization is just one of many valuable change proficiencies possible in the agile production operation.

The capabilities extolled above are not meant to be comprehensively defining, but rather to set the stage for a discussion about real machines and real production processes that do all of this. The first example we use is from the semiconductor manufacturing industry; but the principles and concepts illuminated are applicable in any industry.

The U.S. lost the semiconductor market to Japan in the '70s, and hopes for regaining leadership were hampered by a non-competitive process equipment industry - the builders of the "machine tools" for semiconductor fabrication. In this high paced industry, production technology advances significantly every three years or so, with each new generation of processing equipment cramming significantly more transistors into the same space.

With each new generation of equipment semiconductor manufacturers build a completely new plant, investing $250 million or more in equipment from various vendors, and twice that for environmentally conditioning the building to control micro-contaminates.

For equipment vendors, each new generation of process equipment presses the understandings of applied physics and chemistry. Million dollar machines are developed to deposit thinner layers of atoms, etch narrower channels, imprint denser patterns, test higher complexities, and sculpt materials at new accuracy and precession. Generally each machine carries out its work in a reaction chamber under high vacuum, and sports a sizable supporting cast of controls, valves, pipes, plumbing, material handling, and whatnot.

New equipment development is actually new invention, frequently taking longer than the three-year prime-time of its life. And because the technology utilized in each generation is so unique, market success with one generation of equipment has little to do with the next or the last generation. The industry's history is littered with small vendors that brought a single product-generation to market.

Single purpose, short lived, complex machines. Long equipment development cycles. Repeatability and reliability problems. All targeted for a high volume, highly competitive production environment serving impatient, unforgiving markets. And every new generation requires a new plant with more stringent environmental conditioning to house the new machines. The learning curve in this industry is dominated by touchy equipment that takes half its product life to reveal its operating characteristics. Forget about rework here, and get used to scrap rates way above 50% in the early periods of production. Heavy industry may scoff at the low scrap cost, but this means lost deliverables with devastating loss of critical short-lived-market penetration. Equipment budgets routinely factor high outage expectations into extra million dollar machines.

Getting product out the door is so critical, and mastering the process so tough, that no one has time to question the craziness. This is the way of semiconductors.

Or rather, it was until something occurred in 1987: Applied Materials, Incorporated, a California-based company, brought a new machine architecture to market -- an architecture based on reusable, reconfigurable, scalable concepts.

Depicted in Figure 3, the AMI Precision 5000 machines decoupled the plumbing and utility infrastructure from the vacuum chamber physics, and introduced a "multichamber" architectural concept. Instead of one dedicated processing chamber, these machines contained up to four independent processing modules serviced by a shared programmed robotic arm. Attached like outboard motors, process modules are mixed and matched for custom configured process requirements. A centralized chamber under partial vacuum houses a robotic arm for moving work-in-process wafers among the various workstations. The arm also services the transfer of wafer cassettes in and out of the machine's external material interface.

A single machine can integrate four sequential steps in semiconductor fabrication, decreasing the scrap caused by contamination during inter-machine material transfer. Yield rate is everything in the competitive race down the learning curve -- but this integrated modular approach pays other big dividends too.

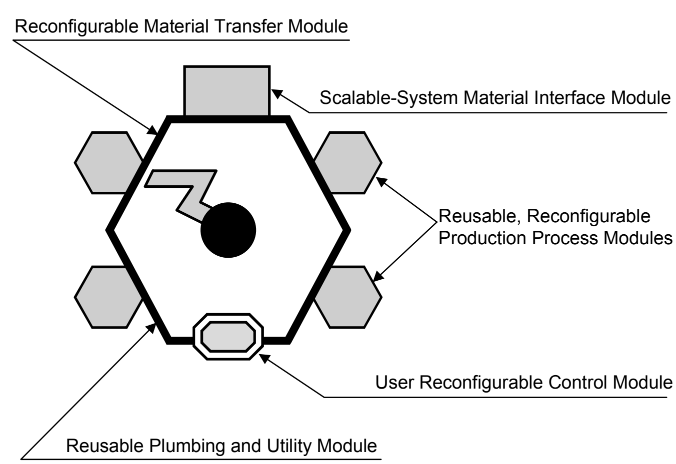
Applied Materials shortened its equipment development time and cost significantly by separating the utility platform from the processing technology. Development resources are focused now on process technology, reusing a utility base common across technology generations, which accounts for 60% of the machine. This eliminates a significant design effort for each additional process capability Applied brings to market, and shrinks the complexity and time of shakeout and debug in prototyping stages. More importantly, perhaps, is the increased reliability that Applied's customers enjoy with a mature and stable machine foundation.

In process sequences with disparate time differences among the steps, a configuration might double-up on two of the modules to optimize the work flow through a three-step process.

A malfunction in a process module is isolated to that module alone. It can be taken off-line and repaired while the remaining modules stay in service. The architecture also facilitates rapid and affordable swap-out and replacement servicing if repair time impacts production schedules.

Semiconductor manufacturing is barraged with prototype run requests from product engineering. New

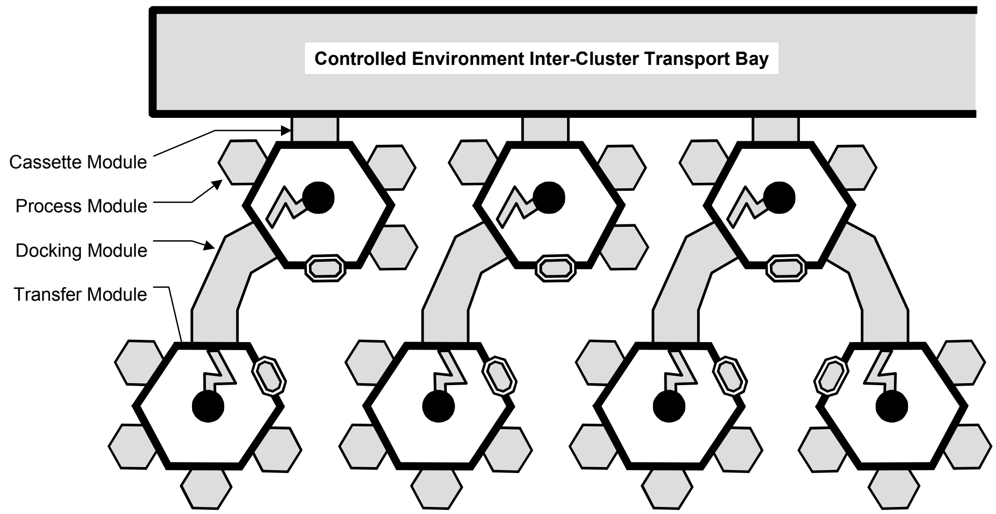
Figure 3 - Semiconductor Wafer-Processing "Cluster" Machine
Architecture: Reusable, Reconfigurable, Scalable



Stylized Depiction of *Precision 5000* Family from Applied Materials Inc.

products typically require new process setups and often require new process capability. When needed, redundant process modules can be dedicated to prototyping for the period of test-analyze-adjust iterations it takes to get process parameters understood. And if a new capability is required, a single new “outboard motor” is delivered quicker and at a lot less cost then a fully equipped and dedicated machine.

Figure 4 - Scalable Machine Clusters



SEMI, 10/16/89, Document #1796, “Cluster Tool Module Interface and Wafer Transport Standard”

Cluster architecture also brings a very major savings in both time and cost for creating new fabrication facilities. The ultra-clean environment needed for work-in-process can be reduced to controlled hallways rather than the entire building. People can attend and service the machines without elaborate decontamination procedures and special body suits.

Work-in-process is most vulnerable to contamination when it is brought in and out of high vacuum. The cluster machine architecture reduces these occurrences by integrating multiple process steps in one machine. Using a docking module, as depicted in Figure 4, these machines can be directly interconnected to increase the scale of integration.

Extending these concepts and combining them with a strategy for reconfigurable facilities might push the utility services below the floor and the clean transport above the machines. Though this “ultimate” configuration shown in Figure 5 does not yet exist in a production environment, the possibility is obvious.

In 1989 the Modular Equipment Standards Committee of SEMI (Semiconductor Equipment and Materials International) started work on standards for mechanical, utility, and communications interfaces. What started as a proprietary idea at Applied Materials is moving toward an industry open architecture, promising compatible modular process units from a variety of venders.

Applied Materials revolutionized the semiconductor industry. Their cluster machines propelled them into global leadership as the largest semiconductor equipment supplier in the world. Leadership is defined by followers, and today, every major equipment supplier in the world has a “cluster” tool strategy.

Here we see the ten Rrs design principles introduced in the last section in action; with an agile machine architecture that enables an agile production environment. Next we will look at an equally agile metal-cutting production operation; but with machine tools that are not themselves agile.

3. Agile Cells and Agile Production

Manufacturing cells in general and flexible machining cells specifically are not especially new concepts, though their use and deployment is still in an early stage. Machining centers are not inexpensive machine tools, and the economics of building cells from multiples of these machines is still beyond the vision and justification procedures for many. It is typical to expect benefits from these flexible machining cells in production operations with a high part variety and low volume runs. When justification and benefit values are based on flexible configurations and objectives this is understandable.

Recently, however, innovators are finding important values in quick market response: rapid new product introduction, accommodation to unpredictable demand, fast prototype turnaround, non-premium-priced pre-production runs, efficient ECO (Engineering Change Order) incorporation, longer equipment applicability, and the latitude to accept (or insource) atypical production contracts to improve facility utilization.

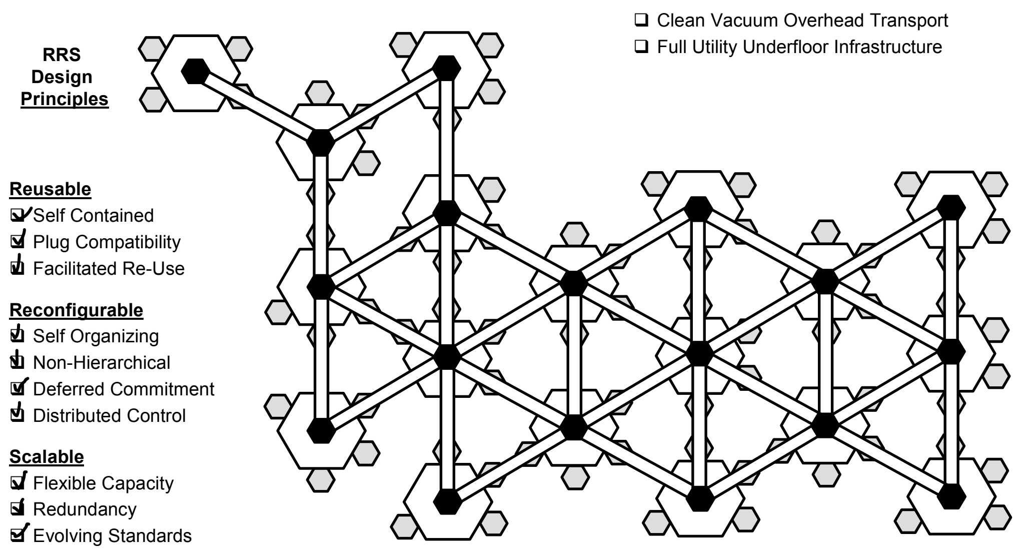


Figure 5 - Agile Machines In A Reconfigurable Plant Framework

These new agile system values now challenge applications where transfer lines and dedicated machinery have traditionally reigned - and their applicability is based upon concepts that push beyond the traditional flexible values. After examining these values Kelsey-Hayes decided to build two entirely cellular plants for the production of ABS and other braking systems. “We want to achieve a strategic advantage on product cost and delivery” was the vision voiced by Richard Allen, president of their Foundation Brake Operations [5].

We are not talking mass customization here, with custom configured products. We are talking about fundamental change in the value structure of the high-volume-car / high-volume-brake markets. Technological advances in ABS systems have cut each succeeding product generation’s life-time in half.

The trend to higher automotive-system integration and more technology promises even more change. Car companies want leadership in functionality and feature, and faster times to market; and can not afford to feature obsolete systems when competitors innovate. Kelsey-Hayes sees opportunity in this faster paced, less predictable market.

To put the problem in perspective and provide a basis for evaluating the depicted solutions, we will look at some change proficiency issues first.

Product life-cycle for ABS has dropped from ten years to three years over three generations of product, and is expected to go lower yet - so taking 4-6 months to retool a dedicated transfer line is a significant part of the production life - not good. As automakers mine new niche markets and increase total systems integration in standard models the frequency of ABS model-change increases. Within this shortened life of any model is the increasing frequency of modifications to add feature advantages and necessities. Of course all these modifications and new models do not spring to life from pure paper - they each need prototypes and small pre-production runs.

Automakers, like most everyone else, have never been able to forecast demand accurately, and it is only getting worse. Coupled with new JIT requirements and reduced finished goods auto inventories the automakers need to throttle production in concert with demand on a week-by-week basis. Suppliers must either be proficient at capacity variation or face increased costs with their own finished goods inventories and obsolete scrap.

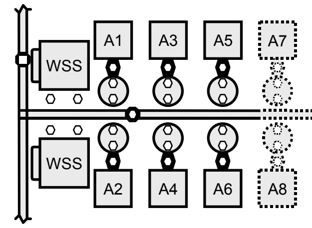
The ABS market is not alone in this application of technology and continual improvement as we will see with a look at some machine tool advances.

Previously we looked at an example of an agile semiconductor-production machine architecture, and how those machines might (and do) support an agile production operation. Now we continue the illumination of design principles that give us agility by looking at an agile cell architecture and how it supports an agile production operation. Both the agile cell (Figure 6) and the agile production environment (Figure 7) make use of capabilities and configurations possible with the LeBlond Makino A55 machining centers, and are substantially similar to actual installations. Perhaps other vendors can provide a similar capability, our purpose in using the LeBlond example is to show that these concepts are real and not imagined.

Figure 6 - Agile Machining Cell

Change Proficiency

- ☐Install and Set Up New Cell in 4-8 Weeks.
- ☐Reconfigure Cell for Entirely New Part in 1-4 Weeks.
- ☐Duplicate Cell Functionality in in 1-2 Days.
- ☐Add/Calibrate New Machine in 1-2 Days While Cell Operates.
- ☐Remove or Service Machine without Cell Disruption.
- ☐JIT Part Program Download.
- ☐Insert Prototypes Seamlessly.



Concept Based on LeBlond Makino A55 Cells at Kelsey-Hayes

Observed RRS Design Principles

Reusable
- ☐ Self Contained - Machines, work setting stations, pallet changers, fixtures.
- ☐ Plug Compatibility - Common human, mechanical, electrical, and coolant framework.
- ☐ Facilitated Re-Use - Machines do not require pits or special foundations, and are relatively light and easy to move.

Reconfigurable
- ☐ Self Organizing - Cell control software dynamically changes work routing to accommodate module status changes and new or removed modules on the fly.
- ☐ Non-Hierarchical - Complete autonomous part machining, non-sequential.
- ☐ Deferred Commitment - Machines and material transfers are scheduled by cell control software in real time according to current cell status, part programs downloaded to accommodate individual work requirements when needed.
- ☐ Distributed Control - Part programs downloaded to machines, machine life history kept in machine controller, machines ask for appropriate work when ready.

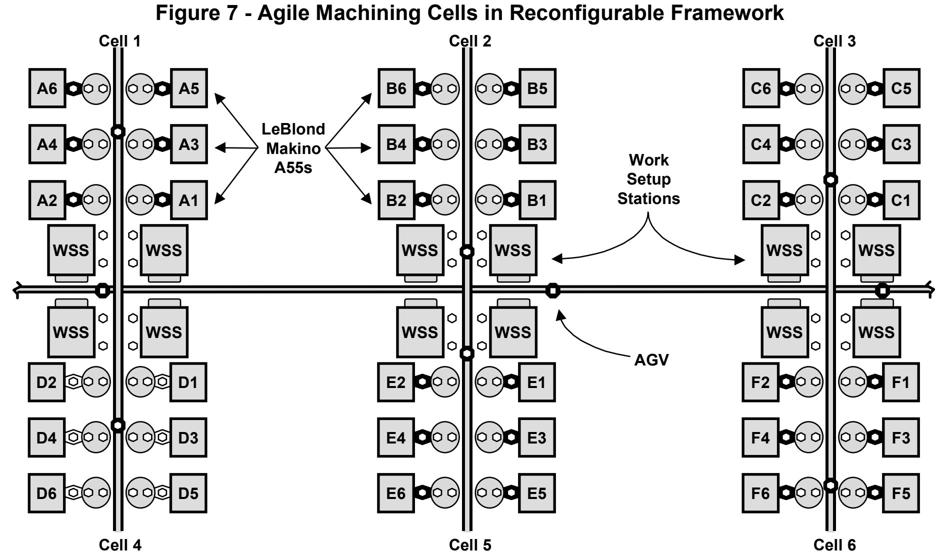
Scalable
- ☐ Flexible Capacity - Cell can accommodate any number of machines and up to four work setting stations.
- ☐ Redundancy - All modules are standard and interchangeable with like modules, cells have multiple instances of each module in operation, machines capable of duplicate work functionality.
- ☐ Evolving Standards - Utility services and vehicle tracks can be extended without restrictions imposed by the cell or its modules.

The depiction of the agile machining cell in Figure 6 includes a synopsis of some of the change proficiencies obtained by the configuration. Flexible machining cells have been implemented in many places, but the agile configuration here brings additional values. The configuration and the specific modules were chosen to increase the responsiveness to identified types of change. The LeBlond Makino A55 horizontal machining centers do not require pits or special foundations, so they are (relatively speaking) readily movable. A cell can increase or decrease its machining capacity in the space of a day and never miss a lick in the process. This is facilitated by a plant infrastructure of common utility, coolant, mechanical, and human interfaces that provide a framework for reconfiguring modules easily. These and other Reusable-Reconfigurable-Scalable system-design principles are detailed in the depiction.

It is accepted knowledge that replacement or massive retooling of a rigid production module is more expensive than transformation of a flexible production module. Now we see where agile system configurations can further change the economics to overcome an initial investment that has been higher. “Has been” should be stressed. The price/performance ratios of modular production units are becoming better as increased sales increases their production quantities.

Do not let the examples so far lead you to a wrong conclusion. Agile production requires neither agile nor flexible machines - for the agility is a function of how the modules of production are permitted to interact. An agile system must be readily reconfigurable, and may gain this characteristic by simply having a very large variety of compatible but inconsistently or infrequently utilized production units.

Figure 7 - Agile Machining Cells in Reconfigurable Framework



The toy industry is an example where this is a common approach. Not knowing from year to year what kind of toys the kids will want until a few months before volume deliveries are required, toy manufacturers are either highly vertically integrated (with poor resource utilization) or broadly leveraged on outsourced manufacturing potential. Agility is a relative issue - and the toy industry has few alternatives to either agile outsourcing or just-in-case vertical integration. As virtual production concepts mature to support agile outsourcing, this approach might become more proficient then the just-in-case captive capability alternative - unless of course those practitioners become proficient at insourcing other company's needs to cover the costs of their insurance base.

From the enterprise viewpoint an agile production capability can be built from a reconfigurable network of outsources, which is what we look at next.

4. Agile Enterprise and Agile Production

The agile enterprise is adaptable enough to transform itself proficiently into whatever the times require. At least, with the unpredictable and increased pace of change driving businesses out of business today, that is the salvation hoped-for by corporate management. They understand that business is not just about making money, it is also about staying in business. We used to think that making money was all it took to stay in business. Now we know that you can make money right up to the day you become irrelevant - then you are probably the last to know while you are ignored to death.

A corporation stays alive because customers continue to pay more for goods than the "real" cost of production. This excess payment is required to cover the cost of production inefficiencies (nothing is perfect), and the cost of preparing for new goods to replace ones that (eventually) lose favor. With increased global competition it is getting harder to fund these production inefficiencies: someone is always finding a better way to produce the same thing. With faster technological obsolescence it is getting harder to fund the preparation for new goods: reduced product life generates both less investment cash and a higher risk of investing in the wrong thing.

The profit making predictability of any company that wants to outlive its currently successful product family becomes more important and more difficult than ever. The marketplace grows less tolerant of mistakes and inefficiencies, and deep pockets are getting shallower. Borrowing from one successful area of a business to cover problems in another increases the threat to all.

Resources that were correct for customer satisfaction only yesterday may no longer be relevant today. With the increased risk to the entire business comes sharpened recognition that every internal resource must either be making profits today or insuring profits tomorrow.

The board room knows this, and business reengineering is proceeding accordingly. Most companies "leaned" out in the mid-'90s. Downsizing was the dominant strategy employed by companies seeking leaner operating modes, and outsourcing was the strategy for increasing responsiveness.

Nobody likes the downsizing process, but cost and skill mismatches threaten the viability of the entire corporation. When business picks up or new products enjoy high demand, these downsized corporations are not upsizing as they once would - instead they are seeking alternative ways to gain the necessary skills and capability without the inertia of captive resources. Consulting and professional-temp organizations are growing to fill the gap for managerial and professional help, contract manufacturing is providing new options for fluctuating production capacity, and outsourcing in general is broadening the capabilities and capacities available to a company on quick notice.

Successfully living with fickle markets and unpredictable technological change requires a higher frequency and freedom of resource reconfiguration than in the past. Looking at it from the corporate view, gaining new productive capacity as well as new productive capability through outsourcing has several potential advantages: short term requirements are not burdened with long term costs, capital investment and its associated risk are both eliminated, the learning curve to develop new production competency is eliminated, and unit costs may well be lower.

Contract manufacturers and outsource firms are thriving. At least the good ones are. They are focusing on areas where they have a high degree of competency, innovating in these areas to maintain leadership, organizing common-process production facilities applicable to a variety of manufacturing customers, and loosely coupling the elements of production so they can be reconfigured to meet demand fluctuations among their customers. Many reach advantageous scale economies by aggregating similar needs of multiple customers;

and in any event spread their risk over a broader base of market servers. Kelsey-Hayes is a prime example of all of these points.

On the internal production downside, operations in large corporations carry baggage filled by many captive years, generally lack local authority to invest in the future, and typically subsidize less effective sister operations.

At the corporate level, with or without a conscious corporate strategy, most companies are moving toward agility, some faster than others. They have no choice. Too much inertia impedes the ability to capitalize on market opportunities and handicaps the ability to bring innovation to fruition. The continued survival of any corporation demands a more agile operating capability, and most corporate strategies are following a path in this direction.

There are, however, many paths. We have previously looked at the paths that build agile production from agile machines and agile cells. Now we look at a path that builds agile enterprise from agile production; and we look from the corporate view where there are alternatives, if there is a will.

From the enterprise point of view, agile production is achieved when the makeup and relationships of the enterprise's production resources are easily adapted to the precise needs of the moment, and a fleeting moment it is.

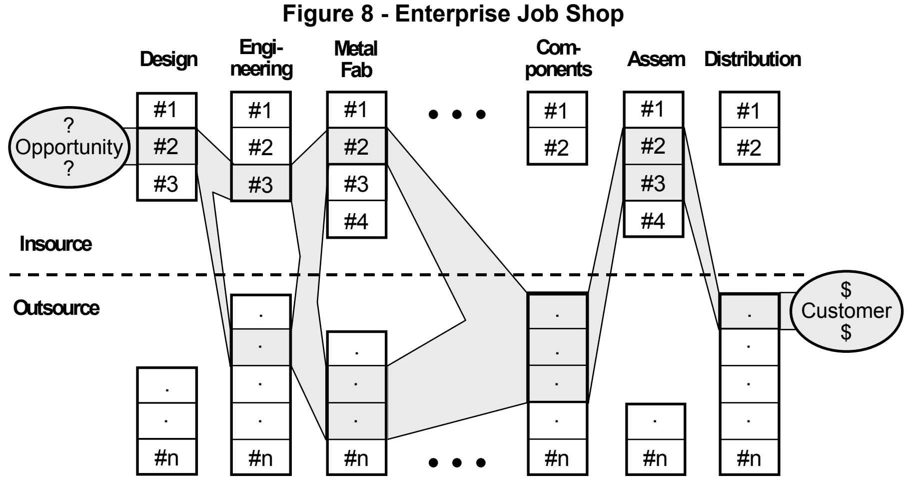
The internal strategy breaks the company into independent functional resource units that look like one big job shop (Figure 8) - where units bid on work based on their performance capabilities. Good performance is rewarded with lots of jobs, bad performance is starved to death, and the "system" is self-organizing. Some units learn and improve, others get traded out, shut down, or simply ignored to death. Subsidies are replaced with local profit responsibility and investment authority.

Nucor Steel decentralized decision making so much in the mid-90s that plant managers found their own raw materials, found their own customers, and set their own production quotas. Sure, there are efficiencies to be gained with centralized purchasing . . . and a crushing price to pay in overall corporate health. These are not lonely ideas, an irrefutable success base abounds. Nor are they simply another swing of the centralize-decentralize cycle seen in older corporations with history.

The external strategy recognizes that production resources do not necessarily have to be owned and captive, they only have to perform effectively when needed. Outsourcing and contract manufacturing enters the corporate mix of possibilities here (Figure 9). When a good system is set up these outside alternatives are not used as threats to distort internal costing, but rather as a self-organizing influence that brings best-in-class to the table. If management values the retention of captive resources it builds a system that levels the real difference over a reasonable time. Invariably this leads back to local responsibility and local authority. Internal units that must compete with best-in-class external alternatives are allowed to compete on an even basis. And by the same token, they are able to find other customers that will help maintain a balanced production rate, justify new capability investment, and inspire innovative leadership.

From the corporate point of view these liberated internal resources are incomparably stronger assets than they were as exclusive captives. Stronger as profit generators for the corporate coffers, and stronger as reliable best-in-class suppliers. A good system might institute a most-favored-nation relationship

Figure 8 - Enterprise Job Shop

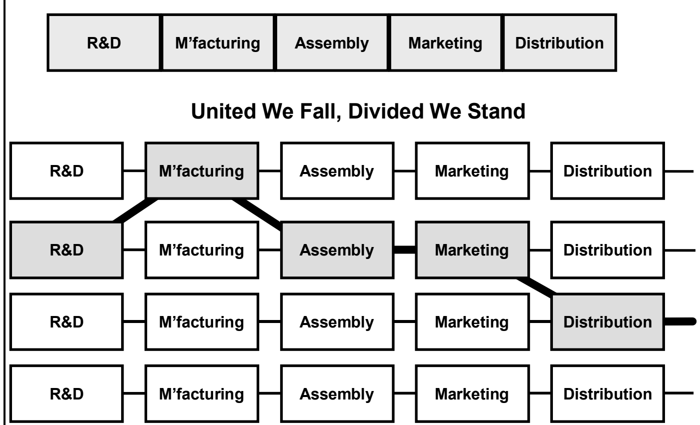


Resources Bid on Opportunity Fulfillment with some group profit sharing plans as the ties that bind. Large partner-based organizations like Andersen Consulting offer interesting models here.

So what is a plant manager to do if stuck in a corporate environment where the agility decisions are being made at the higher levels. A plant manager, with hands tied, is liable to (is likely to) see the outsourcing alternatives favored. Think about it - we all know it is cheaper to get it ready-made elsewhere than it is to re-tailor the resources we have. We must, observation says that this is human nature.

So a plant manager could go take a job with one of these outsourcing firms that has all the advantages. Some have. Some keep marching with their heads down figuring they will retire before the inevitable happens. A few might see the inherent advantage that an internal resource has with the corporation if it is an irresistible member of the family.

Figure 9 - Loosely Coupling the Enterprise



People get downsized, plants get outsourced. But nobody outsources a plant that can respond to the changing corporate needs; just as nobody downsizes the employee that keeps one step ahead of the employer's needs.

Viable business entities are those that can keep up with the mercurial markets that are only going to get more slippery. The agile enterprise is an imperative, and it will happen with or without captive agile plants. But those that have agile plants will have a more robust and broader scope foundation.

You can build an agile system out of rigid in-agile modules by considering those modules expendable. Thus, you can have an agile enterprise composed at any one time of in-agile production facilities, wholly un-owned and virtual, and replaceable at whim and will. But when the enterprise includes captured and enduring business units, the agility of each captured unit becomes important to the agility of the total enterprise. If they are rigid rather than agile, they become defining anchors. They must either be agile enough to transform as needed when needed, or they too must be replaced. And replacing an owned unit, unlike an outsourced unit, is a change transformation that extracts a toll.

When Rrs design principles are employed, replacement of a rigid module is more expensive than transformation of an agile module. Thus, it costs more to fire and hire than it does to retrain (an agile person). Of course, if you are dealing with a contract employee, one you do not own and can consider expendable, than you have our other model of an agile system.

Plant management that waits for the corporate light to go on may see it shine in a different room. As a newscaster in San Francisco used to say: "If you don't like the news, go out and make some of your own". Agile production is not dependent on machinery and capital investments - as the corporate alternatives clearly show. Good application of Rrs principles with people, organization, and practices can make a decisive difference in the response ability of any plant before the corporate strategists consider the options.

5. Design Principles For Agile Production

We have been exploring the nature of agility in production systems and occasionally the enterprise systems that encompass them; making the argument more than once that agility is a characteristic which emerges from design. Behind each of these systems are “business engineers” responsible for the system’s design - consciously or unconsciously as the case may be.

Good engineering is applied science. Some would argue about management as science, and others believe a manufacturing science remains elusive. Nevertheless, the design of manufacturing enterprise systems, from production process to business procedure, can result in a more or less adaptable system to the extent that certain design principles are employed. The expression of Rrs design principles explored in three production systems (Figure 10) is assembled in Figure 11 in tabular form, showing various applications.

Science is born from gathering data, analyzing this data for patterns, making hypothesis on principles, and iterating toward validation. The ten principles employed here have been discovered, refined, and validated in numerous analytical exercises [6]. We have found useful repeatable patterns that appear to govern adaptability. Methods for conducting change proficiency analysis in your production environment, and building customized change proficiency maturity profiles of your competitive agility can be found in "Response Ability - Understanding the Agile Enterprise" [7].

Few would disagree that information automation systems are critical enablers for modern production; but what will the information automation system do to support an agile operating environment? Perhaps more importantly, what will make the system itself agile so that it can continue to support an agile operating environment rather than guarantee its obsolescence? Are there fundamental characteristics that provide agility that we can look for in selecting information automation systems?

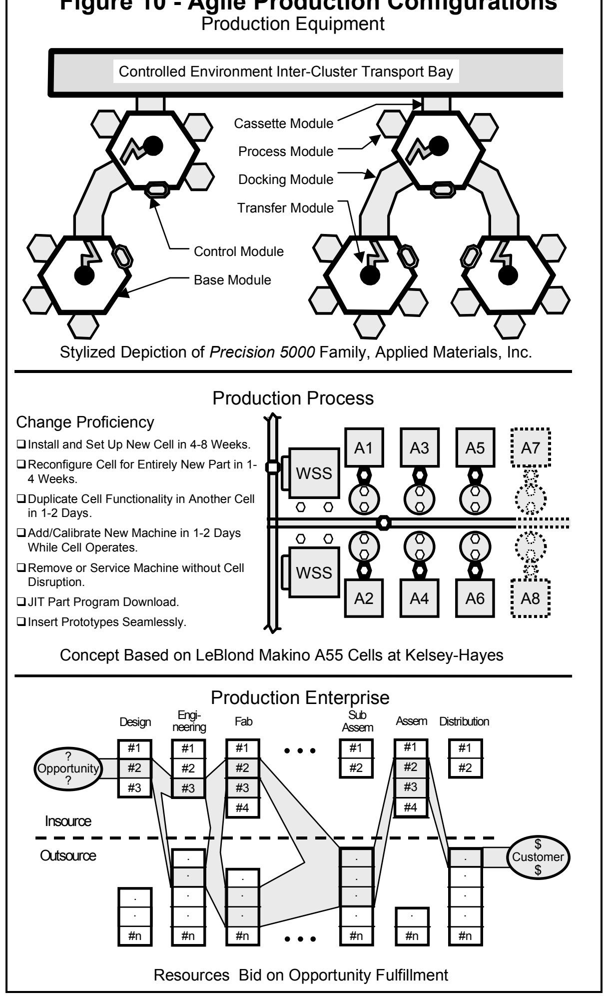
Adaptability (agility) actually became a reasoned focus with the advent of object-oriented software interests in the early '80s. The progress of software technology and deployment of large integrated software systems has provided an interesting laboratory for the study of complex interacting systems in all parts of enterprise. The integrated software system, whether it is in the accounting area, providing management decision support, or spread over countless factory computers and programmable logic controllers, is understood to be the creation of a team of programmers and system integrators. We recognize that these people also have the responsibility for ongoing maintenance and upgrade during the life of the system. In short, the integrated software system is the product of intentional design, constant improvement, and eventual replacement with the cycle repeating.

As engineering efforts, the design and implementation of these integrated software systems proceeds according to an "architecture", whether planned or defacto. By the early eighties the size and complexity of these systems grew to a point where traditional techniques were recognized as ineffective. This awareness came from experience: from waiting in line for years to get necessary changes to the corporate accounting system; from living with the bugs in the production control system rather than risk the uncertainty of a software change; and from watching budgets, schedules, and design specifications have little or no impact on the actual system integration effort.

The problem stems from dynamics. Traditional techniques approach software design and implementation as if a system will remain static and have a long and stable life. New techniques, based on "object oriented" architectures, recognize that systems must constantly change, that improvements and repairs must be made without risk, that portions of the system must take advantage of new sub-systems when their advantages become compelling, and that interactions among subsystems must be partitioned to eliminate side-effects.

These new approaches have been maturing for almost two decades now, and have emerged most visibly into everyday employment under the name client-server architecture. Though there are significant differences between systems concepts called client-server and those called object-oriented, “encapsulated” modularity and independent functionality are important and shared key concepts. More to the point, information automation practitioners are now focusing a good deal of thought on the architectures of

Figure 10 - Agile Production Configurations



systems that accommodate change; providing a rich laboratory and experience base from which fundamental agile-system principles are beginning to emerge.

The ten Rrs design principles introduced earlier and tabulated in Figure 11 grew from object-oriented concepts, and have since been augmented with understandings from production and enterprise systems which exhibit high degrees of adaptability.

Figure 11 - RRS Design Principles Employed in Agile Production Configurations

RRS	Design Principles	Production Equipment (Cluster Machines)	Production Process (Agile Machining Cell)	Production Enterprise (Enterprise Job Shop)
Reusable	Self Contained Units: System of separable self-sufficient units not intimately integrated. Internal workings unimportant externally.	Wafer transfer module, various process modules, docking module, cassette transfer module, utility-base module.	Machines, work-setting stations, pallet changers, fixtures, rail-guided vehicles.	Design, engineering, fabrication, sub-assembly, assembly, and distribution resource modules.
	Plug Compatibility: System units share common interaction and interface standards, and are easily inserted or removed.	Common human, mechanical, electrical, vacuum, and control system interfaces.	Common human, mechanical, electrical, and coolant system interfaces. Common inter-module mechanical interfaces.	Common info system and procedures among captured corporate resources, common interface in outsourcing contracts.
	Facilitated Re-Use: Unit inventory management, modification tools, and designated maintenance responsibilities.	Machine manufacturer extends/replicates module family for new capabilities. Fast module-swap maintenance is facilitated.	Machines do not require pits or special foundations, and are relatively light and easy to move.	Corporate outsourcing department maintains pre-qualified pool of potential outsources.
Reconfigurable	Non-Hierarchical Interaction: Non-hierarchical direct negotiation, communication, and interaction among system units.	Processing modules decide how to meet part production objectives with closed-loop controls.	Complete autonomous part machining, direct machine-repository download negotiation.	Business unit resources free to bid on internal jobs and external jobs.
	Deferred Commitment: Relationships are transient when possible; fixed binding is postponed until immediately necessary.	Machine custom configured with processing modules at customer installation time.	Machines and material scheduled in real-time, downloaded part programs serve individual work requirements.	Individual business unit assigned to opportunity fulfillment at last possible moment.
	Distributed Control & Information: Units respond to objectives; decisions made at point of knowledge; data retained locally but accessible globally.	Intelligent process modules keep personal usage histories and evolving process characterization curves.	Part programs downloaded to machines, machine history kept in machine controller, machines ask for work when ready.	Enterprise integration information system queries data bases local to the business unit.
	Self Organizing Relationships: Dynamic unit alliances and scheduling; open bidding; and other self-adapting behaviors.	Real-time control system makes use of processing units available at any given time, scheduling and re-routing as needed.	Cell control software dynamically changes work routing for status changes and new or removed machines on the fly.	Bid-based production-flow alliances.
Scalable	Flexible Capacity: Unrestricted unit populations that allow large increases and decreases in total unit population.	Machines can be interconnected into larger constant-vacuum macro-clusters.	Cell can accommodate any number of machines and up to four work-setting stations.	Outsourced resources can be easily added or deleted to increase the population of production modules with no size restrictions.
	Unit Redundancy: Duplicate unit types or capabilities to provide capacity fluctuation options and fault tolerance.	Machine utility bases are all identical, duplicate processing chambers can be mounted on same base or different bases.	Cells have multiples of each module, all cells made from same types of modules, machines have full work functionality.	Multiple duplicate production resources and second-outsources.
	Evolving Standards: Evolving, open system framework capable of accommodating legacy, common, and completely new units.	Base framework becoming standard across vendors, and has accommodated processing technology across generations.	Utility services and vehicle tracks can be extended without restrictions imposed by a cell or its modules.	Enterprise integration Information system is open architecture, client-server based.

The choice of terminology for these ten principles is important. Would-be users far removed from systems engineering or computer technology may find some words used to describe these principles too abstract at first. For instance, the first principle was initially called encapsulated modules. A human resources director suggested the more generic self-contained units, which he could readily translate into empowered work team.

The Rrs design principles identified here are presented as a useful working set that will undergo interpretation and augmentation with use and mastery. Their value is in their universal applicability across any system that would be adaptable. Instead of simply lurching to the next competitive state, Rrs design principles facilitate continuous evolution.

Next we will look at two real-life case studies that were captured and cataloged during analytical workshops conducted in mid-1997 [6]. The purpose of these workshops was to analyze production activities that exhibited high degrees of adaptability - and to look for evidence of the ten Rrs principles in action.

6. Case Study: Assembly Lines - Built Just in Time

You work in a GM stamping plant outside of Pittsburgh that specializes in after-model-year body parts. Your principal customer is GM's Service Parts Organization. They might order '73 Chevelle hoods quantity 50, '84 Chevy Impala right fenders quantity 100, or '89 Cutlass Supreme right front doors quantity 300. Your plant stamps the sheet metal and then assembles a deliverable product. Small lots, high variety.

Every new part that the plant takes on came from a production process at a GM OEM plant that occupied some hundreds of square meters (thousands of square feet) on the average; and the part was made with specialized equipment optimized for high volume runs and custom built for that part geometry. To stamp a new deck lid (trunk door) part you bring in a new die set - maybe six or seven dies, each the size of a full grown automobile, but weighing considerably more. And you bring in assembly equipment from an OEM line that might consist of a hemmer to fold the edges of the stamped metal, perhaps a pre-hemmer for a two-stage process, dedicated welding apparatus for joining the inner lid to the outer lid, adhesive equipment for applying mastic at part-specific locations, piercer units for part-specific holes, and automated custom material handling equipment for moving work between process workstations.

You got a call a few weeks ago that said your plant will start making the Celebrity deck lids, and production has to start in 21 days. Not too bad - sometimes you only have four days. For new business like this your job is to get the necessary assembly equipment from the OEM plant, reconfigure the equipment and process to fit your plant, and have people ready to produce quality parts in the next three weeks. Others are responsible for the die sets and stamping end of the production process.

In the last 12 months this happened 300 times. In the last five years you have recycled some 75,000 square meters (800,000 square feet) of floor space in OEM plants for new model production. At this point you have assembly equipment and process for some 1000 different parts - but no extra floor space ever came with any of it.

And no extra floor space materialized in your plant either. Good thing you have not needed it - the core competency here is rapid new-part starts, and small-lot, high-variety production - in a business that is traditionally based on high volume economics - and you have learned to do it without the usual capital budget. Eight years at this has evolved some pretty unique techniques - and a pretty unique culture as well.

You do not do this by yourself - you are a team leader that may use almost anyone from anywhere in the plant. At this point almost everyone is qualified to help bring in new work - surviving under these conditions has developed a self confident attitude almost everywhere, and a shared understanding of how to get the job done.

Eight years ago the plant went to a single job classification in production, cross training everyone on everything - a press operator one day might change dies as well, the next day work in the assembly area building hoods in the morning and fenders in the afternoon - and the following day go off to another plant to review a piece of equipment or part for how to bring it back.

For this new business one of the guys on the last recon team wants to lead this one. Last time he experimented with his video camera. Now he thinks he is ready to do a perfect taping job. He got the idea himself on that last job while trying to bring several jobs at once back from another GM facility. This environment encourages self initiative.

In addition to taping the operational assembly process he added close-ups of key equipment pieces this time. In the debrief review everyone saw the same thing at the same time - there was almost no debate over what to bring back and what to ignore - and you got a jump on the equipment modifications by seeing what was needed in advance. Some time ago the value of having a good cross section represented in these reviews became evident: nobody gets surprised, everyone shares their knowledge, and when the equipment arrives the modification team is prepared.

Two keys at this stage: knowing what to bring back and knowing what modifications to make.

This new deck lid would be handled by bringing back the hemmer only; ignoring the mastic application machine, two welding robots, the welding fixtures, two press piercers, the shuttles, the press welders, and the three automated material handling fixtures. Basically bringing back a foot print of 19 square meters (200 square feet) from a process that covered 230 square meters (2500 square feet). The rest will go to salvage disposition while the hemmer goes to "hemmer heaven" - that place in your plant where some 200 different hemmers hang out until needed.

That you only need the hemmer is where a key part of the plant's unique core competency comes into play. Rather than build a growing variety of product on some sort of omnipotent universal assembly line, a line that grows to accommodate next year's unpredictable new business as well as the last ten-to-twenty years of legacy parts, this plant builds a custom assembly line for each product - and builds that assembly line just before it runs a batch of, say, 300 hoods. When the hoods are done you tear down the assembly line and build another one for fenders, perhaps, on the same floor space - and then run 500 or so fenders. Tear that down and build the next, and so forth. The same people that built the hoods build the fenders, and the deck lids, and the doors, and the .... and tomorrow some of them will be running a press, changing press dies, or running off to evaluate the next incoming equipment opportunity.

Necessity is the mother of invention - and the driving force here is the unrelenting requirement to increase product variety - without increasing costs or making capital investments. But fundamentally, for assembly, the scarcest resource is floor space.

Yes - a newly built customized assembly line for each and every small-batch run, every time, just in time.

The plant has six assembly areas, and can build any part in any of those areas. Usually you like to do the deck lids in the "A" area, though, as it has the most flexibility for welding.

While you were waiting for that new hemmer to arrive you got the process system configuration designed. Usually the same two people do this working as a team. Once they figure out which assembly modules are best and how they should be spaced, they put together a configuration sheet (Figure 12) for the assembly system by cutting and pasting standard icons for each module, and running it through the copy machine. The development of these configuration sheets themselves are another example of simple reconfigurable system generation.

It was not always this easy, but you have learned a lot over the years. You build these assembly systems according to these one-page configuration diagrams kept in a three-ring binder - in real-time from reusable modules. Modules are easily moved into place and they share common interface standards and quick disconnects. On the average it takes about 15 minutes to break down the last assembly system and configure the next one.

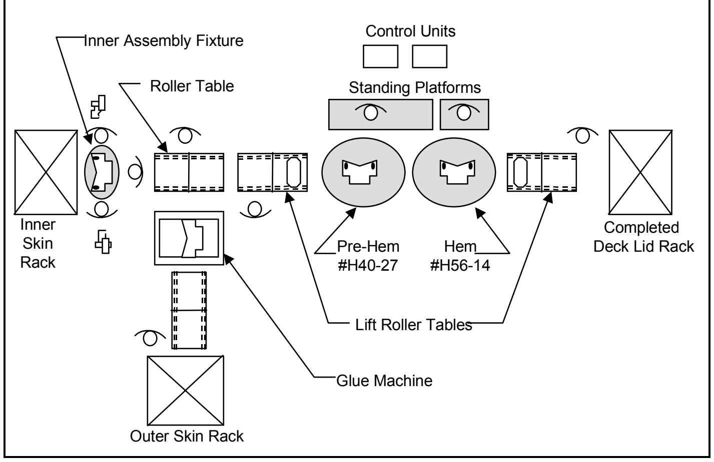
First rule: Nothing is attached to the floor permanently. If it can not be lifted and carried easily by anybody it will have wheels on it, or as a last resort, fork-lift notches.

A typical deck lid assembly sequence might hem the outer skin, mastic some cushioning material to the inner skin, then weld a brace into place, and finally weld the inner skin to the outer skin in 30 places. In the process the material has to be turned over once and some gauging is done. The assembly system configuration might call for two 1 meter (3 foot) long roller tables in the front to receive the inner and outer pieces - think of these as hospital gurneys, on wheels, with rollers on top so the "patient" can be rolled across the table to the next station when the designated operation is complete. Next in line for the outer skin is the hemmer - it is on wheels too, and it is quick-connected to a standard controller off on the side out of the way. Yes, the controller is on wheels too. The outer skin is lifted into the hemmer with the aid of an overhead TDA Buddy - one advantage of doing lids in the "A" area: two TDA Buddies hang from the ceiling grid. When deck lids are assembled in another area a variant of the roller table is used that includes lifting aids. After hemming, inner and outer skins move to roller tables under the welding guns. The configuration sheet shows how many guns are active, where to position them, and which tip variant to install. All told there might be 12 simple icons on the sheet positioned in a suggested geometry.

A hemmer is a very specialized piece of machinery. When it comes to this plant it loses most of its specialness - and becomes plug compatible with all the other modules in the just-in-time assembly family. Importantly, the hemmer's integrated controls are removed and quick-connect ports installed to interface with the one standard electronic/hydraulic controller used for all hemmers. It is modified if necessary to work with one of the six standard control programs. Maybe a seventh will be added some day, but six has covered all needs so far. Finally, the set-up sequence for the hemmer is typed up and attached to its side - better there than in a file drawer.

Hemmers are pooled in hemmer heaven awaiting their time in the assembly area - each one being individually part specific. Other pools hold variants of standardized modules that have use in multiple assembly systems: twelve different types of roller tables, two types of quick-connect weld guns, three types of weld tips, one standard controller type, six standard downloadable controller programs, and other reusable standardized items.

Figure 12 - Configuration Sheet: P14 Deck Lid Assembly Line



Whatever the configuration sheet shows is quickly carried, rolled, or forked into place, quick-connected or downloaded if required, and ready for action. The assembly area has an overhead utility framework that enables the adaptability below; providing tracked weld-gun hookups, quick-connect power and air, light, and water. The operating atmosphere is not unlike the hospital operating room - except patient throughput is a lot faster - fast enough in this case to satisfy service parts economics.

It is common for production team members to make real-time changes to the configuration when they find a better way - better is better, and everyone knows what that means.

Rule two: People rule. These assembly systems take advantage of the fact that people think better and adjust better than automated positioning devices, cast-in-stone configuration sheets, and ivory-tower industrial engineers. People bring flexibility when they are enabled and supported, but not constrained, by mechanical and electronic aids.

There is lots more in this vein here that is equally thought provoking. Next we will look at a completely different lesson in innovative adaptability from this same plant - and see where common concepts emerge.

7. Case Study: Fixtures Built While You Wait

We are still in Pittsburgh, at the GM service-parts metal-fabrication plant. We have already looked at their just-in-time assembly concept. Now we will look at a check-fixturing technique for auto-body-part contour verification. Two very different aspects of production - both exhibiting uncommonly high degrees of adaptability.

Is there a common set of design principles responsible for this adaptability? A warning: we are going to look pretty closely at the architecture of this check fixture concept . . . and there will be a test later.

Picture this - a room about 9 by 12 meters (30 by 40 feet). In the middle, on the floor, is a 3 by 7 meter (9 by 23 foot) cast iron slab 30 cm (1 foot) thick. You can not see much of this slab because it is mostly covered with four smaller plates of aluminum, each approximately 1 by 2 meters (3 by 7 feet) and 10 cm (4") high. These plates are punctured by a pattern of holes on a 55 mm grid; looking like an industrial strength Lego sheet, just waiting for some imaginative construction.

Actually, some construction appears to have started. Maybe 75% of this grid is covered by swarms of identical little devices called punch retainers - in no discernable pattern. Ten or twelve are grouped together in one place, twenty or so in another, six or eight somewhere else - maybe 40 islands all told on this Cartesian sea. It turns out that these groupings have evolved over six years of use, and continue to grow as new retainers are occasionally added to the collage - slow motion art.

Referring the figure 13, a punch retainer looks like a metal cam - sort of a triangle with rounded points, and about 4 cm (1.5") thick - almost as high as it is wide. You lay it down flat on its side and bolt it to the grid; and thereby establish a virtually perfect repeatable coordinate position - with a quick disconnect socket.

A few of these true-position sockets have a 5/8ths diameter drill rod sticking straight up out of them, all with different lengths, most with a positioning detent and a spring clamp to hold a sheet metal part against the detent. They are called details - these rods with clamps and detents.

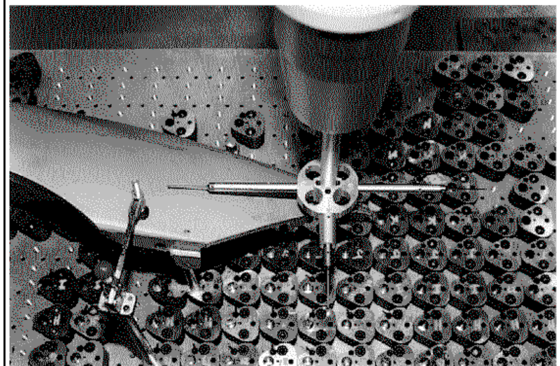
Remember that cast iron slab? On both sides of this slab are cantilevered rails supporting two traveling coordinate measuring machines. These two Zeiss CMMs are program driven and can each can reach anywhere in the full space. Each base plate has a spherical 3-axis reference point fixed to it. The machines find these reference points in preparation for measuring relative distances thereafter.

So now the phone rings. Bill picks it up, listens, grunts affirmative, hangs up, and yells to his partner Bob. An '85 Pontiac left front fender is coming in hot off the press - and needs an immediate check.

Now they swing into action. Bill goes over to one of the four base plates, inserts a stiff wire into a hole in one of the retainers, and removes the unlocked detail rod. He repeats this process a dozen times in the next 45 seconds, placing each of the freed details in a blue plastic container about the size of a shoe box. We know its 45 seconds because Bob has been looking at his watch the whole time.

Bill disappears with the container into a side room. In here is a shelving unit that holds 540 identical containers in labeled rows and columns. Bill puts the one he has into its home slot, reads slot labels until he finds the new one he needs, and returns with a new blue box in hand. This adds another 45 seconds to the time. We know because Bob has finished his first cup of coffee now.

Figure 13 - Pittsburgh Universal Holding Device



Bill heads over to the base plate while Bob heads over to the coffee pot. Bill removes one detail from the blue box and examines it - he notes the coordinate position stamped into the bottom of the holding detail, and inserts it into the corresponding retainer. In two minutes flat he has placed 14 details into their respective coordinate locations. We know its two minutes because Bob's coffee break just ended - just in time for him to open the door as the fender arrives. He points the guy toward Bill.

Three and a half minutes after the phone call, Bill clamps the fender into the newly-constructed holding fixture and enters the fender code into the Zeiss console. Bob presses the start button and the verification begins.

Remember that side room - the one with the 540-slot shelving? When you figure the 6 x 0.6 meter (20x2 foot) foot-print of the shelf space and add a reasonable access aisle you find that details for 540 check-fixtures need 11 square meters (120 square feet). Add to that the 1x2 meter (3x7) foot holding device base plate and you have less than 14 square meters (150 square feet) tied up for 540 checking fixtures. The existing side room is mostly empty and could easily accommodate three times the shelf capacity.

There is nothing magic about those base plates. You can put one on a cart and take it to a press on the floor and check a part every 60 seconds. Not with the Zeiss machine - with traditional gauges.

Bill and Bob invented this concept while car pooling to work together. They call it the Pittsburgh Universal Holding Device. They are die-makers by background - and a product of the innovative take-charge culture at GM's Pittsburgh plant. We caught Bob on his coffee break so that you could see that a single person is all that is needed to accomplish the actions.

Remember the part about the test? Re-read the last case study again - the one about the assembly system, and then this one again. The workshop conducted at GM dissected this check-fixturing concept and cataloged the design characteristics as shown in Figure 14. Can you find the same principles at work in the assembly system - and catalog the design characteristics similarly?

This case study is not about check fixturing - it is about generic design principles for making any production process or business practice highly change proficient - able to turn on a dime at a moment's notice.

With close examination of the example you might notice that the contents are not pure - there is a mixture of multiple "system" levels. The Zeiss machines, for instance, are not really a part of the check fixture system, but rather a part of the next higher level system: contour verification. Similarly, the detents and clamps on the drill rods are a part of a lower-level holding system. For our purpose here the distinction is not important - clear system definition becomes

Figure 14 - Pittsburgh Universal Holding Device: Systems Design

System(s)	Body-part contour check fixtures.
Framework	Base plate coordinate gridwork, 4x8x12 container shelving, 5/8ths punch retainer.
Modules	Zeiss Machines, base plates, punch retainers, containers, fixture details, drill rods, detail clamps, detail detents.

Principles Observed in System Design

Self Contained Units: System composed of distinct, separable, self-sufficient units not intimately integrated. • Base plates. • Containers • Retainers. • Shelf Slots • Details.	**Flexible Capacity:** Unrestricted unit populations that allow large increases and decreases in total unit population. • Base plate can be extended to any size. • Unlimited shelving can be added. • Details for large/complex fixture could occupy multiple containers.
Plug Compatibility: Units share common interaction and interface standards, and are easily inserted/removed. • Standard retainers bolted to base plate. • Coordinate gridwork. • 5/8ths drill rods inserted in retainers. • Common form factor containers in shelving slots.	**Unit Redundancy:** Duplicate unit types or capabilities to provide capacity fluctuation options and fault tolerance. • Base plates. • Retainers. • Blue containers. • Multiple CMM machines. • Shelf slots.

Facilitated Re-Use: Unit inventory management, modification tools, and designated maintenance responsibilities.
• "Zeiss Room" personnel are responsible for obtaining/maintaining:
  • Pool of common retainers.
  • Common off-the-shelf shelving.
	Evolving Standards: Evolving, open system framework capable of accommodating legacy, common, and completely new units.
	• Base plate can be any size or shape.
	• Retainers are installed as needed when needed.
	• Can use with traditional layout table and gauges as well as CMMs.

Non-Hierarchical Interaction: Non-hierarchical direct negotiation, communication, and interaction among system units. • None noted.	**Distributed Control & Information:** Units respond to objectives; decisions made at point of knowledge; data retained locally but accessible globally. • Coordinates stamped on rods.
Deferred Commitment: Relationships are transient when possible; fixed binding is postponed until immediately necessary. • Reference sphere provides real-time zero point. • Rods inserted in retainers when fixture needed. • Retainers bolted to plates as needed when needed.	**Self Organizing Unit Relationships:** Dynamic unit alliances and scheduling; open bidding; and other self-adapting behaviors. • Reference sphere provides real-time zero point.

important when the principles are used to design new systems.

8. Capturing and Displaying Principles in Action

Virtually every business unit within a company has a few practices that exhibit high change proficiency. Typically these competencies emerge as necessary accommodations to an unforgiving operating environment. Maybe it is the ability to accommodate frequent management changes - each with a new operating philosophy. Or the production unit that automatically tracks a chaotically changing priority schedule. Or the logistics department that routinely turns late production and carrier problems into on-time deliveries. It might be a purchasing department that never lets a supplier problem impact production schedules. Or an engineering group that custom designs a timely solution for every opportunity or problem.

Every business unit has its own brand of tactical chaos it manages to deal with - intuitively - implicitly - routinely - automatically - without explicit process knowledge rooted in change proficiency. Yet at the same time virtually every business unit today is facing strategic challenges that cry out for this same innate competency.

What are the common underlying principles at work in these implicitly managed tactical successes? Can the enabling factors for these successes be abstracted and reapplied to other areas of the business? More importantly, can these successes become wide-spread role models that communicate these enabling factors at the depth of insight across the corporation?

Metaphors have a great power to create and communicate insight. The trick is to find a meaningful metaphor that can transfer this leverageable knowledge among a specific group of people. Workshops structured to analyze highly adaptable practices for their underlying change-proficiency enablers have been effective at this when they packaged their conclusions as metaphors [6].

The structured analysis process builds a model of the change proficiency issues (proactive and reactive response requirements) and the architecture (reusable modules, compatibility framework, system engineering responsibilities). Then this architecture is examined for local manifestations of the ten Rrs design principles. The combined result produces a local metaphor model for change proficiency - local in that it is present at the plant site and respected intuitively for its capabilities - metaphor model in that the analysis explicitly illuminates common underlying principles responsible for this change proficiency.

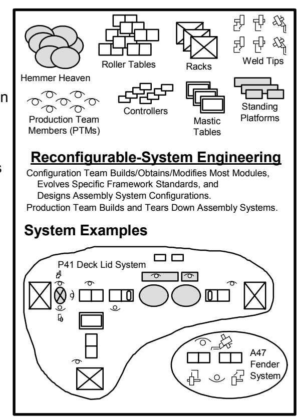
For example, the local metaphor model shown in Figure 15 synopsizes the underlying principles at work in the case study of the just-in-time assembly line - and graphically depicts the concept of assembling reconfigurable systems from reusable modules. When coupled with the case study description this tool can be employed outside the local environment as well.

Figure 15 - Local Metaphor Model: Small-Lot Assembly Lines

Change Proficiency

Key Proactive Issues:
Creation:
Assembly line construction
Improvement:
Space productivity
Migration:
New performance metrics
Addition/Subtraction:
PTM staff changes

Key Reactive Issues:
Correction:
Labor/mgmnt relations
Variation:
System set-up time
Expansion:
Space availability
Reconfiguration:
Flexibility culture



Reusable Modules:
- Cross-trained PTMs (Production Team Members)
- Roller tables
- Weld tips
- Hemmers
- Controllers
- Mastic tables
- Racks
- Standing platforms
- Et al ....

Compatibility Framework:
- Overhead support grid
- Physical space
- Utility standards
- System compatibility rules
- Unit compatibility rules
- Plant flexibility culture
- Local union contract

Selected Observations of System Design Principles	
Self Contained Units: System composed of distinct, separable, self-sufficient units not intimately integrated. • Hemmers with set-up data sheet, quick-disconnect sockets, and wheels. • Modules enumerated above plus: Standard control programs, multiple assembly areas, special fixtures, mastic templates, weld guns.	**Flexible Capacity:** Unrestricted unit populations that allow large increases and decreases in total unit population. • Number of simultaneous assembly configurations limited only by assembly area space availability. • Number of modules limited only by contiguous storage space availability and access logistics for remote warehousing.
Plug Compatibility: System units share common interaction and interface standards, and are easily inserted or removed. • Unit Compatibility Rules (hemmers): no integrated controllers, standard controller interface, use 1 of 6 standard controller programs, common piping/wiring, quick disconnect fittings. • System Compatibility Rules: Nothing attached to the floor, everything carry/roll/fork portable, etc.	**Unit Redundancy:** Duplicate unit types or capabilities to provide capacity fluctuation options and fault tolerance. • Eight identical controllers. • Cross-trained production team with one work classification. • Multiples of roller tables, mastic machines, standing platforms, racks, weld guns, weld tips, assembly areas, etc.
Facilitated Re-Use: Unit inventory management, modification tools, and designated maintenance responsibilities. • Configuration Team has responsibility for hardware/software module acquisition/modification/maintenance/inventory and for evolution of associated compatibility framework. • Management & Union share joint responsibility for PTM classification and cross-training.	**Evolving Standards:** Evolving, open system framework capable of accommodating legacy, common, and completely new units. • Used to leave useless wiring/switches/etc on incoming hemmers, now strip all un-used legacy items to eliminate maintenance confusion. • TDA Buddies added to overhead support grid in Area A. • Intuitive flexibility culture is now being explicitly formalized.
Non-Hierarchical Interaction: Non-hierarchical direct negotiation, communication, and interaction among system units. • Production Teams free to make process changes w/o seeking permission or approval. • Free communication permitted and encouraged among: tradesmen, engineer, supervisor, and customer.	**Distributed Control & Information:** Units respond to objectives; decisions made at point of knowledge; data retained locally but accessible globally. • PTMs (Production Team Members) make real time decisions on process configuration improvements and changes. • Operation sequence sheet attached to hemmer (facilitating easy movement to anywhere in the plant).
Deferred Commitment: Relationships are transient when possible; fixed binding is postponed until immediately necessary. • Process lines assembled JIT for production. • New-part acquisition/transfer team is not designated until a transfer opportunity requires action.	**Self Organizing Unit Relationships:** Dynamic unit alliances and scheduling; open bidding; and other self-adapting behaviors. • People show initiative in solving problems and making operating improvements on their own - because risk is encouraged and occasional failure is expected.

Biography

Rick Dove is Chairman of Paradigm Shift International (www.parshift.com), an enterprise research and guidance firm. In 1991 he co-chaired the 21st Century Manufacturing Enterprise Strategy project at Lehigh University - the industry led effort responsible for today's interest in agility. Subsequently, as the Agility Forum's first Director of Strategic Analysis, he established its initial research agenda and industry involvement structure. He has developed structured assessment and maturity-modeling concepts and processes used for strategic planning and analysis of change-proficiency, and for guiding management through a knowledge development and transfer process. He is a contributor to corporate management training and development courses, a key-note speaker internationally, and conducts seminars and workshops for industry and corporate groups. His book "Response Ability - Understanding the Agile Enterprise", to be published in early 2000 by Wiley, provides the first analytical techniques and models for agile enterprise assessment and strategy development. Prior to his interest in Agility and change proficiency, Dove led companies, raised venture funding, and founded and fixed companies in the systems integration, office products, software, computer, and food processing industries.

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