Complexity and Uncertainty in Operations Management and Logistics

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1. VUCA (VOLATILE, UNCERTAIN, COMPLEX, AMBIGUOUS)

1.1. Introduction

Nothing bothers an engineer more than having to make a decision without knowing its impact, and even if this were possible, it would still be difficult.

In the 21st century, businesses make decisions in a world which is VUCA (volatile, uncertain, complex and ambiguous).

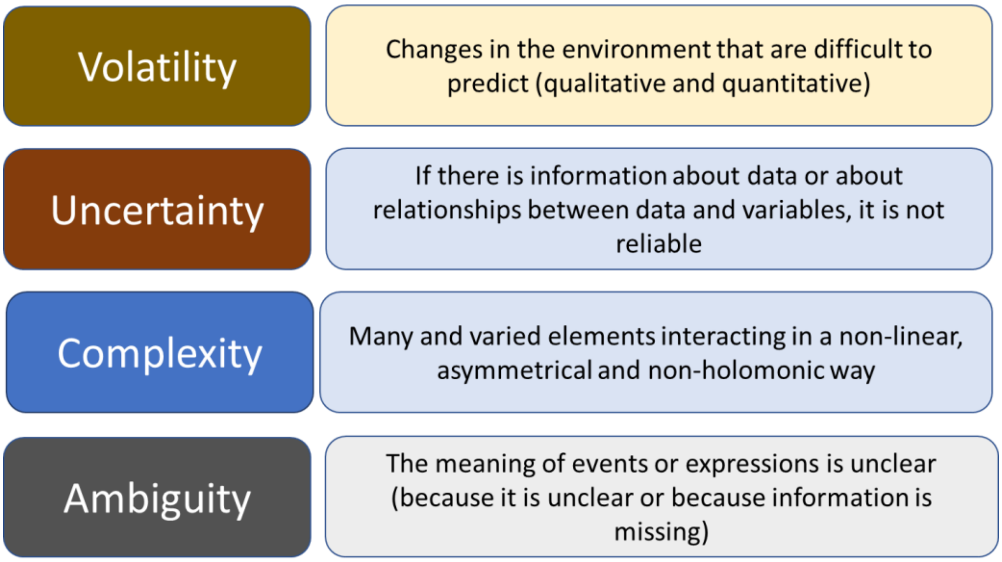

Figure 1: VUCA environments

An ambiguous environment is one in which the meaning of events or expressions is unclear. This lack of clarity may be because a consensus has not yet been reached or because there is a preference not to communicate the information that would clarify the situation.

A volatile environment is one that constantly changes in a highly unpredictable manner. Quantitative volatility is of little importance (it is really a type of uncertainty). Instead, it is qualitative volatility that does the real damage, changing scenarios completely and often in unpredictable ways.

An environment is called complex when it has many and varied elements that are interlinked via linear and non-linear relationships. An operations manager lives in a complex environment all the time; the question is how complex. Some complexity is inherent to the environment and has to be worked with, while other types of complexity result from ways of working that stubbornly persist.

An environment is called uncertain when the information relating to it is not fully reliable, which is unfortunately true of any environment. Uncertainty can affect data, but also the relationships between data and variables, and between variables themselves.

Of these four characteristics, the operations manager is primarily concerned with two: complexity and uncertainty.

Resolving volatility and ambiguity should be the responsibility of those dealing with the outside world: financial and sales staff. However, at times, instead of resolving these issues, they simply pass them on.

This does not mean that volatility and ambiguity are not part of an operations manager's life. Unfortunately, the financial and sales staff will have to be helped, since ultimately a factory's operations cannot be ambiguous or volatile, and neither can be the decisions made by operations staff. Operations staff will have to help them convert volatility and ambiguity into probability distributions, scenarios and alternatives, i.e. transform volatility and ambiguity into complexity and uncertainty.

1.2. Volatility

Of the four VUCA elements, volatility is probably the most challenging for an operations manager. Volatility refers to changes in the environment that are not predictable (if they were predictable they would be part of complexity).

In other business environments, volatility can be managed with varying degrees of difficulty, but in the operations function volatility can have dangerous consequences, since resources are the key to operations and resources are difficult to reconvert and reallocate.

Volatility can be quantitative or qualitative. Quantitative volatility can be transformed into uncertainty (if quantified) by defining variability or possible scenarios.

As qualitative volatility has a strong impact on the survival of the organisation, it is a headache for operations managers who often have to work with fixed resources that are difficult to replace. Volatility can lead to fear of investing in tangible assets (physical resources), resulting in environments that are very hard to manage.

1.3. Ambiguity

Ambiguity stems from difficulty in defining the current reality or the requirements and objectives pursued. Ambiguity is often hidden behind vague (and usually grandiloquent) words and expressions that are widely used in the political sphere.

The deliberate or unintentional confusion of cause and effect and the use of words containing concepts that are not clearly defined lead to ambiguous situations in which the engineer often feels ill at ease.

Ambiguity can also hide behind very large amounts of information from which nothing relevant can be extracted, for example data about the past that does not allow the future to be anticipated ("*driving while looking through the rear-view mirror*").

Ambiguity arises when the product or service the customer will receive has not been defined since the customer does not know exactly what he or she will receive either and therefore has not expressed an opinion.

Ambiguity also arises when the data on an internal situation is not merely uncertain, but rather not even an approximate value for the data is available, since no one had considered that such data could be measured.

In industrial environments where the problem is not clear and neither are the objective and the means, the only way forward is to rush solutions that put decision-makers in the position of expressing what they want (usually everything) and what they are willing to pay for.

One way to deal with ambiguity is to rush solutions, even if we know they will not fit what the other party has in mind. When they realise their mental picture has been incorrectly portrayed, the person concerned will resolve contradictions, define the most distorted aspects, or at least discuss the matter without going over and over the same point.

1.4. Uncertainty

System uncertainty can be defined as the characteristics of a system that make decision-making harder due to a difficulty in knowing the value of certain parameters or ensuring strict compliance with the decisions made.

What most often surprises an engineering student upon entering the professional world is the lack of data.

However, the absence of data is not the worst possible situation. Still worse is where the data exists and everyone assumes it is accurate, since most often it is not. In almost all cases, data is not reliable (though it may appear to be).

Data linked to the following will be uncertain (to a varying degree):

- Inventory levels
- Fulfilment of orders
- Machine performance
- Machine availability
- Lead times
- Operating times
- Quality problems
- Delivery reliability
- Estimated demand

Reliable information is expensive to keep up to date and it is rarely that useful to have complete accuracy for all data.

Therefore, to make a system more efficient, uncertainty is often allowed to grow to the limits of acceptability.

What is the limit of acceptability? When decisions made (with the available data) do not produce the expected results, a lack of data or unreliable data becomes a problem.

Generally, when someone accesses a system for the first time, they are surprised by how unreliable the data is. However, this is to be expected.

It is very unlikely that a piece of data in an IT system will match the physical reality at all times. Moreover, it would be costly and probably pointless to improve reliability (Cortés-Fibla, Vidal-Carreras and García-Sabater, 2015) where the system works well enough.

Before addressing the problem of uncertainty, it would be preferable to know how well or poorly the system performs and whether any poor performance is a result of uncertainty in the data. Data is not reality. It is merely data. It has its uses at a given moment, it is difficult to obtain and even more difficult to keep up to date.

1.5. Complexity

System complexity can be defined as the characteristic of a system that makes decision-making hard due to the difficulty in anticipating the impact of decisions, even where all the data is explicitly available and accurate. (Yates, 1978) defines a complex system as one that has at least one of the following attributes:

1. Significant interactions
2. A high number of component parts or interactions
3. Non-linearity of relationships
4. Broken symmetry
5. Non-holonomic constraints

This scheme will be used below to highlight the sources of complexity in an operations system.

The greater the complexity, the more difficult it is to predict the outcome of decisions. For anyone who is not a gambler, this makes decision-making more challenging.

The number of products and the number of processes is usually associated with complexity. However, it is not only numbers that are important. So is the dimensionality of the whole. Simply put, either the ten products the company handles are all similar or some have constant demand while others have seasonal demand. Either the five machines the company uses are all the same or each is different from the others. The higher the number, the greater the complexity; the higher the dimensionality, the greater the complexity (Coronado-Hernández and García-Sabater, 2017).

Less often referred to (and more important) is the effect of interactions between the component parts of a whole and between wholes. For example, products are related to each other via bills of materials (BOMs), but also via a shared machine that does not have significant excess capacity, or via a buffer with limited capacity, which also connects different machines to each other.

The non-linearity of relationships is expressed, for example, through demand that varies over time, or when the composition of the BOM depends on relative humidity. In addition, binary relationships such as those that arise in the BOM are also non-linear, as is the growth of queues as a result of machine saturation. Moreover, IT systems with complex computational procedures are clearly non-linear (Cortes-Fibla, Vidal-Carreras and García-Sabater, 2016).

Temporal asymmetry and non-holonomy are highly complex concepts that are beyond the scope of this paper (and probably beyond the comprehension of its author). It is said that in operations management there are many ways to do the same thing, but virtually none to undo what has been done. This is broken symmetry and holonomy, and it increases the complexity of the system.

In any case, what is certain is that complexity grows naturally in any system, and even more so when there is an attempt to improve its efficiency. The more efficient a system, the more complex it is, but decisions have unintended effects.

To summarise, the following can be considered drivers of complexity:

- Number of products, machines and resources available
- Number of components and levels in the BOM
- Dimensionality of products, machines and resources
- Saturation level of bottlenecks
- Availability and distance to capacity cushions
- Product birth/death rates
- Dynamic nature of demand, availability of raw materials and resources
- Shelf life and obsolescence of products, raw materials and semi-finished products
- Extent of lead times (from suppliers to customers)
- Limit on stock levels
- Lack of operator polyvalence
- Substitute products and directionality of substitution
- Implementation alternatives and symmetry of alternatives
- Geographic size of network, number of facilities
- Number of equivalent decision rules
- Existence of automatic decision-making tools

Any operations manager will identify with the entire list given here. The classic reaction to this list is to say: "*in my company there's all of that and more*".

This makes sense, since this is why managers have jobs. Without complexity humans would not be needed. Instead, Excel macros would do everything.

Growth in the complexity of a system is at times the result of seemingly innocuous decisions not related to the operating system but rather to the relationship with customers itself.

At other times complexity grows as a market demand for a more efficient system (sometimes this demand is self-imposed).

Problems arise when the increase in one of these factors combines with other factor(s), leading the system into a situation of continuous emergency. “Emergency” here implies the classic sense of time (urgency) and also the sense of emergence (new situations neither foreseen nor foreseeable).

2. THE COMBINED EFFECT OF COMPLEXITY AND UNCERTAINTY

Complexity combines with uncertainty to generate “chaos”. In mathematics, chaos theory is the study of non-linear systems that are very sensitive to initial conditions. Small variations in these conditions (variations in the available data) can imply large differences in the trajectory of the system. It is therefore very difficult, if not impossible, to predict the behaviour of the system, even if it would have been possible had all the initial data been known.

With greater complexity, the effect of uncertainty is to make the outcome of decisions more unpredictable.

This combination of complexity and uncertainty which keeps the operations manager and production manager busy at all times in a system that evolves through small and continuous fixes can be called the chaos frontier.

Every organisation (or rather every individual) can withstand a certain level of complexity combined with a certain level of uncertainty.

2.1. And where do *you* work?

If it were possible (which it is not) to divide the spectrum between high and low complexity and high and low uncertainty, this would give four working environments for an operations employee.

In an environment with low uncertainty and low complexity there is no real work to be done. If we know what needs to be done, have reliable data to do it and doing it is easy, a robot or Excel macro will soon be able to do it.

Environments with high uncertainty and low complexity require specific mental skills, working methods and personal aptitudes. The calculations are straightforward, but it is hard to gather enough data to make the right decision, so it becomes necessary to accept errors in decisions, which are to be expected.

In environments with high complexity and low uncertainty, data (approximate enough) is available and decision-making involves properly processing this data and computing the relationships (known to a varying degree) to see how everything will turn out over time.

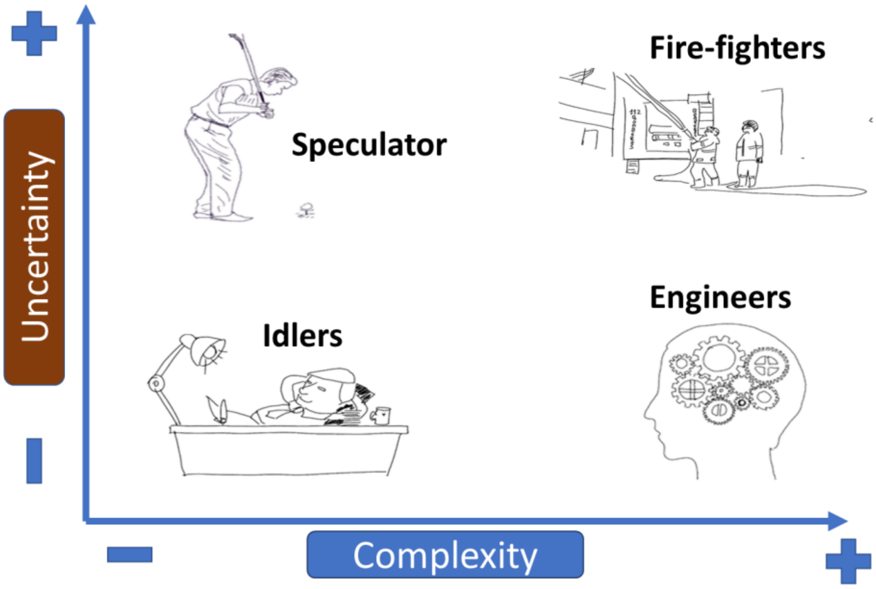

Figure 2: what work may look like depending on the complexity and uncertainty of the environment

This is what the work environment of operations staff usually looks like in highly organised companies, where everything is known and reasonably predictable.

However, in operations management one typically finds oneself in a complex and highly uncertain environment in which emergencies arise that are urgent and need to be resolved immediately without sufficient information.

Operations managers, production managers and heads of logistics almost always find themselves at the limit of what is bearable. Very often panic sets in, but with hard work and dedication they go home tired but satisfied that they have survived another day without succumbing to the inferno.

2.2. Chaos in operations management

Hell has many forms. One form is a factory where workers stand idle while orders are not being shipped, where customers call to complain about products not being delivered while machines produce superfluous items, and where warehouses are filled with dust-covered products while IT systems show zero, or even negative, stock for many other items (a less intense inferno is where the dust-covered product is that showing up as negative stock).

Chaos in a factory is where workers have to do overtime despite having poor productivity during work hours, where product deliveries are delayed despite promised deadlines having been significantly extended, and where indicators show machine utilisation of less than 50%.

At times there is calm amid the chaos; but this does not mean the problems have been solved. The calm is merely a further sign of the chaos: the storm always precedes the calm, and the calm the storm.

Thus, in many companies the operations manager (production manager, warehouse manager) seems more like a fireman putting out fires than an engineer planning for the future.

The descent into hell is gradual and painless. Indeed, it is even quite pleasant.

Gradually the system has less and less spare capacity, the product catalogue grows, standards are no longer applied, while the spare capacity itself allows workers to overproduce when it suits them or to spend more time than planned at changeover. Stocks slowly rise and the factory fills with material, to the joy of all who can't see beyond the apparent increase in activity.

With more material in the system, product movements become more costly and unpredictable. Greater unpredictability in the accumulation of materials makes idle machines seem less so, since they are waiting for tools, parts or workers to arrive. Everything moves about in a frenzy of activity worthy of a better objective.

"*Busy doing nothing*" (St Paul)

The manager puts out the first fires with a few tricks that everyone sees as a sign of his or her intelligence (using a different component, changing the production schedule, making up an excuse for the customer, working unplanned overtime, etc.). Gradually the fires are brought under control. The system learns to face flare ups without alarm and to extinguish them before those ultimately in charge take note. Now everyone is indispensable.

"Bad news—it wasn't by chance,

I wanted it to happen to us and you let it" (Calamaro)

2.3. Living on the frontier of chaos

Complex systems are not static. They change together with the environment. However, systems freely evolve towards higher levels of complexity and uncertainty, and so what was bearable yesterday may no longer be bearable today. We therefore have to learn to reduce and/or manage complexity, and/or reduce and/or manage uncertainty.

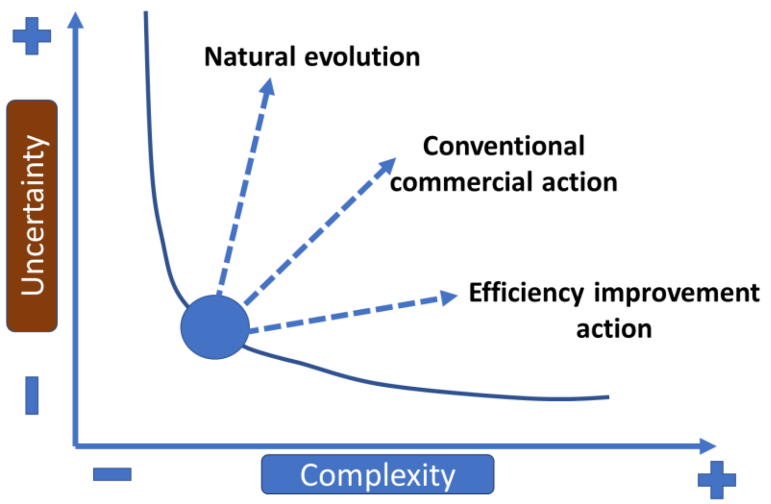

Figure 3: entering the land of chaos

The natural evolution of things leads to an increase in uncertainty. Gathering information has a cost, and if this information is not strictly necessary, the quality of the available data deteriorates (either because reality evolves or because the discipline in gathering information become more lax). The lack of tension and the required flexibility result in less senior workers being allowed to make decisions that are not necessarily known.

If the company can withstand a certain amount of customers and products, the sales department will almost certainly add new products and new customers, thus increasing complexity and uncertainty.

Furthermore, if the company is in a reasonably comfortable situation, the operations manager may try to improve efficiency, which often leads to increased complexity.

Thus, a balanced system moves dangerously towards the turmoil of small daily fires.

2.4. Towards greater efficiency

If, instead of being left to evolve freely, a system is altered so that it can achieve its objectives more effectively and efficiently, it will become increasingly complex, thus requiring a prior reduction in uncertainty.

A decision to improve efficiency is sometimes made when the operations manager is replaced in order to kick-start a system in which it had become impossible to make decisions with known effects. Usually the operations manager is replaced when the inability to foresee the effects of decisions is such that the system becomes blocked.

Chaos can be subdued by reducing complexity (bringing suppliers closer, shrinking the product catalogue, focusing factories, etc.).

It can also be overcome by reducing uncertainty (implementing control systems, establishing standard worksheets, etc.).

Absorbing uncertainty (by increasing safety stocks, adding capacity, etc.) is another good strategy.

Sometimes subduing chaos means adding further complexity to the system. An example of this is when a new IT system is included in the company's existing systems.

Clearly, if the system is made more complex without first reducing uncertainty, it is thrown further into chaos. Therefore, uncertainty must be reduced (preparing data, clarifying processes, etc.) before implementing new and sophisticated systems that will allow a leap forward.

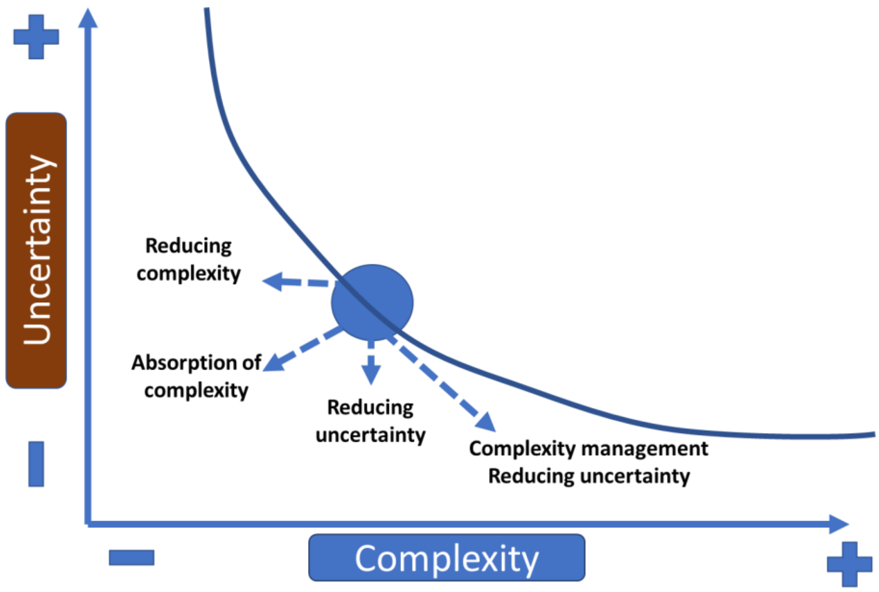

Figure 4: navigating the frontier

However, this always takes place on the frontier of chaos (mostly because reducing uncertainty has a cost and over-investment has to be justified).

2.5. Reducing complexity

From the list of possible sources of complexity cited in previous sections, we can try to create a list of ways to reduce it.

Upgrading the catalogue may reduce the number of products and can also lead to factories being separated (focused factories, group technology).

Lowering machine saturation reduces the complexity of a system by loosening the link between different products that require the same resource. One way to reduce saturation is to make overtime possible. However, this is clearly expensive. A cheaper way is to have a flexible working day, although this is generally more complex to manage.

Cutting changeover time reduces machine saturation, thus reducing complexity. Working with large batches reduces the same kind of complexity (provided there is enough space, since limited space is also a source of complexity).

Smoothing demand (*heijunka* in Japanese) reduces complexity by reducing the dynamic component of demand. Actions such as removing special offers or managing demand generally result in improved system performance.

Standardising products and processes and communicating this standardisation reduces complexity in managing the system.

Since complexity has many forms, certain decisions may increase complexity instead of reducing it (or rather reduce one type of complexity but increase another type in turn).

Reducing the number of suppliers reduces complexity. Reducing them to one increases complexity.

Bringing suppliers closer (in time rather than distance) reduces complexity, but integrating suppliers into the organisation increases complexity for the person who has to manage them.

Reducing the number of components reduces complexity to a certain extent. Using the same component in various products can increase complexity because it creates additional relationships between products, which can make planning more difficult.

Having more multi-skilled workers reduces some types of complexity but managing them can also be more complex.

2.6. Managing complexity

Managing complexity is usually associated with more sophisticated information systems, which require more data and make more autonomous decisions.

In small companies that are starting to grow, spreadsheets are used more and more for decisions of all kinds. Spreadsheets are generally disconnected from work on the ground and create a sense of complexity. They appear unprofessional but facilitate decentralised decision-making.

In large companies that for years have relied on a centralised ERP system (enterprise resource planning), spreadsheets are used more and more for decisions of all kinds. Spreadsheets are generally disconnected from work on the ground and create a sense of complexity. They appear unprofessional but facilitate decentralised decision-making.

Every now and then a company has to acquire a larger ERP system that includes everything and reduces the apparent complexity of the decision-making process.

With an MRP system (material requirements planning), the company can manage greater complexity in its product catalogue and materials procurement, but clearly requires greater certainty about the quality of data (BOMs, MPS (master production schedules), inventories).

Warehouse management systems (WMS) have a very large number of modules, which should ideally be incorporated on a gradual basis.

Operations scheduling tools (sequences, schedules and calendars) allow the management of highly saturated systems, but the decisions they make are generally not intuitive and require very low levels of uncertainty, for example by computerising data that would otherwise not even be captured.

Training workers (especially via Training Within Industry) not only reduces uncertainty, it can also enable them to make decisions autonomously.

Automating operations reduces operational uncertainty, allows for more complicated operations, requires more skilled staff, and can allow progress in more complex areas.

Simulation tools can also help manage complexity by making it possible to visualise the effects of alternatives and by facilitating decision-making.

2.7. Absorbing uncertainty

There are two basic ways of dealing with uncertainty: absorb or reduce it.

Absorbing uncertainty often requires investment in additional resources, with obvious costs. These costs are obvious because they are necessary, but also because the entire focus is on them.

Processing products well in advance (resulting in abnormally long lead times) allows for peace of mind in the face of capacity and quality issues.

Having 30% spare capacity in all resources allows for the absorption of high variability in demand and production rates. However, the focus will inevitably fall on that extra 30%, since without it, the entire facility may come to a halt or customer service may face excessive delays.

Holding significant safety stocks of a product permits the use of forecasting tools that are not very accurate.

A large supplier network increases complexity, but alternative suppliers reduce uncertainty in product availability.

Having a broad network of subcontractors to fall back on when demand grows beyond capacity allows you to work with the peace of mind that demand can always be met.

2.8. Reducing uncertainty

As systems become more complex, it becomes necessary to reduce uncertainty and improve the quality of data and forecasts.

Uncertainty can be reduced by creating standard worksheets, by implementing a manufacturing execution system (MES) or with better demand forecasting, for example.

Sometimes reducing uncertainty simply requires capturing data on the factory floor. Some companies commission simulation studies for the sole purpose of having an external party gather the specific data needed to make decisions.

Reducing uncertainty can be very costly for some and absolutely essential for others (the latter are frequently labelled “square-headed” or “systematic”, whereas the former are often referred to as “sloppy” or “flexible”).

A pathological approach can be taken to reducing uncertainty, which is common among those who come to operations from the world of finance. In finance, all data and transactions are correct (or at least they should be, if one wishes to avoid committing a tax offence).

Weighing a pig doesn’t fatten it

Having all data available all of the time is not necessarily the best option. In fact, it is an expensive option. To put an end to a chaotic situation it is probably enough to place (and update) a visual panel next to the worker, who will then fill it in using tally marks. Later, when we know it is necessary, we can switch to a computerised system.

At times the duplication and inconsistency of data becomes endemic. One common solution in such cases is to purchase an expensive German system.

What is SAP? Ningú ho sap ("nobody knows", for those of you who speak Valencian)

Since the system is computerised and designed by Germans, the entire company believes that it will solve data inconsistency by eliminating duplication (it does not necessarily improve data quality, but at least there are no duplicates), streamlining processes and probably even cleaning the windows while it's at it.

After the titanic effort in terms of time and money required to implement the new German ERP system, one might ask what percentage of this time and money would have been needed to improve data quality to almost the same extent if instead an effort had been made to improve discipline without acquiring the software. The answer is clear: without the software no one would have made the effort, not even the owner, who instead would have waited for the data to improve as if by magic.

Another type of system increasingly used to reduce uncertainty in operations is the MES (manufacturing execution system). MESs access data at its source (the machine), thus identifying data that was previously unknown.

However, since not everything in a company is automated to the same degree, from time to time the machine operator will have to justify machine downtime. At this point, they have to decide whether to blame themselves, a colleague, the raw material, or Murphy's law, or to simply write a note saying "*I've gone for coffee*", knowing that none of these data will ever be read.

Lastly, a few tens of thousands of euros spent on demand forecasting or production planning tools will also help reduce system uncertainty. A pity that sales staff insist on saying that customers do not behave as expected.

Reducing uncertainty requires systems, but above all it requires discipline in the use of systems. However, since *what has no price tends not to be appreciated*, it may seem that paying a lot of money for something which is very inflexible is the best way to promote a culture of discipline in data collection.

3. THE EVOLUTION OF INDUSTRIAL SYSTEMS

The operations manager has a vast number of tools for transforming a business.

Any of these tools involves modifications in terms of the uncertainty or complexity the operations system is faced with.

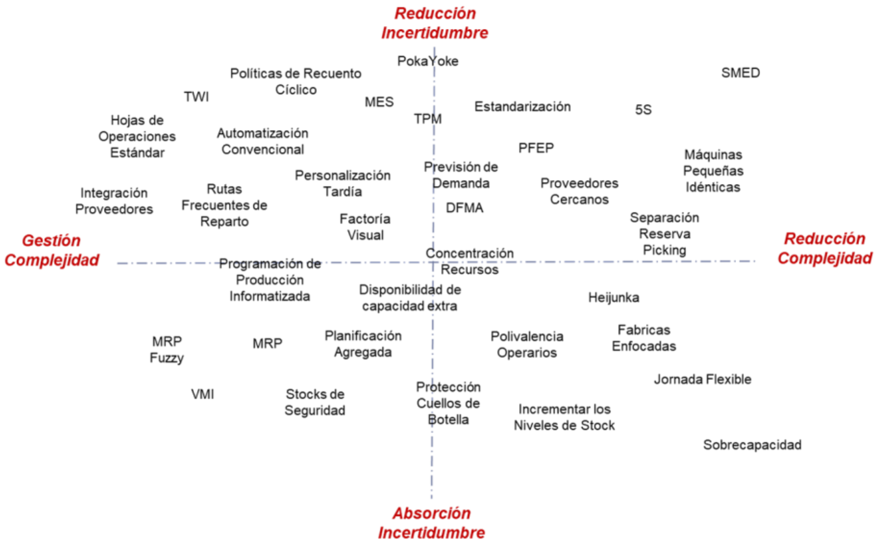

Figure 5: classification of some operations management tools based on complexity and uncertainty

The use of tools (whether correct or incorrect) will condition the next stage in the company's evolution. Evolutionary biology applied to operations should let us explain a posteriori how this came to be.

And someone will even have the nerve to explain to everyone else what should have been done.

"All happy families are alike; each unhappy family is unhappy in its own way" (Tolstoy)

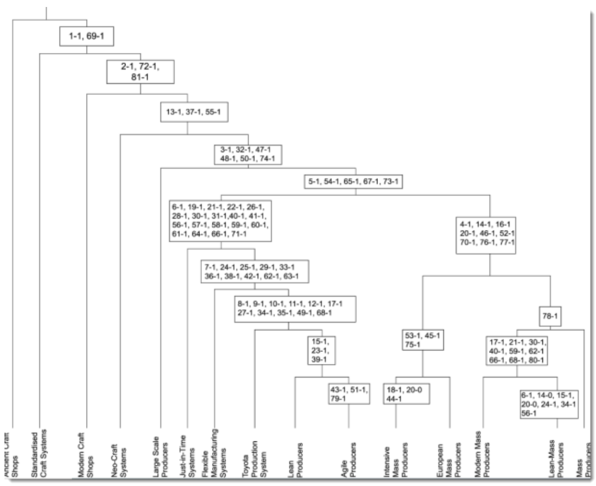

Figure 6: Automotive assembly cladogram (source: (Leseure, 2002)*)*

As a company evolves, the level of uncertainty will fall, while the level of complexity rises.

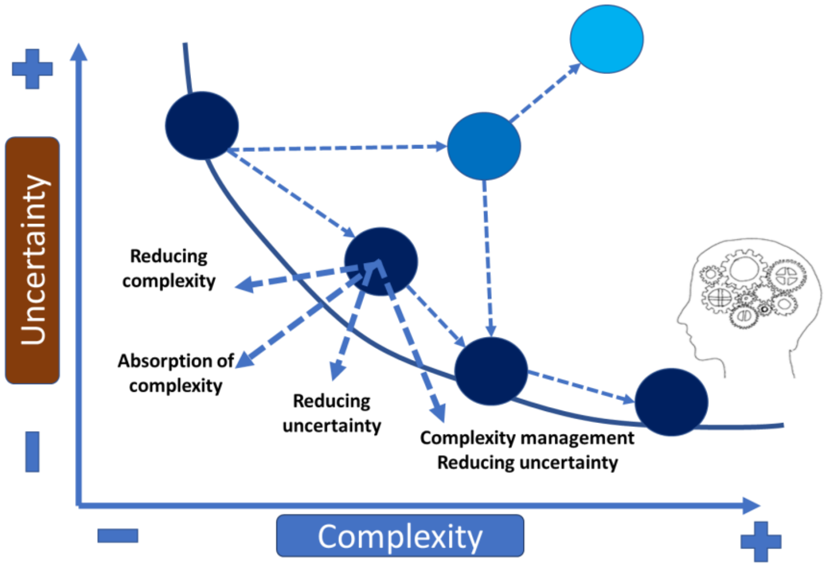

Figure 7: intelligent evolution requires increasing intelligence

As companies (industries) evolve, more intelligence is needed to manage them, since decisions are increasingly complex and involve greater uncertainty. Perhaps for this reason, companies with engineers hire more and more engineers. However, it may simply be that engineers reproduce under the right conditions.

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