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THE BENEFITS OF LEAN MANUFACTURING
What Lean Thinking has to Offer the Process Industries

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How many people in the manufacturing industry can truly say that they have not heard of LEAN? Not many. Yet how many of these believe in lean, have implemented lean, are the passionate change agents who have convinced senior stakeholders than lean is the way forward for their company? Less. Much Less. Lean is a revolution—it isn't just about using tools, or changing a few steps in our manufacturing processes—it's about the complete change of our businesses—how the supply chain operates, how the directors direct, how the managers manage, how employees—people—go about their daily work. Everything. So what is this revolution, and how is it impacting the process industries? The background of lean thinking is based in the history of Japanese manufacturing techniques which have now been applied world-wide within many types of industry.

Keywords: lean manufacturing; waste; value; flow; value stream; bottleneck.

A BRIEF HISTORY OF 'LEAN'

Mention 'lean' and most 'lean thinkers' will know that this is a reference to the lean production approach pioneered by Toyota but also the subject of *The Machine that Changed the World* (Womack *et al.*, 1990); a book which first highlighted Japanese production methods as compared to traditional Western mass production systems; it also highlighted the superior performance of the former. The follow-on book, *Lean Thinking: Banish Waste and Create Wealth in your Organisation* (Womack and Jones, 1996), is equally a key step in the history of lean as it summarizes the lean principles which 'guide action'. It also coined the phrase 'Lean Production'.

But let's go back to the beginning—the birth of lean was in Japan within Toyota in the 1940s: The Toyota Production System was based around the desire to produce in a continuous flow which did not rely on long production runs to be efficient; it was based around the recognition that only a small fraction of the total time and effort to process a product added value to the end customer. This was clearly the opposite of what the Western world was doing—here mass production based around materials resource planning (MRP) and complex computerized systems was developing alongside the mass production philosophies originally developed by Henry Ford, i.e., large high volume production of standardized products with minimal product changeovers.

Taiichi Ohno had started work on the Toyota Production system in the 1940s and continued it's development into the late 1980s unhindered by the advancements in computers which had allowed mass production to be further 'enhanced' by MRP Systems. By the 1970s Toyota's own supply base was 'lean'; by the 1980s their distribution base was also 'lean'.

Key tools and techniques within the 'lean' system, included:

- Kanban—a visual signal to support flow by 'pulling' product through the manufacturing process as required by the customer.
- 5 S's—a visual housekeeping technique which devolved control to the shopfloor.
- Visual control—a method of measuring performance at the 'shop floor' which was visual and owned by the operator team.
- Poke yoke—an 'error-proofing' technique.
- SMED (single minute exchange of dies)—a changeover reduction technique.

However let us return to the 1990s and the two landmark works discussed at the start of this section.

The Machine that Changed the World (Womack *et al.*, 1990) compared and contrasted the Mass Production System seen in the US and Europe, with the Lean Production System, seen in Japan, within the automotive industry.

Table 1 is a summary of some of the comparisons highlighted by Womack *et al.* (1990).

- The mass producers were able to maintain long production runs using standard designs which ensured that the customer got a lower cost; they also got less variety

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Table 1. Production Systems Compared.

	Mass production	Lean production
Basis	• Henry Ford	• Toyota
People–design	• Narrowly skilled professionals	• Teams of multi-skilled workers at all levels in the organization
People–production	• Unskilled or semi-skilled workers	• Teams of multi-skilled workers at all levels in the organization
Equipment	• Expensive, single-purpose machines	• Manual and automated systems which can produce large volumes with large product variety
Production methods	• Make high volumes of standardized products	• Make products which the customer has ordered
Organizational philosophy	• Hierarchical—management take responsibility	• Value streams using appropriate levels of empowerment—pushing responsibility further down the organization
Philosophy	• Aim for 'good enough'	• Aim for perfection

as did the workforce who found this mode of operation tedious.

- In comparison, the term 'lean' comes from the 'upside' of the production method which requires 'half the human effort, half the manufacturing space, half the investment and half the engineering hours to develop a new product in half the time'.

However, it is not difficult to see that the world of car-parts and conveyor belt production lines did not immediately grab the interest and excitement of the process industries. Apart from the packaging lines the analogies seemed hard to find.

However, *Lean Thinking* (Womack and Jones, 1996) helped us to understand the principles of lean:

- The identification of *value*.
- The elimination of *waste*.
- The generation of *flow* (of value to the customer).

It clearly demonstrated that this was not a philosophy or technique which was only applicable to the automotive industry.

THE BENEFITS OF BEING 'LEAN'

The benefits seen within non-process industries (see Figure 1), such as the automotive industry, are well documented:

- decreased lead times for customers;
- reduced inventories for manufacturers;
- improved knowledge management;

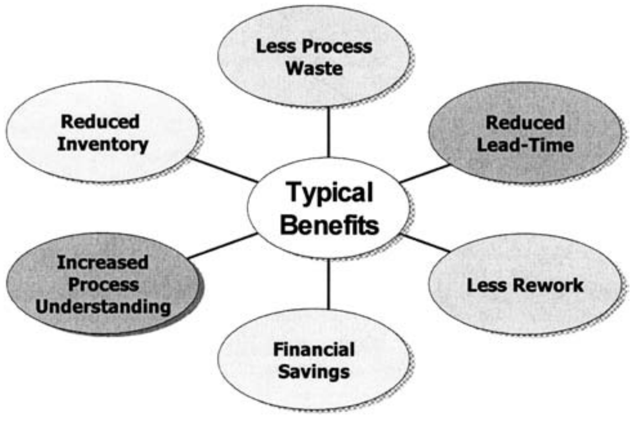

Figure 1. The benefits of 'lean'.

- more robust processes (as measured by less errors and therefore less rework).

This makes lean a very real and physical concept—especially for manufacturing.

Lean production has now expanded and lean thinking has been applied to all aspects of the supply chain. There are many well documented examples of the application of 'lean thinking' to business processes such as project management (Melton, 2003); construction, design, and so on.

Lean can be applied to all aspects of the supply chain and should be if the maximum benefits within the organization are to be sustainably realized. The two biggest problems with the application of lean to business processes are the perceived lack of tangible benefits and the view that many business processes are already efficient. Both assumptions can be challenged (Melton, 2004):

- There are many tangible benefits associated with lean business processes. A lean business process will be faster, e.g. the speed of response to a request for the business process will be faster, and as most business processes are linked to organizational supply chains, then this can deliver significant financial benefits to a company.
- The perception that a business process is already efficient is all too often an illusion. Functionally, many business processes may appear very efficient, however the application of Lean Thinking forces us to review the whole supply chain in which the business process sits, and this frequently reveals bottlenecks and pockets of inefficiency.

But for now let us return to the world of manufacturing within the process industries.

WHAT'S STOPPING US?

With the benefits so apparently obvious the question has to be—what's stopping us?

For some in the process industries the answer is simple—nothing! There are good examples of the implementation of lean philosophies across the process industries. For example, PICME (Process Industries Centre for Manufacturing Excellence), an organization part funded by the DTI to specifically help manufacturing in the process industries to become more efficient and more competitive, quote estimated projected savings of over £75 million over their first 5 years of operation (PICME, 2004).

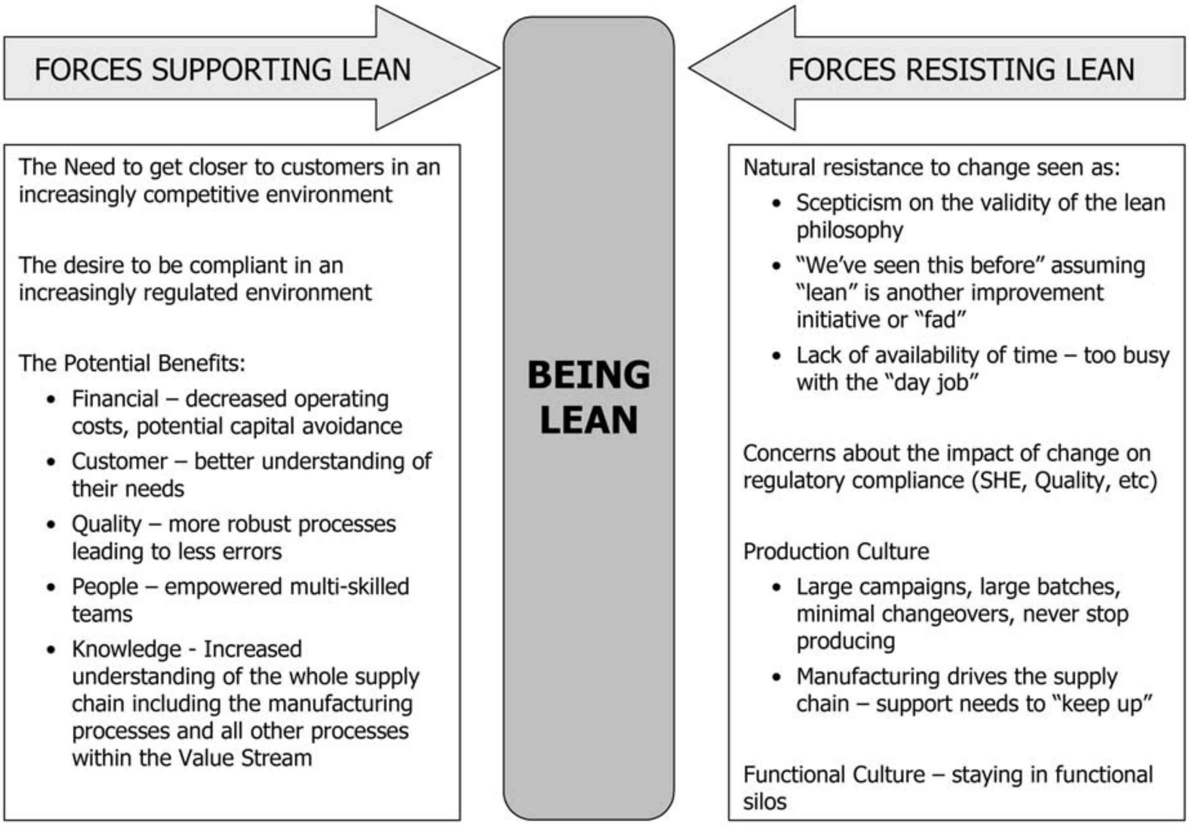

Figure 2. The forces opposing and driving a change to 'lean'.

But for some the 'case for change' cannot be as compelling as it would appear to be. Figure 2 is a force field diagram which shows some of the drivers and resistors within the manufacturing sector of the process industries; it is only when the specific driving forces for an organization are greater than the opposing forces that the change will occur. The ultimate sustainability then requires additional supporting forces to further reduce and eliminate opposition.

Within the process industries specific sectors have been under increasing pressure:

- Chemical Industry—the continuing pressure on the cost base.
- Pharmaceutical manufacturing—the pressure on the supply chain has increased as there are more external competitive pressures for manufacturers to deliver new, safe efficacious drugs quicker than ever before.

But—lean manufacturing has now been applied within the pharmaceutical sector both within primary and secondary operations and the use within the wider process industries is increasingly likely as the breadth of benefits are demonstrated and the driving forces for change increase.

Lean thinkers would probably want an additional driving force for change: lean is easy to implement! But although the principles and tools associated with lean thinking may appear at face value an easy concept to use within an apparently willing industry they present huge 'change' challenges to any business truly wishing to become lean. Perhaps the biggest resisting force for the process industries will be the huge inertia that must be overcome: the resistance to change.

Lean thinking involves a serious challenge to the status quo and for many this level of challenge to the 'way we do things round here' is a sufficient deterrent to application—particularly after the surge of business changes implemented following initiatives seemingly aiming for a similar goal—greater business effectiveness and therefore profit! However it can be demonstrated that the forces supporting the application of lean are greater than those resisting it.

WHAT IS LEAN THINKING?

Lean Thinking starts with the customer and the definition of *value*. Therefore, as a manufacturing process is a vehicle to deliver value (a product) to a customer, the principles of lean thinking should be applicable to the Process Industries and the specific manufacturing processes within that industry.

We can remove *waste* from many steps of our manufacturing processes, from how we develop the initial product and process design, how we assure compliance, to how we design to operate a completed facility. However, to be truly lean we have to link all these elements within a robust supply chain—we need to ensure the *flow of value*. This leads to what many are calling a 'lean enterprise' (LERC, 2004).

The Lean Enterprise Research Centre (LERC, 2004) at Cardiff Business School highlighted that for most production operations:

- 5% of activities add value;
- 35% are necessary non-value activities;
- 60% add no value at all.

Therefore, there is no doubt that the elimination of waste represents a huge potential in terms of manufacturing improvements—the key is to:

- identify both waste and value;
- develop our *knowledge management* base;
- realize that sustainable improvement requires the buy in of the people operating the processes and managing the business, and therefore a culture of *continuous improvement*.

Value

The identification of value and the definition of value propositions for specific customers is the starting point. Without a robust understanding of what the customer values you cannot move forwards (see Table 2). Outside of the process industries there are many examples of what we mean by a 'value proposition'—as a consumer buying a washing machine what we value may be the ability to wash our clothes at home; for others the value may be related to cost or specific design features or even the colour. The challenge for the manufacturer is to develop a product portfolio based on these value propositions.

Table 2 gives some examples of value propositions which manufacturers in the process industries have developed as related to their specific customer group, their product portfolio and their potential capabilities.

For customer A, development of the process they handover to the toll manufacturer is a value added activity; for customer B this would be considered waste.

Table 2. Examples of value propositions within the process industries.

Customer type	Value proposition	Manufacturer type
A. Major pharmaceutical manufacturer of drug products	• Robust process and product development at fast track speed ensuring regulatory compliance	• Toll manufacturer of pharmaceutical intermediates
B. Other manufacturer in a low cost base industry	• Correct specification, low cost and delivered on time in the volumes specified	• Bulk chemicals manufacturer
C. The patient (via the companies who distribute the drugs)	• High quality, safe drugs that 'work' at an appropriate price	• Major pharmaceutical manufacturer of drug products

Waste

Any activity in a process which does not add value to the customer is called 'waste'. Sometimes the waste is a necessary part of the process and adds value to the company and this cannot be eliminated, e.g., financial controls.

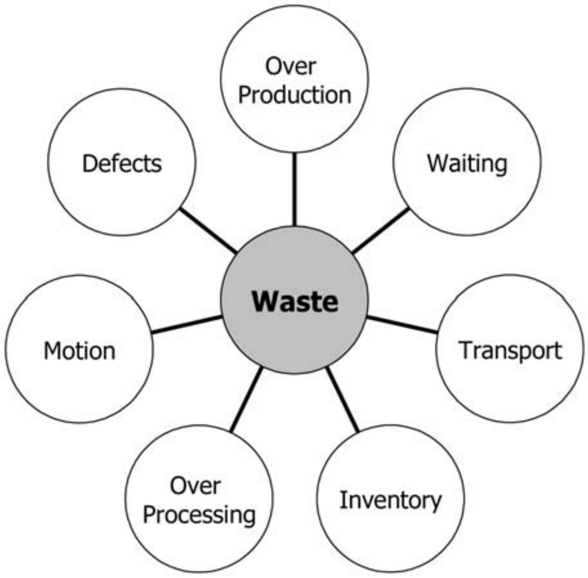

Figure 3. The seven types of waste.

Otherwise all 'Muda', as the Japanese call waste, should be eliminated.

There are seven main types of waste as outlined in Figure 3 and further detailed in Table 3.

Initially, waste can be easily identified in all processes and early changes can reap huge savings. As the processes continually improve, the waste reduction will be more incremental as the company strives to achieve a waste-free process. Continuous improvement is at the core of lean thinking.

The data in Table 3 is only the tip of the iceberg in terms of the amount and types of waste which will be within our manufacturing processes and overall supply chains. The key is to identify it, i.e., to ensure that the root cause—the real waste—is eliminated, not just the symptom.

Flow

Flow is probably the hardest lean concept to understand. It is the concept which most obviously contradicts with mass production systems; the comparison of one piece flow versus batch and queue processes.

It is a lack of flow in our manufacturing processes which accounts for the huge warehouses which house the mass of inventory which consumes the working capital of the business.

To understand flow you need to understand the concept of the *value stream*—that linkage of events or activities which ultimately delivers value to a customer. A value stream crosses functional and, usually, organizational boundaries.

Figure 4 shows a simple value stream which would be typical for a toll manufacturer. The value stream does not show all the supporting activities, only the main value adding stages and the key multi-functional teams involved.

Flow is concerned with processes, people and culture and it is appropriate at this stage to mention the work of Goldratt and Cox (1993) who's book *The Goal* introduced

Table 3. The seven types of waste.

Type of waste	Description	Within the process industry	Example symptom
1. Over production	• Product made for no specific customer • Development of a product, a process or a manufacturing facility for no additional value	• Large campaign—large batch and continuous large-scale manufacturing processes • Development of alternative process routes which are not used or the development of processes which do not support the bottleneck • Redesign of parts of the manufacturing facility which are 'standard', e.g., reactors	• The extent of warehouse space needed and used • Development and production organization imbalance • An ever changing process (tweaked) • Large engineering costs/time associated with facility modifications
2. Waiting	• As people, equipment or product waits to be processed it is not adding any value to the customer	• Storage tanks acting as product buffers in the manufacturing process—waiting to be processed by the next step • Intermediate product which cannot leave site until lab tests and paperwork are complete	• The large amount of 'work in progress' held up in the manufacturing process—often seen on the balance sheet and as 'piles of inventory' around the site
3. Transport	• Moving the product to several locations • Whilst the product is in motion it is not being processed and therefore not adding value to the customer	• Raw materials are made in several locations and transported to one site where a bulk intermediate is made. This is then transported to another site for final product processing • Packaging for customer use may be at a separate site	• Movement of pallets of intermediate product around a site or between sites • Large warehousing and continual movement of intermediate material on and off site rather than final product
4. Inventory	• Storage of products, intermediates, raw materials, and so on, all costs money	• Economically large batches of raw material are purchased for large campaigns and sit in the warehouse for extended periods • Queued batches of intermediate material may require specific warehousing or segregation especially if the lab analysis is yet to be completed or confirmed	• Large buffer stocks within a manufacturing facility and also large warehousing on the site; financially seen as a huge use of working capital
5. Over processing	• When a particular process step does not add value to the product	• A cautious approach to the design of unit operations can extend processing times and can include steps, such as hold or testing, which add no value • The duplication of any steps related to the supply chain process, e.g., sampling, checking	• The reaction stage is typically complete within minutes yet we continue to process for hours or days • We have in process controls which never show a failure • The delay of documents to accompany finished product
6. Motion	• The excessive movement of the people who operate the manufacturing facility is wasteful. Whilst they are in motion they cannot support the processing of the product • Excessive movement of data, decisions and information	• People transporting samples or documentation • People required to move work in progress to and from the warehouse • People required to meet with other people to confirm key decisions in the supply chain process • People entering key data into MRP systems	• Large teams of operators moving to and from the manufacturing unit but less activity actually within the unit • Data entry being seen as a problem within MRP systems
7. Defects	• Errors during the process—either requiring re-work or additional work	• Material out of specification; batch documentation incomplete • Data and data entry errors • General miscommunication	• Missed or late orders • Excessive overtime • Increased operating costs

the Theory of Constraints. This theory aligns with lean thinking in the way it considers an organization as a system consisting of resources which are connected by processes which ultimately make product which can be sold.

It effectively talks about a value stream and the main causes for the lack of flow—constraints in the system.

Godratt and Cox (1993) introduced some development of operational rules to guide how a production plant should be operated based on three measurements:

- *Throughput*: the rate at which the system generates money through sales (use sales not production—if you produce something, but do not sell it, it is not throughput)—this links into the lean philosophy of producing product when the customer 'pulls' for it.
- *Inventory*: all the money that the system has invested in purchasing things which it intends to sell.
- *Operational expense*: all the money the system spends in order to turn inventory into throughput.

They then define the goal of that production operation as increasing throughput while simultaneously reducing both inventory and operating expense and that any plant improvement must be challenged against this, i.e.,

- as a result of this improvement will we:
  — Sell any more products? (Did *Throughput* go up?)
  — Reduce the amount of raw materials or overtime? (Did *Operating* Expense go down?)
  — Reduce the plant *Inventory*?

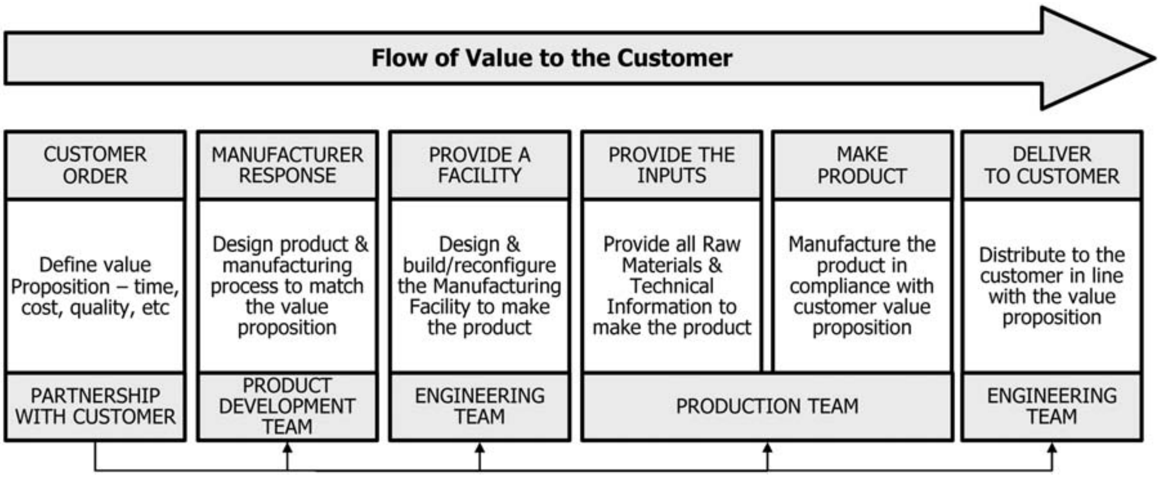

Figure 4. A simple value stream.

The final concept they introduce is that of the *bottleneck*—that step in a process which determines the throughput of the whole process. This also aligns with lean 'pull' production which tells production that it's OK to stop production! (if there is no customer 'pull').

Within the process industries we do strive for production efficiencies, however, 'a value stream perspective means working on the big picture, not just individual processes, and improving the whole, not just optimising the parts' (Rother and Shook, 1999). In other words we need to improve the efficiency and effectiveness of the whole supply chain not just improve one part of it and we need to operate the supply chain not the production unit.

Figure 5 summarizes the above discussion on flow by demonstrating how a part of a supply chain could operate if 'pulled' rather than 'pushed'. In a 'push' system production works as much as it can to fill a warehouse; In a 'pull' system production works only when it needs to at the pull of customer orders.

Figure 5 demonstrates that the process (the grey boxes) only operates when an appropriate 'signal' is seen:

- The packaging operation only operates when it is packaging for a customer order (it's 'signal to pack'). It takes product from a final product silo (kanban).
- When the level in the silo falls past the red line this is a signal for the final product manufacture to commence. Once the silo is at the green level this is a signal for the manufacture to stop. This operation takes its material from the raw materials kanban and the intermediate kanban.

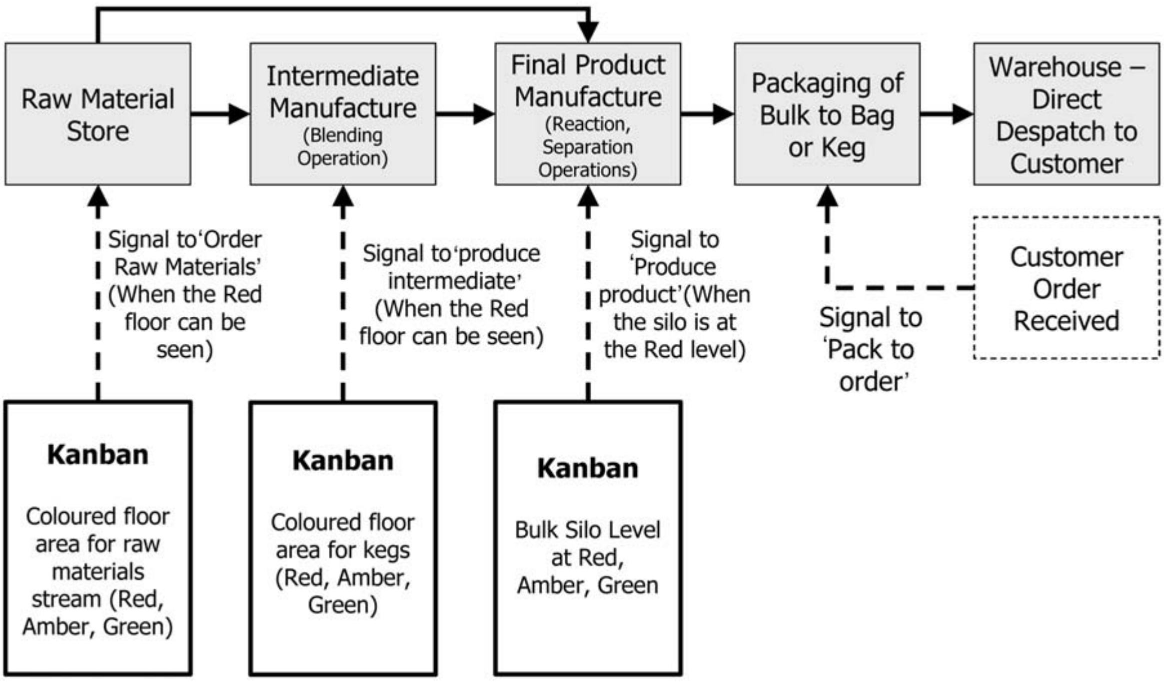

Figure 5. 'Pull' production example—using kanbans.

- Both of these are storage areas. Specific kegs are placed on a coloured floor. When enough kegs have been used so that the red area of the floor can be seen—this is a signal for the preceding operation to commence, i.e., intermediate manufacture or purchasing of raw materials.

The sizing of the kanbans and their operation to ensure FIFO (first in-first out) has to be thought through but this can be an effective method of:

- Implementing a 'pull' production system.
- Reducing lead-time to the customer.
- Reducing inventory at all stages in a process.

Knowledge Management

The knowledge we have in our systems and more importantly, our people, is fundamental to the implementation of lean.

The success of lean in some manufacturing organizations has been in part due to the reorganization of the teams at both operational and management level.

Example changes are:

- reorganization of all resources around value streams;
- multi-skilled or cross-functional teams with more responsibility for the day to day operation of a manufacturing unit.

Additionally, formally capturing knowledge of processes is necessary especially within a work environment where corporate knowledge is no longer defined by the large numbers of employees who have worked there all their lives. Some companies have used some form of IT solution to capture knowledge formally; for others a process of knowledge sharing spreads the knowledge wider than previously. A well-managed knowledge base is critical to the sustainability of change.

Continuous Improvement

Lean thinkers are aiming for 'perfection' and in doing so the improvement cycle is never ending. For many in the process industries this culture change is the hardest change of all.

However, for assured sustainability the organizations who are truly lean will invest the time and effort to support a change in culture—the way we do things around here. The case study attempts to highlight some of the ways in which culture can be impacted.

HOW TO START 'LEAN THINKING'

A data-rational, structured approach is needed if the key principles of value, waste and flow are to be rigorously applied along the supply chain.

The process of 'how to lean' (Figure 6) can be summarized as:

- Document current process performance—how do we do it now.
- Define value and then eliminate waste.
- Identify undesirable effects and determine their root cause in order to find the real problem.

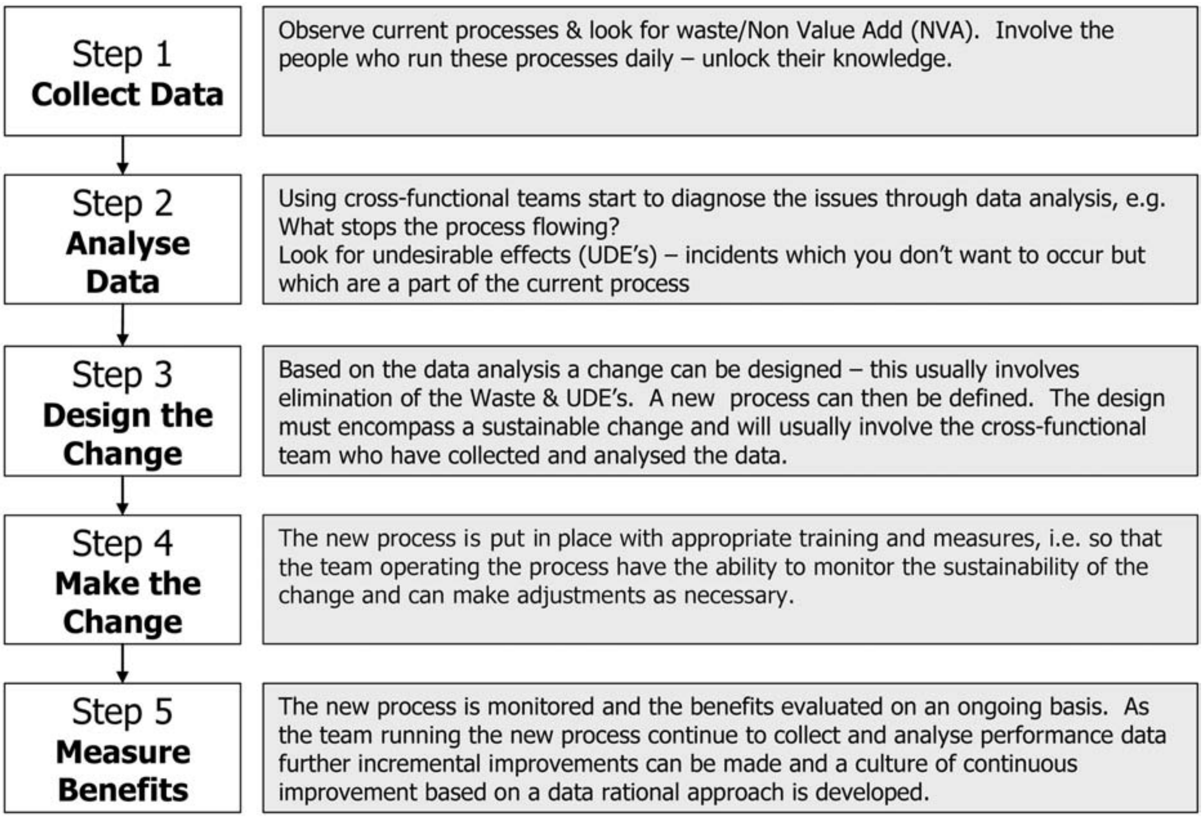

Figure 6. How to 'lean'.

- Solve the problem and re-design the process.
- Test and demonstrate that value is now flowing to the customer of that process.

There are many tools and techniques to support each step in the above process—they support implementation of the principles.

Table 4 shows a sample of the tools a 'lean thinker' would have in their toolkit. What surprises many skeptics is that the lean principles can be put into action using tools which are very familiar to those who have been involved in performance improvements.

What is different is the fact that they are used to ensure that:

- manufacturing processes deliver value to their customers;
- all activities which do not add value—waste—are eliminated or reduced;
- the manufacturing processes flow within a robust and 'lean' supply chain.

PRESENTING THE EVIDENCE: A CASE STUDY

The following case study is taken from a real situation—it aims to demonstrate the benefits from lean manufacturing and also lean supply chains—two facets of lean thinking which are revolutionising the parts of process industries in which they have been implemented.

Making a Value Stream: The Design and Implementation of Lean

The following is a case study example taken from the process industries. It shows how the three principles of lean supported by the enabling principles, can deliver step change business benefits and ongoing incremental benefits.

A multi-product manufacturing process was taking 10 weeks from the introduction of raw materials to the completion of final product processing. The customers generally expected a lead-time of 6 weeks from order placement to receipt of the goods.

Table 4. A sample 'lean' toolkit.

Tool	Description	Typical Use
Force field diagramming	• A tool which allows analysis of the forces supporting or resisting a particular change	• When looking at a potential design • When looking at the implementation planning for a change following design
IPO diagramming	• A basic flowchart tool mapping inputs, processes and outputs. Based on the required outputs, the appropriate process can be defined and the required inputs specified	• To design a team session at any stage of the implementation of lean, e.g., data collection day, kaizen day (implement a change in one day), implementation planning
Process flow mapping	• A map showing each process step in the value stream	• A data collection activity • Also used to analyze the VA (value-add) and NVA (non value-add) steps and as a tool for redesign
Time-value mapping	• A map of the time taken for each process step in the value stream	• A data collection activity • Also used to analyze the VA and NVA steps and as a tool for redesign
Spaghetti diagramming	• A map of the physical path taken by a product as it passes down the value stream	• A data collection activity
Five whys	• Taiichi Ohno (Womack *et al.*, 1990) had a practice of asking why five times whenever a problem was found. In this way the root cause was solved rather than the symptom.	• As a part of the data analysis so that the root cause problem can be solved in the design phase
Five S's	• Five activities used to create a workplace suited for visual control and lean practices: • Seiri—separate required from unnecessary tools and remove the latter • Seiton—arrange tools for ease of use • Seiso—clean-up • Seiketsu—do the above regularly—maintain the system you've set up • Shitsuke—get into the habit of following the first four S's	• Can be used at the start of a lean induction to break down barriers and get a team to own their workspace • Often used during Kaizens as workplace layout and tidiness is often an issue which causes waste (unable to find the right equipment, use what's there, lose key paperwork, and so on)
Risk assessment	• A structured assessment of what could stop the achievement of specific objectives and how this can be mitigated	• Assessment of a design prior to implementation as a final challenge of the design • Assessment of the issues post-implementation—looking specifically at what would stop the sustainability of the change
Kaizen	• An improvement activity to create more value and remove waste. Commonly called a breakthrough kaizen	• Kaizen workshops are a common method to kick-off the start of a large step change within an area or value stream • Kaizens would actually start with data collection and continue to do some data analysis, design and even implementation
Kanban	• Japanese for 'signboard'. This is a 'visual' shop floor pull system which means that each supplying work centre does not make anything until the next work centre requests supply	• This is a design solution to materials flow problems within a process (examples within both manufacturing and lab situations have been seen)

As the *Manufacturing Time* > *Customer Lead-Time* all production was scheduled according to a sales forecast.

Sales forecasts within this particular organization, as with many others, were unreliable and the Production Manager had to build up significant stock of finished product to ensure that all eventual orders could be met.

The Site Director was faced with a set of key performance indicators (KPI) which showed a trend for late or incorrect customer orders, decreasing product quality, increasing manufacturing time and another request for an additional warehouse for all materials associated with the manufacturing process as well as finished product. Additionally, a new KPI was emerging: the amount of product which became unsaleable due to shelf life issues—indicating both a problem with the length of time product was being stored in warehouses and the process by which product was chosen for customer orders.

Initially a Kaizen was used to pull together a cross-section of all the operational teams that were involved in the manufacturing unit: Operators, Lab Analysts, Warehouse Staff, Customer Service Staff, Schedulers, MRP Data Handlers, Technical Support Scientists, and so on.

The aim of the Kaizen was twofold:

- to collect and analyse data to identify the REAL problem and design some solutions;
- to start to break down functional barriers and general skepticism about lean thinking.

The data collection and data analysis phases yielded some key problems:

- *Process mapping*—the total number of steps both within and outside of the manufacturing process was 34; approximately 60% of these involved either travel or waiting, i.e., pure waste (see Figure 7).
  - — The process mapping was reviewed via closer observation after the kaizen and a number of variations came to light as well as a realisation that the discrete number of steps was nearly double!
  - — Typical variations were seen when urgent orders were expedited through the system and the teams worked closer together to naturally eliminate steps which didn't help get the product to the customer
- *Spaghetti mapping*—demonstrated the extent to which the product, its associated batch documentation, the operators, the samples and the support staff had to travel—it was miles!
- *Time-value mapping*—of the 10 weeks to produce a typical product from raw materials only 25% was value adding (Figure 8).
  - — The data collected during process mapping was converted into a time-value map (Figure 8). This type of analysis denotes value added activities as green and waste as red, i.e., the initial days are shown as waiting for the schedule.
  - — The Blend sample test (1 day) also has a 50% waste content as only 50% of the tests done on the sample ever fail.
  - — The space between each activity is the waiting time.
  - — This gives an excellent visual representation of the overall process—if all the red and 'white space' is removed then the process could theoretically be reduced from 10 weeks to 1 week!
- *Undesirable effects analysis*—the supply chain was managed via functional silos with little or no contact between them; the support functions did not behave as though they were actually producing a product for a

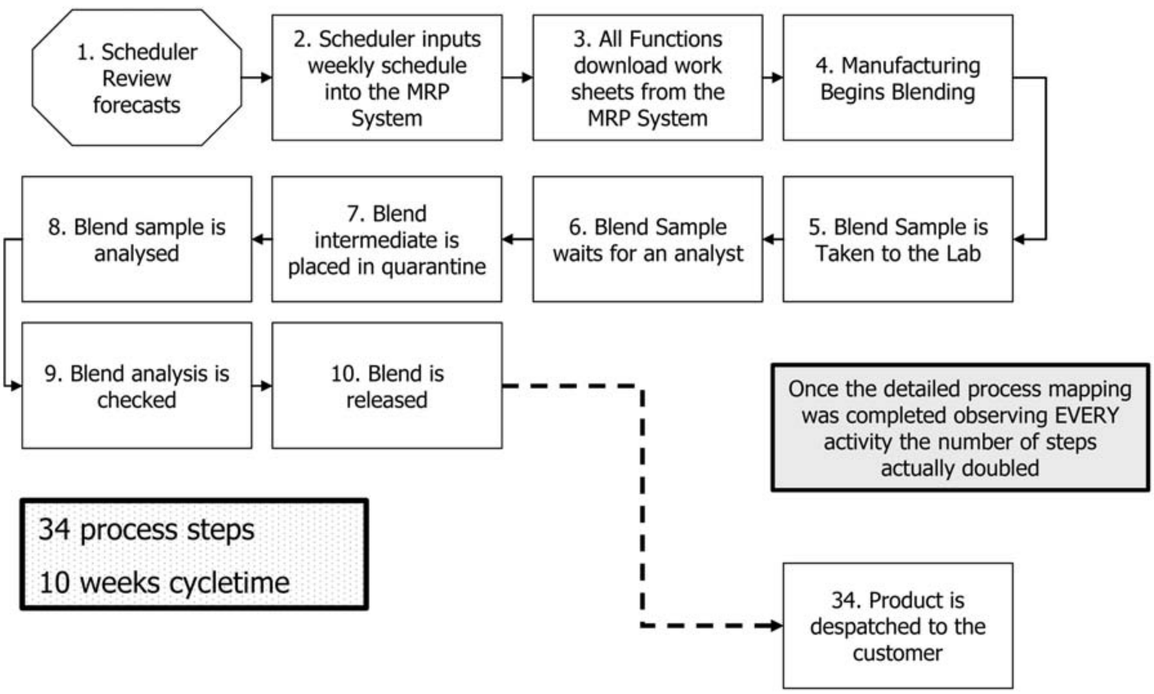

Figure 7. Process mapping—before.

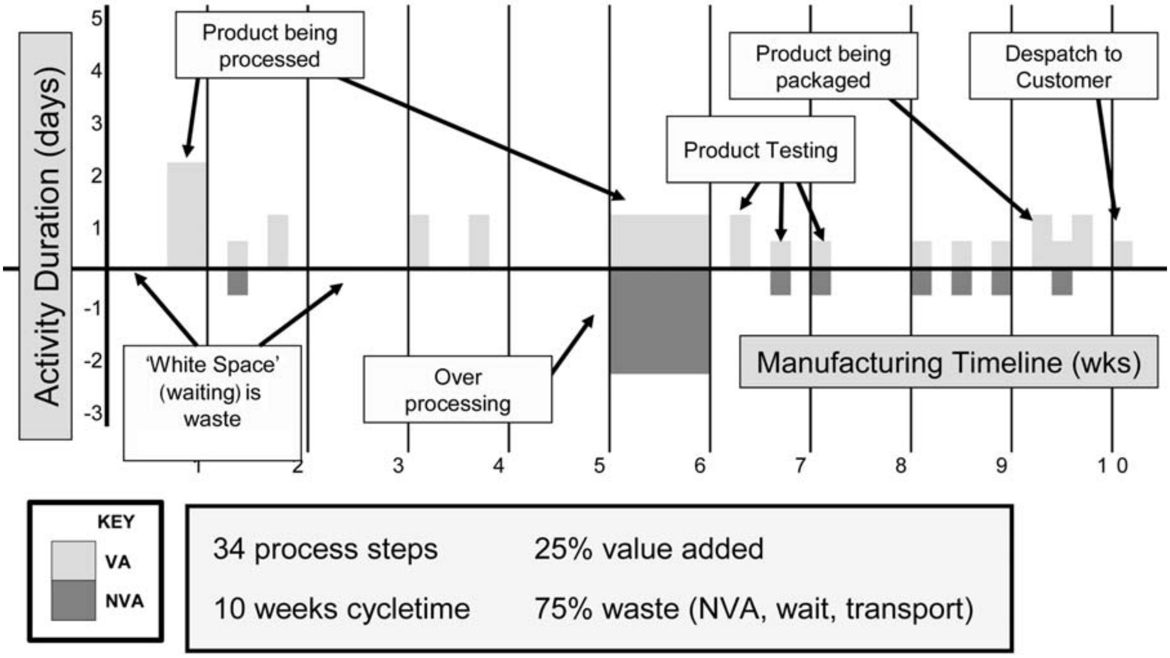

Figure 8. Time-value mapping—before...

customer—just a lab analysis or a signed batch record; the financial systems pushed all parts of the supply chain to large supply purchases in order to reap supplier discounts

- *Root cause analysis*—the symptoms revealed by the data analysis were root caused with a major issue being the lack of flow in the process and another being the functional behaviour of the various parts of the supply chain. The real problems were identified as:
  - — Lack of flow and functional behaviour—lack of connectivity of the supply chain; each step was operated as a distinct entity; functional teams were praised for functional efficiency even when customer orders were not being filled.
  - — Lack of flow—the system was literally too full. The warehouse was full of work in progress; the lab was overflowing with samples; the production area contained kegs of raw materials and intermediates waiting to be processed.
  - — Functional behaviour—no one person in the supply chain was accountable for the delivery of customer orders apart from the site director who had no direct influence on this. Functional effort was seemingly better whilst overall cycletime got worse.

As a result of the Kaizen event a number of quick changes were able to take place:

- *Communication*—the Kaizen team could see that it made no sense NOT to communicate with each other more often—formal agreements were made (and subsequently kept!):
  - — Production operators were going to speak to the warehouse each morning to check on key materials.
  - — Lab analysts were going to speak to the production area each day to check on the volume of samples likely that day.
- *Production and lab stoppages*—both the production area and the lab had a culture of 'team breaks' which effectively stopped value adding activities and reduced the capacity of the plant; i.e., parts of the supply chain were identified as the bottleneck (lab) or a near-bottleneck (packaging)
  - — The lab agreed to stagger break times for analysts so that the processing of samples could continue without stoppage.
  - — The production areas agreed to review the system of breaks and to ensure that 'cover' was provided to the near bottleneck process during break periods (this area was highly automated and did not have a large team even through it was one of the most unreliable areas in the supply chain from an equipment perspective).

The design phase for the main change project took some time as it extended to all parts of the supply chain:

- *Value streams* were formed—these were dedicated to a family of products with similar manufacturing processes and with similar customer requirements.
  - — This impacted the manufacturing, laboratory and warehouse layout.
  - — It changes the whole organization of resources associated with the product.
- *Kanbans* were introduced—these were only at key stages in the overall process but they visually signaled when production was required—no signal = no production.
  - — Laboratory—analysts worked in cells dedicated to the value stream and within the lab a kanban system was set up to ensure that all materials were available for the anticipated volume of samples. The system was very visual.
  - — Manufacturing area—earlier stages in the manufacturing process were signaled to commence if they

received a visual signal from the kanban (a storage based visual system as per Figure 5); this was important as they had a capacity far greater than the packaging step.

- *Visual factory* was introduced—this ensured that value stream KPIs were aligned along the value stream and were available either in the production area, the lab or the warehouse.
  - As soon as you entered each area it was clear how the area was performing; how many samples were being processed in the lab; what level of order fulfillment to target lead-time had been achieved in the warehouse; the throughput of the value chain.
  - Functional measures were no longer used.

Overall the benefits for the organization can be measured in 'hard' terms:

- Approximately 50% reduction in overall supply chain cycle time (see Figure 9).
- Approximately 25% increase in customer order accuracy (delivery and quality).
- Approximately 30% reduction in inventory (including safety stock kept due to the inherent inaccuracy in sales forecasts).

There are also softer benefits and these should not be forgotten:

- Breakdown of in-company functional barriers.
- Joint development of value stream KPIs with all functions buy-in.

Changing the Manufacturing Culture: Sustaining Lean

Following the completion of the change project it was critical that key sustainability measures were tracked:

- Were the new processes being followed?
- Was the layout being kept as per the design?
- Was the visual performance board being used?

A process of 'hot tagging' was used within the value stream to consolidate the culture. This process involved all the team members highlighting when a part of the value stream was not in alignment, e.g., kanbans being overfilled; sloppy housekeeping not in line with the 5 S's (see Table 4).

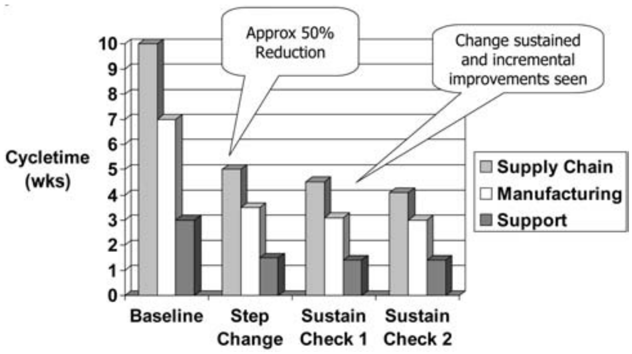

Figure 9. Cycle time reduction results.

LOOKING AHEAD: APPLICATION WITHIN THE PROCESS INDUSTRIES

Clearly lean manufacturing has, and could be further, applied within the process industries. The tools and techniques described in previous sections can and have been used within chemicals and pharmaceuticals manufacturing in the UK.

For some parts of the process industries the revolution has yet to begin—for others it is a case of expanding lean thinking into all parts of the supply chain.

- To start the implementation of lean thinking:
  - start on a manufacturing process;
  - build a small cross-functional team;
  - ensure senior management demonstrate their support;
  - ensure that all change is based on a structured data rational process;
  - communicate success effectively.
- To develop lean thinking further within your organization:
  - communicate the sustainable successes from the implementation within manufacturing;
  - review the value chain for a specific customer or set of customers;
  - review the business processes as well as the physical processes and apply the same structured data rational process, based on using cross-functional teams empowered to implement change;
  - keep looking for waste, keep checking up on the value you deliver to customers, keep controlling the flow—make it a part of your business culture.

CONCLUSIONS

It is clear that the climate for change within the process industries over the last couple of years has been an 'open door' to lean thinkers. We are seeing, and hearing of, more and more examples of how manufacturing processes within the chemicals and pharmaceuticals industries are being improved through the use of relatively simple techniques.

It is obvious what 'lean' has to offer the process industries:

- Performance improvements across the whole supply chain supporting increased business performance.

Ultimately 'lean' will enable UK based manufacturing operations to compete more globally—but only if the time, expertise and senior management backing is available.

Implementing lean is a revolution but one that the process industries should be welcoming with open arms. The leaders of this revolution will have to continue to show by example the financial, cultural and organizational benefits of starting down a route of REAL continuous improvement—this is not an initiative, not a fad, it's a philosophy which has the potential to transform your business. The data can speak for itself:

- Release of working capital.
- Increased supply chain speed.
- Reduced manufacturing costs.

Lean manufacturing has been applied within the process industries, most notably chemicals and pharmaceuticals sectors, to great effect. The wider use is increasingly likely, but more than that it is required!

Lean thinking is applicable to all business processes within the process industries. The challenge, if we decide we want to be lean, is whether we know enough about our ways of working, what customers of the business processes truly value, and how our businesses operate and need to operate.

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