QUALITY INNOVATION

a QFD approach

By Frede Jensen

Quality Innovation: A QFD approach

First edition

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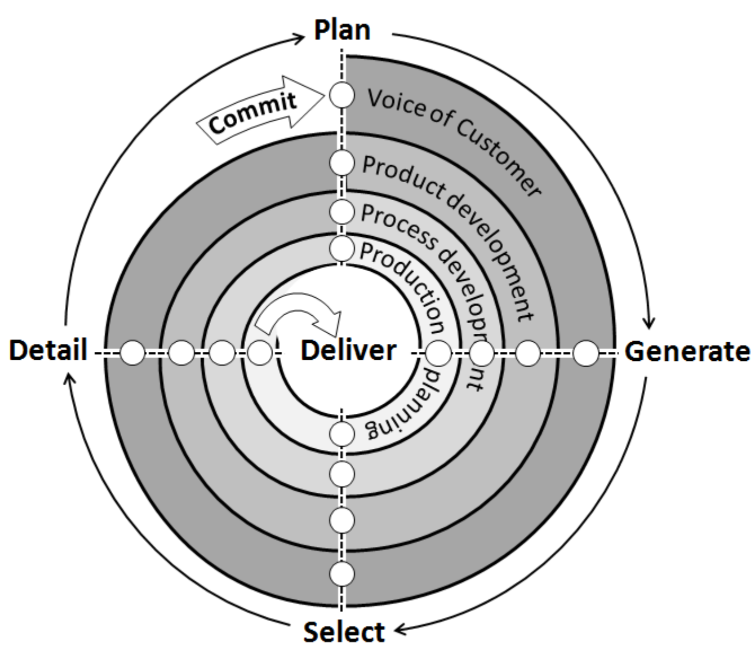


PREFACE

Quality and innovation are above all about people. Firstly, it is a natural human trait that we like to see others be pleased with the product of our efforts. We are thereby all equipped with an inherent drive for producing quality. Poor quality happens when people have either stopped caring; or when they have not got available to them the correct tools and information; or when a disorderly work process results in unintended oversights. Secondly, the human inquisitiveness and ingenuity, when combined with its continual natural craving for something more and better, manifest as an inherent talent for innovation.

To succeed in producing quality and innovation we simply have to enable an orderly process that assures against oversights and involves, effectively equips and informs people in applying their natural given drives. QFD does just that.

When recognised and allowed, people will generally get on with tasks without the need for any additional motivating. We simply have to be careful not to de-motivate – such as by subordination to assertive controls. The less formulated a work process is the more intense the supervisory management intervention tends to become. A well formulated systematic approach, therefore, can in a sense 'liberate' self-managing people to deliver their best. This involvement idea is contained in the spirit of QFD.

Frede Jensen, London 2016

GLOSSARY

D&D	Design and Development
DFM	Design For Manufacturing
FMEA	Failure Mode and Effects Analysis
HoQ	House of Quality
Innovation	Something novel of commercial or professional value
IP	Intellectual Property
ISO 9001	International standard on requirements for quality management systems
NPD	New Product Development
PFA	Potential Failure Assessment (FMEA variant)
R&D	Research and Development
RED	Robust Engineering Design
QFD	Quality Function Deployment
QMS	Quality Management System
Quality	(Generally) to meet or exceed requirements
VOC	Voice Of Customer

Introduction

The ability to 'think in action' and to plan the eventualities on an *ad-hoc* basis, as and when we encounter them, is an admirable human quality. However, it is a poor primary approach to product and process development. The design value creation and time-to-market are simply too important to be allowed to evolve haphazardly. It is a misguided belief that innovation is necessarily dependent on 'artistic freedom' and that it therefore cannot be systemised. The unsystematic approach is shown to have higher probability for oversights and unforeseen problems. This, on average, results in loss of project efficiency or yields less success.

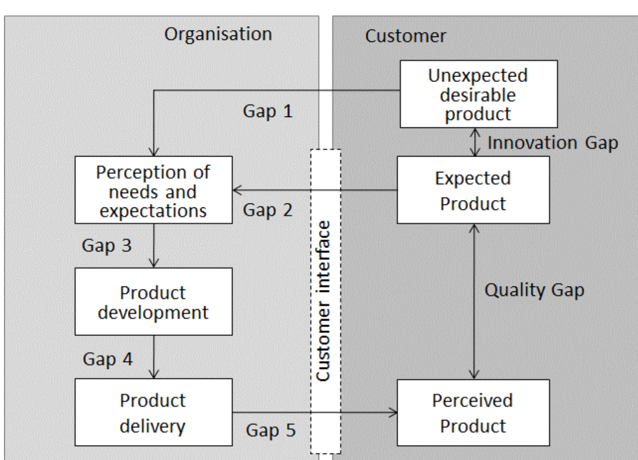
From experience, however, no matter how structured and thorough we are being, the complex field of product and process development can remain an inherently sub-optimal one. Firstly, there exists within the vastness of yet undiscovered solution space a near infinite amount of coming new ideas, which in the future, maybe tomorrow or maybe in 5 years' time, will inevitably out-perform the very best state-of-the-art that anyone is possibly capable of thinking up for today. Secondly, it is rare of the forecasts and assumptions that we input into a new product development plan turning out to be perfectly true, because they were based on an incomplete worldview in a snap-shot of changing time. This does not mean that we should therefore resign ourselves to simply accept the sub-optimum. We should always do our very best in exploring the solution space and in qualifying our input assumptions.

Quality Function Deployment (QFD) is a term for a team-based approach, which is intent on integrating customer needs up-front and on systematically maintaining them in focus throughout a development project. The up-front element includes searching of the solution space and the validating of design input assumptions. In concept, QFD thereby represents what any well-meaning and sensible project team would naturally want to do, whatever they choose to name their approach.

HOW DOES POOR DEVELOPMENT RESULTS HAPPEN?

When products and services do not fully meet customer, market or an organisation's expectations it is invariably because of some insufficiency or oversight in the designer's thought-process. Fixing specification problems too often become a post-launch activity, where with benefit of hindsight the designers can be heard saying: *"Why didn't we think about this earlier; it is so obvious and could so easily have been designed in from the very beginning"?*

The gap model relates the types of gaps in the organisation's world into their resulting gaps in the customers' world.



Model for customer quality and innovation gaps

The Quality Gap and the Innovation Gap result from a combination of Organisational Gaps:

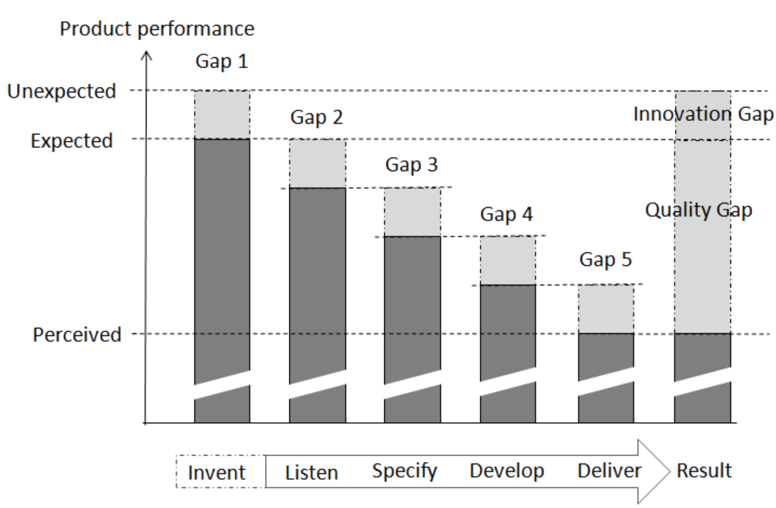
Gap 1: Inventiveness gap: Not thinking beyond current expectations, because customers are not yet asking.

Gap 2: Listening gap: Not knowing current expectations.

Gap 3: Specification gap: Poor translation into design requirements. Misinterpreting the standards.

Gap 4: Development gap: Poorly designed or under-developed product. Lacking solution. Lacking testing and validation.

Gap 5: Performance gap: Inadequate resources and/or poor performance in the delivery system.



Gaps sizing

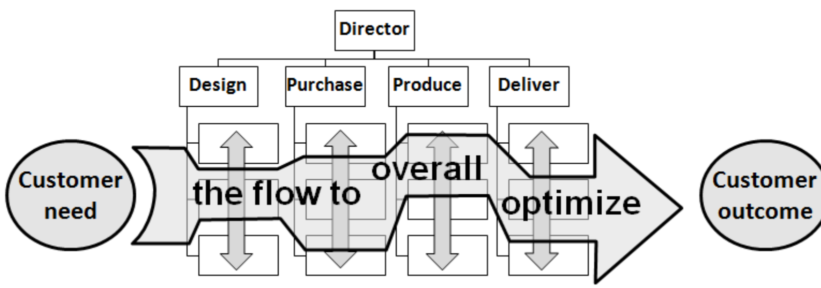
Ideally, we would want the actual perceived performance to meet the expected and unexpected quality – i.e. to end up with no customer gaps at all. The elimination of the quality gap is a prerequisite to customers becoming excited about any innovation. The appropriate sizing of the inventiveness gap (1) only really becomes important once the various other gaps (2 to 5) are assured. If we under-respond to the innovation gap then our product will not excite customers and it will fail to grow its success. If we over-respond then our product will risk becoming too 'alien', where prospective customers cannot recognise their need for it. This effect will be described later in the book. It will be demonstrated how the QFD approach is particularly useful in managing and optimally addressing all of the gaps in the model.

INTEGRATED TEAMS APPROACH

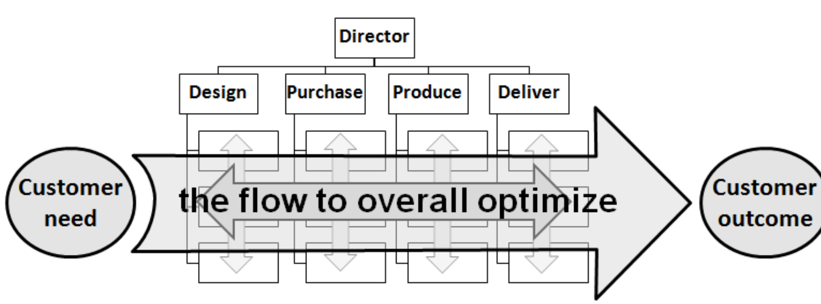
We can define an organisation's approach as integrated or non-integrated in terms of how its cross-functional teams collaborate on transforming customer input requirements into a corresponding output. In the non-integrated organisation, activities are divided according to the organisational structure. This results in narrower procedural thinking, duplications of efforts, handoffs and in tasks being optimised in isolation of the wider purpose. From the customers' perspective, they will perceive an organisation that has an internal focus and thereby becomes static to the evolving requirements – because customer needs reside outside the organisation and they never stand still.

Fact of the matter is that customers don't really care what goes on inside the development organisation. They raise a need and simply expect to receive a corresponding product in return. But this is seldom what is foremost being discussed day-to-day inside the organisation. Although all of the different operational areas have an overall common goal, they can often have differing and possibly even conflicting day-to-day aims. People with experience in industry may recognise discussions similar to the following. Design manager: "*I need this new part from a new supplier*".

Purchasing manager: "*No, I won't buy it because it conflicts with my goal of reducing the supplier based and obtaining overall best pricing for everything*". Production manager: "*I can't worry about what you select, because my immediate focus is on improving our production scheduling efficiency*". Delivery manager: "*I don't really care for what you all do, as long you do something that helps me cost-optimise the loading of my delivery vehicles*". All statements are of course important, but they are not coherent or focussed.



Result within non-integrated approach.



Result within integrated approach.

Instead of thinking of the organisation solely as a structure of departments, we should learn to also think of it as the whole process that flows across it. This enables us to better focus on and be responsive to the customer, at the start and end of the organisation's project. The involvement and responsibilities for managing the development project should be integrated across all functions within the organisation; in effect acting as one coherently interrelated whole, as opposed to co-existing as sequential entities. 'Team' is foremost the chain of differing functions across the organisation. The designer is just as much team with purchasing, production and delivery colleagues, as he or she is with other designers. The concept of integration falls apart when any one unit emphasises its own goals above those of the whole – i.e. seeking to maximise its own performance or benefits in isolation of the wider objectives, even when this is perhaps done with well-meaning intentions towards the customer. Any weakness within the chain is everyone's problem.

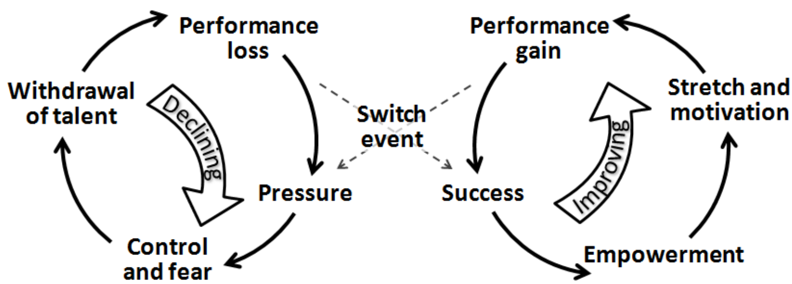
By nature of the short horizon-span in customer aspirations (they mostly prefer what they already know), systematic pure customer responsiveness will mostly lead to stagnation or incremental improvement only. Without looking further than the immediate customer demands there would be little structural re-design and innovation, and it would risk, in the longer term, never exceeding expectations or exciting the customers. Innovation comes from the organisation looking outside the day-to-day customer demands and start thinking up new ways of fulfilling yet unrealised needs that are not yet being demanded. If we teamed up exclusively according to the systemised process flow alone, and erased the functional groupings, then we may well lose the benefit of a critical mass for like-minded competencies getting together to do sufficiently evolved thinking and discover the next new thing. In practice, therefore, we will need to apply both team concepts simultaneously – i.e. recognise that every person within the development team belongs to both a functional structure and to a process structure. Later in the book, including the walk-though example in Appendix 1, it will be shown how the QFD team structure and involvement should be scoped up-front in the approach.

PEOPLE IN TEAMS

People are a particularly dynamic resource that has a significant impact on the outcome of development projects (and on all other performance areas within an organisation for that matter). Firstly, people are extremely adaptable and creative, compared to a machine or tool. Secondly, the individual person has an independent mind, which is sensitive to its environment. People's abilities, concentrations and commitments vary continually.

Peoples' value-based actions are something that cannot be taken for granted. Personal values are rarely well understood (by the person self or the organisation) or it is not always obvious how to align and leverage their powers. Where values do not align, a person will end up feeling they don't fully belong in the organisation. Such lack of connection creates a mental distance, which results in the individual only investing a smaller part of his or her discretionary talent and energy in the project. Clarity around the organisation's values alone makes little difference. Without any kind of deeper purpose or meaning to the individually held personal values, people simply won't pay attention to and 'live' the organisation's values. People have to be clear about their own personal values, and how these connect and contribute to those of the organisation, before they can commit to making principle-based decisions – to move beyond self-interest; to elevate the status of their work; to serve a greater good. Fortunately, most deeply held personal values tend to be few, rather common and stable. They are not impossible to find and usually align well to those of an organisation. We just have to highlight how it is that what is good for customers and the organisation also personally satisfies the project worker.

Organisations tend to drift across, or turn, between the self-enhancing cycles of its people declining or improving in the application of their discretionary talents. Generally, as long as people's feeling of involvement in the agreeable success of the organisation is greater than that of the pressures they feel, then everything should be moving in the right direction. Pressure is often linked to the forever increasing productivity demands and shortening deadlines exerted by the market, via the organisation. Pressure is not all a bad thing. It can have a positive effect in enhancing the sense of success. Success from hard work generally feels more rewarding than light work does. Pressure can therefore be good – as long the feeling of success is even greater.



Self-enhancing decline and improvement cycles

‘Control and fear’ creeps in when managers lose their composure under the pressure, and through lack of confidence resort to micro-managing. This results in people withdrawing their discretionary talent, and replacing it with risk aversion and political behaviours. The declining cycle represents a pitfall that can be hard to get out of. Even when things are going well, something unplanned can happen that puts excessive pressure onto the system and a switch into the declining cycle can occur. For example, a competitor may have created an unmatchable success or a sudden unplanned loss of a key designer resource has occurred. Likewise, when things are going bad, a small success event can become the turning point out of the decline. The positive break tends to be initially weak and has to be fuelled to take hold.

‘Empowerment’ is about giving people the freedom to self-manage, together with the responsibility and accountability that this entails. This is not the same as abandonment or cutting loose. People in a team will need to be furnished with the right skills and information for the context they operate within. The team has to also understand and align with the objectives and values of the wider organisation.

The systematically guided QFD approach provides a higher degree of confidence in the avoidance of insufficiency or oversight in the development and in the avoidance of misalignment to the organisational context. This enables senior managers releasing the talent that comes with empowerment, which results in an improving high performance of the development team.

What is QFD?

Yoji Akao, one of the founding fathers of the QFD concept, describes it as *“a way to assure the design quality while the product is still in the design stage”* (Akao, 1990). International Standard ISO 16355-1:2015 defines QFD, in its broader sense, as the “*managing of all organizational functions and activities to assure product quality*”. The Standard describes that QFD assures satisfaction by “*by designing in […] the requirements that are most important to the customer or stakeholder*”. The first reported use of QFD, by Akao with others in Japan, dates back to the 1970’s. In addition to quality-by-design, Akao demonstrates that QFD design management has helped reducing development time from *“between a half to a third”* of traditional approaches. QFD is an integrated team-based systematic approach for planning, communicating, and addressing customer quality requirements and competitive advantages, throughout the various stages of product and process development. By the term “approach” we simply mean a way of doing something, but not in a strict procedural or methodical sense. We can in fact use the QFD approach somewhat loosely, more as a concept, by adapting its principles with different tools and methodologies of choice, while still assuring quality-by-design. This adaptability will be demonstrated in our case studies in the Appendix. In one study, we alter the sequence of integrating process development in the design of a service product. Another study adapts for a shorthand approach.

QFD is also a project planning tool, but not in the conventional sense – such as a Gantt chart for determining responsibility and resources for doing what by when. **The QFD plan brings out details about what to do, and maybe in what order to do them, but it does not reveal who and when to do something.** The QFD project may therefore still use a Gantt chart for defining when to do specific tasks and to enable progress reporting to a project sponsor. It is not uncommon to hear a practitioner say: "*What does the QFD tell us?*", referring to the "*QFD*" as if it is some kind of a free-thinking entity. QFD is of course not free-thinking or in any way intelligent. However, it does act as a transfer function that is able to bring into perspective and reveal things that might otherwise have been unclear to us. Sometimes it will make us say: "*Ah, I didn't immediately see that, but now it makes good sense*". Practitioners often thereby attribute the creation of new knowledge to the QFD approach. Likewise, when intuitively we can see that something does not add up in a QFD output, then we may hear someone say: "*Ah, the QFD has got this one wrong*". Well, no, it has not. The correct term of phrase would be something like: "*Ah, the QFD tells us that we have overlooked something*". We can then find out what might have been overlooked and add it in for completeness.

If the name QFD does not form any obvious meaning to you then it may have to do with the way it is translated from its original Japanese writing. The literal translation does not make universal sense and it would read a little odd in a non-Japanese context. In the Western context, the three words making up QFD can stand for:

Quality	:	Meet or exceed requirements
Function	:	Specific activity of a product or process
Deployment	:	Organise for use

If we were to chain the words together, to try producing an overall workable definition for QFD, in a Western sense, then we may want to find somewhere we can add the bridging words "integration" and "transformation". QFD is very much about integrating everyone's contribution in transforming customer quality and stakeholder objectives into a corresponding product. In this context, the term "product" encompasses hardware, software, service systems and processed materials – basically, a "product" is any kind of output that has a customer. We can therefore apply QFD to any project that, for one, is a development activity and, two, has a definable customer. QFD addresses quality as a function of the designed system satisfying true needs – i.e. inherent quality – rather than thinking of quality solely as a post-design management function. This does not mean that post-design quality management is made redundant in its entirety. Instead it means that QFD aims to significantly reduce the reliance on it, by integrating quality characteristic up-front, into the designed product, long before we get to an end-of-design handover to the production quality management systems.

Frequently recognised advantages of the QFD approach:

1. Consensus-based co-working that breaks down interdepartmental obstacles.

2. Facilitates team self-management, which encourages the individual's contribution to the collective talent – as opposed

to people holding back on giving each other the full benefit of their true abilities.

3. Brings out and prioritises customer demands, within the context of market and organisation reality, and then transform them into planned development targets. At each phase throughout the development process it preserves customer quality. QFD reveals to us what is important, or not, together with any conflicts to be resolved for the value creation to occur. This increases the chance of creating customer satisfaction. The targeted working also reduces non-essential efforts, project time and cost.

4. The design targets can be adjusted for either generating radical new innovation or for producing a conservatively incremental improvement in a conventional product; or anything in between these two extremes.

5. Flexibly applicable to both new development and the re-design of existing products, whether manufactured articles or service systems, in the private, public or third sector.

6. Preserves information about development decisions in a way that maintains strong traceability of reasoning in the linkage between requirement and solution. This is particularly important for evidential purposes in the design of legally regulated and third party inspected products and processes, such as in medical equipment, automotives, aerospace, toys – increasingly everything now-a-days. It is also useful in retaining information, for referring back to during future design reviews. In this regard, there is an asset management aspect to QFD, where it is considered that information held in systems and processes is an asset (because it is accessible to all, secure, preserved, low cost), as opposed to information held in people, and which is therefore only accessible

through a human ‘gate-keeper’, is a liability (politicised, cost of ‘expert’ compensation, loss risk).

There are also some recognised potential matters to be mindful of when thinking about using the QFD approach:

7. The QFD project leader must remain functionally neutral during the planning stages – i.e. detach him or herself from their background functional focus. For example, if a multiple engineering domains development project is lead by a software engineer then we have to manage the risk of a bias influencing an unwarrantedly high priority on the software development aspects. The opposite would hold true if the same project was lead by a mechanical engineer.

8. Although QFD is not difficult, the basic understanding and skill necessary to effectively practice the approach still has to be sufficiently learned. Such skill demand can conflict with an organisation’s natural desire for adopting a least-skill (= least employee cost) approach to project management. Probably, QFD has therefore mostly been in demand from more advanced development sectors, where first-time-success or product safety is imperative; and from learning organisations that feel compelled to try something promising new to gain understanding from.

9. The systematically guided QFD approach, often including an algorithmic element, can appear objectively dispassionate. Similarly to any other value creation process, the QFD approach depends highly on people talent and inventiveness for its success. We have to be mindful of reserving space within the QFD project for playing around with and allowing a naturally motivated exploring of the design problem. The QFD tools must remain subordinate to the people and never

feel the other way around. Before we let ourselves loose on creating from the heart, however, the QFD is there to help us first develop and share a targeted and realistic game plan for roaming within, to assure that we keep our project's value creation on an optimised track.

10. QFD has been developing differently in pace and application within different world regions. On one hand, this has been favourable in terms of maximising its evolution by the theory of variation. However, there is sometimes much being made out of the differences between Japanese, European and American organisational cultures; where QFD was once said to be mainly a Japanese way of doing things. Today, global organisational cultures and the approaches to QFD are converging to the extent that it would be wrong to define it as being merely a regional tool. QFD is in fact for everybody – in its principles in particular.

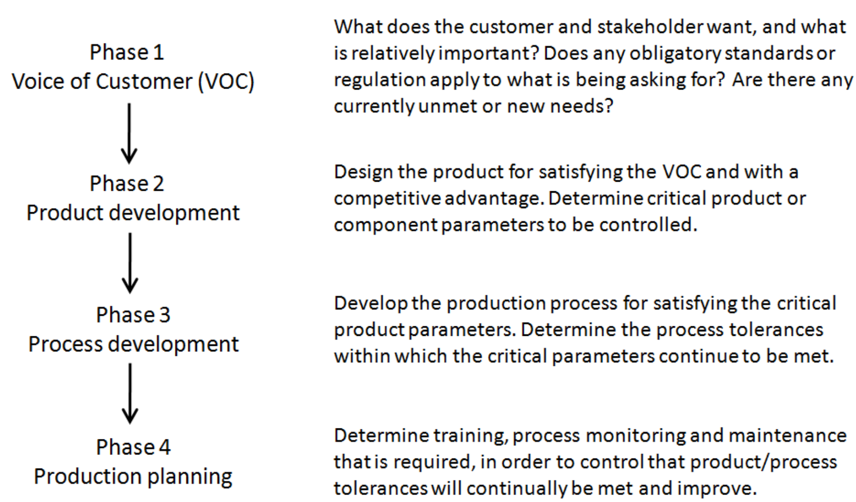
Although the concept behind QFD has been around for many years, the current variant approaches derived from it have not sufficiently matured to enable convergence into a single universally recognised standard. By comparison to other more established design and quality management standards, the standard on QFD can be said to be in its infancy. A national guidance was established in the Japanese JIS Q-9025:2003 on *"performance improvement of management systems – guidelines for Quality Function Deployment"*. This is followed internationally in ISO 16355-1:2015 on "*[...] General principles and perspectives of Quality Function Deployment (QFD)*". However, both standards are yet far off specifying a design management approach. ISO 16355 expressly does not specify any requirements or guidelines. Instead it describes and discusses a set of currently recognised principles and sub-sets of suggestive associated methods – some of which yet have low level evidence or carry trademarks. New standards do need a starting point and ISO 16355-1 is probably as good as any. Remember, it took the ISO 9001 quality management standard, including its forerunners, some 50 years of evolution and broadening, before it could be said to be workable for (nearly) all organisations. In a sense, QFD practitioners are still learners. The approach is continually evolving and being tailored for individual circumstances. It is a tribute to the adaptability of QFD, or whatever we may eventually choose to name it, when so many different practitioners demonstrate so many variant approaches and different tools within the concept model. This abstractness of QFD, however, can sometimes decrease the sense of certainty and confidence amongst the uninitiated. The various parts of this book will hopefully alleviate any such uncertainties. You should find the approach herein relatively easy to learn and use – but it is just one approach amongst many. The expectation is that the experience will eventually enable you evolving your own approach, to best suit your particular situation.

It is important that practitioners develop both deep and wide appreciation of QFD. The book reflects this in being divided into 3 manageably sized parts; where Part 1 is intended to get us concisely into the approach. Part 2 supplies an increasing depth of knowledge about associated tools and methods. Finally, Part 3 is a compilation of broader concepts thinking around strategy, product and process development in general. It is important to the learner and the early practitioner that the methodology is not overly abstract or complex. We therefore start in Part 1, with describing an approach that is evolved from the well-known Clausing model (Clausing *et. al.,* 1991). This variant approach is appropriate for most types of product development.

PART 1

The approach

The QFD-based approach presented here is based on the common 4-phase model. Defining a step-by-step approach helps overcome an otherwise perceivable complexity. It also helps better forecast the amount of work that is going to be involved, for purpose of project mile-stones and resources planning. The 4-phase model is somewhat reductionist in the number of development process steps, but is proven to remain perfectly capable.



The first thing that becomes clear to the uninitiated, when looking at the 4 phases, is that **product development is more than simply about designing and producing a model of something, for others to find out how to make**. The QFD product development project spans upstream, defining clearly what the customer wants; and downstream, to integrate the design of the product realisation system. **The QFD project team should span all of the functions that have significant impact across the whole phased development process.** The team should remain in place to assume responsibility for the initial post-launch customer feedback. **The QFD approach may emphasise development work by different functional groups at different stages, but is performed under the same umbrella project where everyone in the project team have oversight of and contributes to the end-to-end master plan**. This contrasts a non-QFD approach, where product managers, typically, will document a marketing requirements specification, based on their personal market insight, and then pass this specification over-the-wall for the designers to fulfil. The designers then interpret and develop the product in isolation of other organisational functions, before passing the finished design over-the-wall for a production function to start making it. Of course, walls are merely metaphorical and they are never entirely solid. There is always communication going on across the walls; but this tends to be mostly concerned with resolving missing information and design problems in the intermediary stages, where the communication is between the immediately up-/downstream pair-wise functions. For example, the product manager talks to the designers, but likely not to the production function further downstream. The designers and production functions, in an over-the-wall approach, do not have ownership or direct sight of the original customer's demands. Yet, they are the ones tasked with fulfilling them.

A further observation about our 4-phase approach is that the arrangement of activities happens to be well aligned with the mandatory steps in the legally prescribed regimes for developing regulated products, such as in medical and aerospace. It is one thing to design a safe and effective product specification, but such inherent quality is worth nothing unless the subsequent product realisation system is assured against producing something that deviates from the designer's intent. The regulated product cannot be placed in the market until the manufacturing system, including its materials sourcing, equipment, processes and people factors, is successfully validated against the product critical performance criteria. The 4-phase QFD approach helps achieve this within an integrated model.

Each of our 4 phases is now broken down into 4 distinct sub-stages. **The Plan-Generate-Select-Detail cycle is based on the general principles of moving from divergent to convergent thinking** within each of the phases. Divergent thinking refers to a creative and purely exploratory exercise, where we suspend judgement while researching solution space and generating a number of alternative candidate concepts. The convergence stages will subsequently select and turn the most promising solution into workable details.

Plan ⟶ Generate ⟶ Select ⟶ Detail

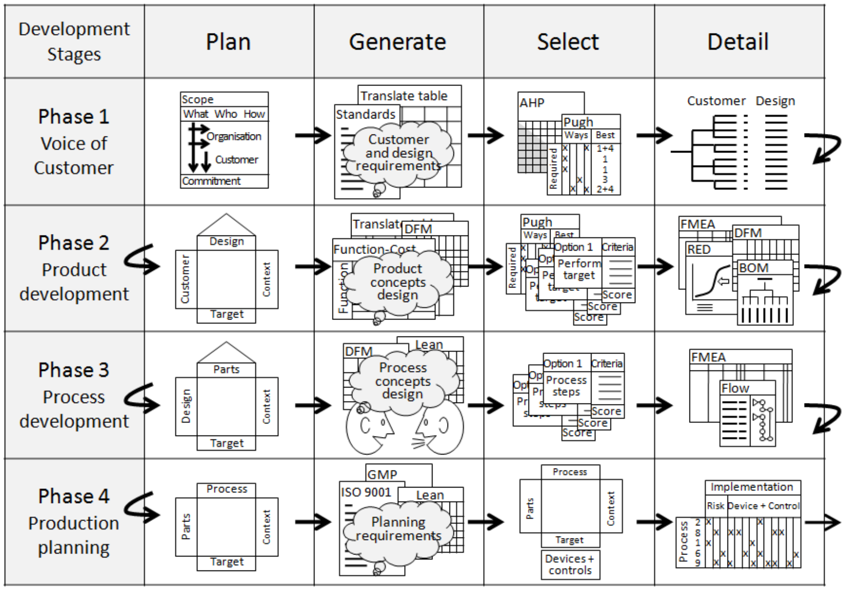
Each project phase starts with an evaluation of requirements and produces a prioritised ‘plan’ for what to do. The ‘generate’ step is where we research and develop our phase solutions. The solutions can range from being radically new to being conservatively old, according to what we set out in our ‘plan’. The ‘select’ step identifies the best option from our generated solutions. Finally we ‘detail’, or refine, our selected solution into a fully workable form.

The ‘plan’ step is where the QFD matrix tool adds particular strength. The matrix, which in some form is called the ‘House of Quality’, is constructed from what we obtained as the outputs in the previous phase. This assures the phases interlinking. Working the matrix, the QFD team deploys the quality characteristics that were inherited from the previous phase, to reveal a fresh set of new phase relevant characteristics for everyone to see. The fresh set of characteristics is inherently linked back to the very original set of customer input requirements. The ‘plan’ step at the beginning of each phase further performs a staged quality-gate function, where development activities cannot proceed until the QFD team is satisfied that the output from the previous phase is complete and translatable. And, if an output is not translatable, then it forces them to go back to the previous phase to resolve the matter. The QFD approach thereby incorporates the kind of staged design verifications that are defined in recognised good practice – e.g. in the ISO 9001 design and development section.

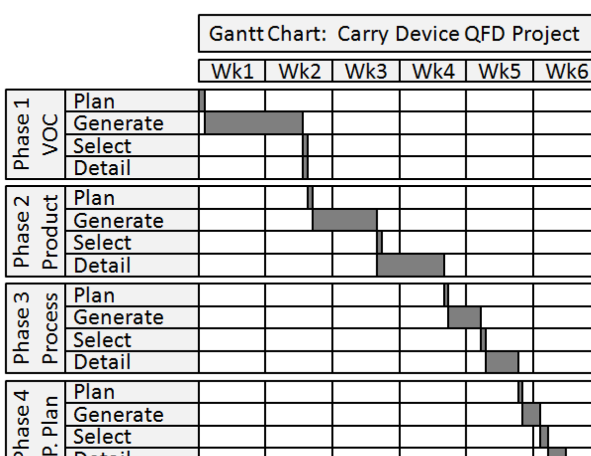
MATRIX OF MATRICES

It is now possible to systematically represent the overall model as a 4x4 matrix, with 16 distinct activity steps (see next page). Some of the individual grid cells in the matrix contain their own matrices, or tables or other form of organised data or information. The arrangement of the 16 steps could therefore be called a matrix of matrices, which is a term originally used by Yoji Akao. **The visual arrangement of knowledge and intentions into matrices, tables and charts has a beneficial effect in helping to identify any gaps or weaknesses in our plan**. Even when a team feels certain that it has all the necessary literal or intuitive knowledge that it will need for completing a project, it is only when it starts formulating and visualising the whole, and evaluating the interrelatedness of sub-sets of information, that it combines into a clearly coherent arrangement.

The 4x4 matrix that we have illustrated here (see next page) is populated with images representing various tools and methods for use in our standard model. In practice, not every cell on the outer matrix necessarily contains a sub-matrix. Instead it will contain whatever tool, table or chart that is most appropriate for the particular project; and we can in fact modify these to suit our purpose.



4x4 matrix for the standard approach



Example Gantt chart

It is not unusual for the QFD project leader to also maintain a Gantt chart, as a recognisable form for measuring and communicating progress monitoring reports to a project sponsor. As it would be expected from any product development, and as illustrated in the example Gantt chart here (relating to the Appendix, Case Study 1), it is the main value-adding 'generate' and 'detail' steps that tend to be the most time demanding. The Gantt chart rows here represent each of our QFD model 16 steps. We see that several are very short in time. Phase 1 'select' and 'detail' steps are scheduled as a combined activity, which is (generously) allocated what looks like one full day. In practice this activity may in fact be performed in just 1 hour.

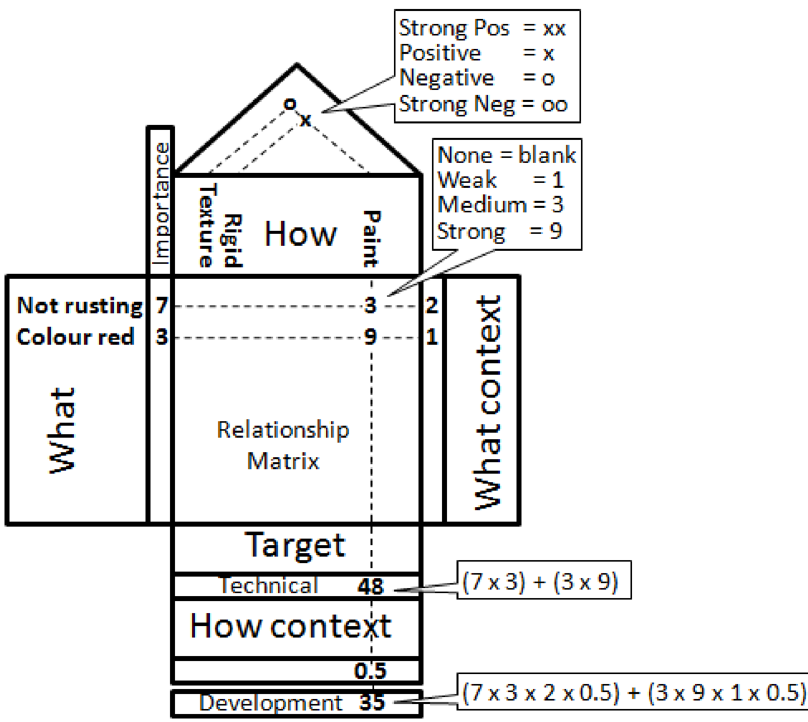
HOUSE OF QUALITY

The House of Quality (HoQ) is a matrix planning tool. Although often thought of as synonymous with QFD, it is worth reminding that the HoQ is not necessarily the only planning tool that can be used. Once we deeper understand the HoQ workings then we may find other ways to perform or approximate the same function.

The HoQ, firstly, records the translation of one set of input requirements into a corresponding set of development requirements. The HoQ does not perform the actual translation, but it does support the translation process indirectly by visualising its completeness and balance. It will help us see if anything is missing or if something is overemphasised in the development requirements that we have defined. The HoQ thereafter procedurally transfers the importance of quality characteristics in the one set of requirements into the other set of requirements, further visualising the interrelationships.

RELATIONSHIP MATRIX

The HoQ is simultaneously a transfer tool and a container for the planning activities, including presenting the output plan for what development to do. At the centre of the HoQ we have a matrix, structured with 'whats' on the left and 'hows' across the top. The 'whats' are the input, such as customer requirements. The importance of each individual 'what' is rated on a scale from 1 to 10, where a higher magnitude indicates a higher importance.



The house of quality (HoQ)

The 'hows' are the corresponding fulfilment features or functions, such as design requirements that we have already translated out from the 'whats'. The central matrix is a grid for intersecting all of the individual 'whats' and 'hows'. The QFD team scores the strength of relationship, for each of the individual grid positions, as one of ‘blank’ = no significant relationship, 1 = weak relationship, 3 = medium strength relationship, 9 = strong relationship. The scoring activity involves team discussions and consensus building. The time spent discussing and scoring a 15x15 requirements matrix does likely not need to exceed 1 hour – unless it has some exceptional complexity or if missing inputs does that the session is widened to also determine the lacking information. Time beyond the 1 hour can be considered to have a diminishing return of value over the time-cost used. The HoQ may look a little complicated when first encountered, but it is actually an easy-to-learn and rather procedural piece of work. Once we have completed one matrix then the others are practically similar.

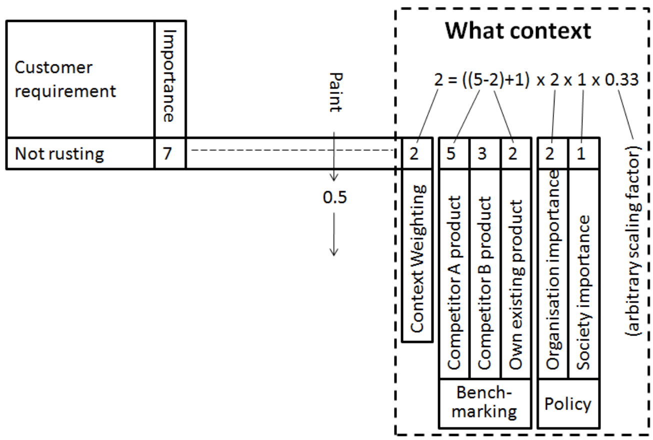
The example HoQ here contains, for illustration, only a few data items. The input requirements for “Not rusting” and “Colour red” are respectively rated by customers as 7 and 3 in importance. The design technical response “Paint” scores medium (=3) in its relationship to “Not rusting”. This is because the paint here is not our principal solution to rust protection, but it does nonetheless have a contributing effect. “Paint” scores strong (=9) in its relationship to “Colour red”. This is because the paint is the principle solution to colouring. The summed-up technical score of 48 reflects the magnitude of customer importance for “Paint”. This score is the one that we will judge our technical solution against. Each interrelationship is further multiplied by a ‘what context’ and a ‘how context’ weighting, before the values are again summed-up for the column, to give us the design development importance for “Paint”. The resulting development importance for our “Paint” is 35 [rounded]. The reason that we need to place relatively less emphasis on the “Paint” development activity (moving from 48 down to 35 in importance score) is that our ‘what context’ tells that the “Colour red” in our existing product solution is already competitively satisfactory. Also, the ‘how context’ tells that we already have the technical ability to select and apply paint. Basically, “Paint” is not going to be a difficulty for us in our development work plan. All of the 'hows' are now calculated in the same way. The various individual design technical requirements will end up with differences in their scores. The magnitude of an individual score, compared to the other scores, indicates the item's relative priority in development planning terms. We can normalise the scores to 100%.

CONTEXT WEIGHTING

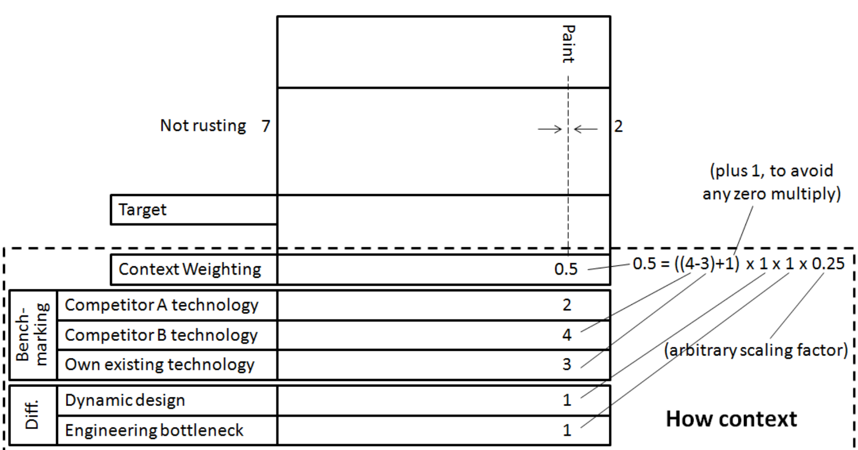
The weightings concept is about emphasising or de-emphasising the development focus on individual customer requirements, to reflect the commercial competitive situation, organisation strategy, or the foreseeable degree of difficulty in achieving the stipulated development targets. **Depending on the organisation's product strategy, we can turn QFD into an innovation approach by amplifying the context weightings for customer requirements that have simultaneous scope for novelty and commercial competitive advantage.** Similarly, we could also play down innovation, by simply leaving these same context weightings at unity gain. Or, possibly, the product strategy could be to emphasise attention to design requirements where we can recognisably differentiate from competitors, without it necessarily being in innovative ways – just distinguishably different. Lastly, we could also force conformance to conventional design solutions, by reducing the context weightings for the associated requirements. This may be necessary, for example, for an aspect of our design that must remain 100% compatible with a prescribed industry standard. In such a situation we are forced to straightforwardly copy the proven standard, which makes the item relatively unimportant when it comes to allocating our resources and development focus.

The 'what context', on the right-hand side of the HoQ, performs a competitive benchmarking and organisational strategy/policy weighing. The exacting measures used in the 'what context' can be varied for different markets and organisations. In returning to our earlier example HoQ, let us consider that our competitor has established a best-in-class rust protection. Our competitor's strong position has led to us weigh the context for "Not rusting" by a factor of 2. This will help amplify the relative importance of all design requirements that are in relationship with "Not rusting", and will thereby increase our attention to developing good rust protection.

It is not normally advisable for the 'what context' weighting to exceed a maximum value of 2. Otherwise we risk losing relativity when visualising our results. In the detailed calculation shown (next page) we have introduced an arbitrary scaling factor of 0.33, which limits the largest item weight to a value of 2. Because of the scaling being applied equally to all of the 'what context' items, it has no effect on relativity in the algorithmic translation – only on its collective magnitude. Without this scaling factor, for example, we would have lost the visual correlation between the values 48 and 35. Context weighting is a somewhat subjective activity. It can be expected that different organisational functions within the QFD team sometimes have conflicting views on how much we adjust the development focus on a customer requirement in this way. Again, the weighting activity involves team discussions and consensus building. **Remember, we are not modifying the actual customer importance rating; but we instead create the development priorities with which we respond to the customer rating.** The customer importance rating belongs to the customer, meaning that it is not ours to change. In fact, it is important that we assure its integrity, to enable its valid use for continually judging our design solutions against. Everyone in the QFD team will usually be able to see if and when a context weighting starts to overly distort the chance of achieving what the customer has asked for. As long as the matrix scoring team is representative of the various organisational functions, then the context weightings will usually turn out reasonable and the HoQ will produce a sensibly prioritised development plan.



What context



How context

The ‘how context’ performs a technology, or solutions, benchmarking and difficulty weighing. The benchmarking compares our own pre-established technical solution for addressing each design requirement, to the technical solutions found in competing products. If we do not yet have any pre-established solution for the particular design requirement, and if we also do not have one available to us from a third party (e.g. it is not easily or effectively bought-in), then we would score ourselves lowly in the particular benchmark. And, if a competitor product simultaneously scores highly in this benchmark then it means that the development work we have to perform on the particular item become even more important – if we are to succeed against our competitor. We would therefore want to increase the ‘how context’ weighting for the relevant item.

The ‘difficulty’ sub-evaluation involves an assessment of design dynamics and engineering bottlenecks. This highlights the demands on effort and potential issues in achieving the technical targets. The information helps us manage the project schedule and budget. There are many possible sources for difficulties, including – but not exclusively – technology immaturity, designer qualifications and experience, manufacturing capability, or supplier capability. If we do not manage the associated risks then they are likely to result in project delays and unplanned costs. Our project can therefore only accept a manageable total amount of difficulty. When the limit for this ‘difficulty budget’ is reached then we are forced to find ways to reduce the net difficulty (unless it makes sense to increase our budget). Say, one design requirement is for a metal shielded enclosure. If our organisation does not have any pre-existing knowledge or process equipment for metal working, then our initial thought may be to find an alternative solution, to try avoiding a design in metal. However, if metal is a firm commercial imperative, and there is no other way around it, then we are forced to develop a new metal working capability. This would increase the degree of difficulty that we can expect to encounter for the enclosure specific design requirement in our development project. We would therefore want to increase the 'how context' weighting for the metal enclosure requirement. When on a budget, we may in turn be forced to find time from within other development activities, in order to enable the enlarged development for metal working be met. One way to 'find' time would be to decide, for example, not to investigate any new paint options and to straightforwardly re-use the paint solution that we know already. In effect we would make paint a 'static' solution, which decreases its 'how context' weighting. Having beforehand transferred customer quality characteristics into the design requirements, we can make informed decisions about where to allocate our 'difficulty budget' – namely where it will do most for achieving overall customer satisfaction. At times we will be forced to reduce our planned activities, to ensure that available resources can realistically complete the development tasks within the given time and cost. Again, the prior relationship matrix work tells us where we can and cannot compromise.

'Dynamic design' scores high (=2) when we decide to perform advanced or new development of a more 'dynamic' solution. It scores low (=1) when we decide to meet a design requirement with a 'static' solution through more straightforward product engineering, using a pre-existing or incremental solution. We can shortcut the 'generate' and 'select' steps in our QFD approach for 'static' design requirements, to simply refine the pre-selected solution. The separation into distinct 'generate' and 'select' steps only becomes more important, and resource demanding, when creating something novel 'dynamic'.

'Engineering bottleneck' is the estimated potential – scoring 1=unlikely, 1.2=possible, or 1.5=likely – for the development of a design requirement becoming a cause for delay or a drain on resources (in avoidance of a delay). The rating is in part judged with respect of the 'dynamic design' assessment. If all of the dynamic aspects are placed in a single engineering domain, then we can expect designers in this domain being overloaded with work, while those in other engineering domains being 'under-loaded'. For example, if we make all our metal work items 'dynamic', while making all our electronic design 'static', then the mechanical engineers are going to find themselves overly stretched, while the electronic engineers may have excess time on their hands. To avoid bottlenecks, there is a need to balance the project work to the kind of resources that we have available; or, better, rebalance the resources to the kind of project work.

The choices made in the 'difficulty' assessment define the degree of ambition that the project team is setting itself, in terms of workload and value creation. The business case, sponsoring the project with time and money, will normally have predefined the required degree of ambition, in terms of the minimum value creation that is required. In case of any doubt, it would normally be a good idea to test the 'how context' assessment with the project sponsor, to ensure that it remains in agreement with the original business case for the project.

CORRELATION ROOF

The correlation roof summarises the interdependences between the various 'hows'. For each grid position in the roof, we ask: *"Does the pair-wise set of 'hows' either enhance or impede each other in the design"?* A positive correlation indicates an enhancement in one or both of the 'hows'. A negative correlation means that the paired 'hows' are in conflict and that a design trade-off is required. We sometimes quantify the correlation as being either weak or strong. Understanding the correlations between the design requirements can be used in three ways:

1. When conflicting design requirements are looked at in combination with their respective technical importance, it helps us define an appropriate trade-off position that bears relation to the transferred customer quality requirements.

2. It highlights an opportunity to think inventively, where clever solving of a conflict difficulty would help create a competitive advantage (see TRIZ in Part 2 of the book, for example).

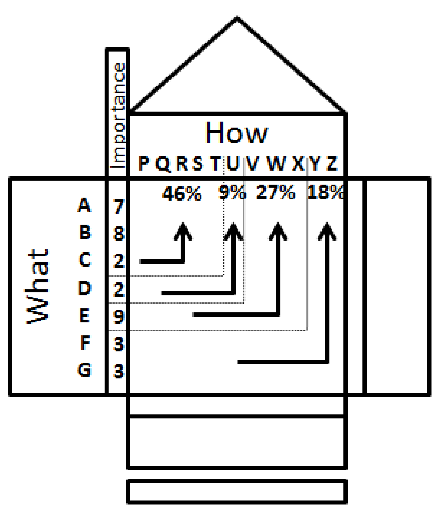
3. It shows us design aspects that are independent of each other, and which can therefore be developed concurrently. It also shows us the ones that are interdependent, and therefore have pre-conditions to the plan for their development.

In the earlier example HoQ, the design requirement for a surface "Texture" is shown to have a weak negative correlation with the requirement for "Paint". This is because the more a surface is textured; the more difficult it becomes to paint it. The requirement for a "Rigid" structure has a weak positive correlation with the requirement for "Paint". This is because a rigid structure is generally better for paint adhesion and longevity, compared to flexing structure.

BALANCED TRANSLATION

The translation of 'whats' into 'hows' is particularly influential on the HoQ algorithmic transfer function. Rudolf Jussel, fellow student from years ago and a friend of mine, tried for the purpose of sensitivity testing to completely inverse all of the customer importance ratings in the 'whats' section of a large HoQ that had many-to-many relationships (Jussel *et. al.*, 1999). The resulting changes to the outputs of the matrix where surprisingly modest. What we came to term the 'Jussel effect' demonstrates that in a large matrix with many-to-many relationships, which is not uncommon, there is a degree of tolerance to imprecision when scoring the 'whats' and 'hows' interactions. The effect can potentially mask flaws in the requirements translation. We must therefore take additional steps to assure that the translation is performed well. Our QFD teacher at the time, Dr Mark Atherton, suggested that the Jussel effect diminishes when the quantity number of design requirements that are translated from each individual or grouping of customer requirements reflects the relative importance rating of the latter. This is what we refer to as a 'balanced translation'.

There has to be that certain balance between the 'hows' and the 'whats'. By this we mean that **there should be proportionality between the importance rating of an individual or related group of customer requirements and the quantity number of design requirements that we translate from it/them**. Common sense tells us that it would be wrong to establish an enhanced focus, by translating a large quantity of very detailed design requirements for our attention, on something that the customer has rated lowly; while simultaneously establish a lesser focus, by translating only a very few design requirements, on something the customer has rated highly. It is not essential that the number is exact, but it should not be too far out either. This balancing should be assured before we start performing any relationship scoring.



Principle for a balanced translation

If a customer requirement is highly important, but the QFD team in the first instance is unable to translate more than a single design requirement from it, then try breaking this single design requirement down into its more detailed constituents. We can return again to our earlier illustration of the "Paint" requirement, for example. Apart from its colour, paint has a number of other attributes, such as surface primer, top coat, thickness, finish (matt, silk, gloss), abrasion resistance, toughness (cracking resistance), and adhesiveness (chipping resistance). If "Paint" was found to relate to a number of highly important customer requirements then it would only be sensible that we better focus on and develop its attributes in more detail. Likewise, if the customer importance for "Paint" was very low, but the QFD team has managed to identify a disproportionally high number of design requirements for it, then try simplifying or merging the multiple design requirements into a reduced number – e.g. revert to just calling it "Paint", for the planning purpose. We cannot identify any adverse effects from creating multiple design requirements in relation to a single customer requirement, other than it will increase matrix complexity through more details. Inappropriately few design requirements, on the other hand, could mean too low a matrix resolution or incomplete translation.

MATRIX RESOLUTION

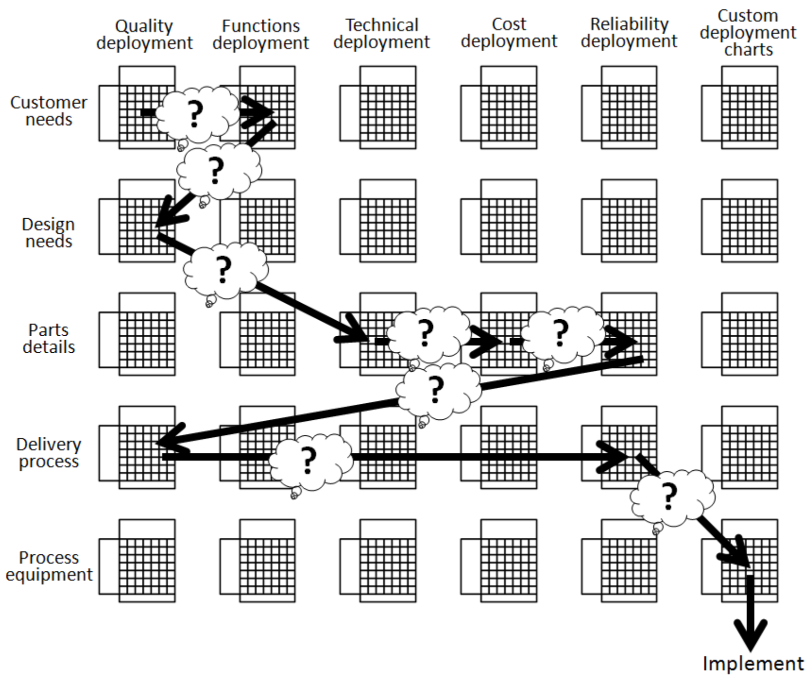
Determining the appropriate level of details in the translated development requirements is a double-edged sword. On one hand, people can lose oversight if the resolution becomes too fine, where the multiplicity of details makes the HoQ so complex that we can no longer visualise the rationale behind our design decisions. People, including the overseeing project sponsors, will perceive a diminishing return-on-investment from efforts, as we grow the amount of work that is required to manage and evaluate a larger number of increasingly trivial planning details. Yet, on the other hand, if requirements in the HoQ are over-simplified then people may (rightly) suspect that important details are being left out. The QFD team members need to have confidence in forward-applying the outputs they obtain from the HoQ.

The Jussel effect teaches that we do not necessarily have to work to decimal points or evolve elaborate, time-consuming methods for scoring the HoQ matrix. Integrating more advanced algorithmic tools, such as fuzzy logic and AHP, may have a place in certain QFD user communities, where it can possibly contribute to user confidence in the output. But remember, in many practical commercial QFD projects, reality is that some team members are non-scientific or are new to QFD and they may not naturally have the fluency in reading a busy algorithmic HoQ. These people will have a lower threshold, before switching off to a perceived academic level of complexity. It is the people in the QFD team who produce quality and innovative design. **Losing the participation of project team members is significantly more critical than it is getting the odd planning refinement perfectly right**. By this is not meant that we can get away with sloppy workings. The HoQ should be worked effectively and efficiently; but its level of details should only be refined to a point that is before people start to fear that they cannot cope with the perceived complexity. Sometimes we have to be brave when simplifying, because peer professionals may look at our work as if it is of lower quality. Just remember, a simplified smaller HoQ, although appearing unrefined to the purist QFD practitioner, still maintains a merit in getting everyone around the table co-working and producing a targeted design. The fact that data is worked at a lesser resolution makes it important to confirm with all team members whether the output from the HoQ agrees with their experiences and intuitions. And, if not all can agree, then we must look at the data again, to resolve any issue. We should not consider the HoQ work completed until everyone is in agreement that its output makes sense.

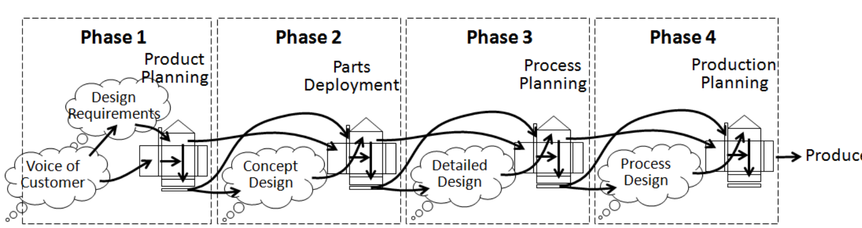
Case Study 1 in the appendix presents a walk-though of the standard approach and HoQ described until here

ADAPTING QFD

In theory, QFD can be applied to any kind of development project that has a definable customer. However, sometimes the product or project circumstances are so unusual that it does not quite lend itself to the standard approach. Yoji Akao recognises that **every organisation has unique conditions and that it is important to be imaginative in applying the QFD**. It was Akao who coined the term matrix of matrices, to which he adds customised tables to suit individual projects. Common project examples presented by Akao deploy about 7 to 12 matrices or special planning tables. The many stages interlinking within Akao's matrix of matrices exist in a lesser formal structure, which can come across somewhat abstract or complex in their presentation to people outside of the project. GOAL/QPC, an American training source, produced a more structured guide version in form of a 30-matrix of matrices (ReVelle *et. al.,* 1998). Not all matrices are intended for use in every project, but the practitioner can map a truncated route that best suits the particular development. The adapted 30-matrix framework shown here (next page) presents a hypothetical project pathway through 9 matrices. Design transformation activities, represented here by a small 'thinking cloud', are taking place in between the interlinked planning and deployment matrices. The acclaim is that investment in planning activities in each development stage – i.e. before each thinking cloud – will improve outcomes and save time over the whole project period. Although each location in the 30-matrix is illustrated by a sub-matrix, the locations may in fact be occupied by any other analysis, planning or deployment tool.



30-matrix guide model, adapted from GOAL/QPC, illustrating a selective 9-matrix project path



Clausing's 4-phase (4-matrix) model

Clausing presented a truncated, more predictable 4-matrix approach (Clausing *et.al.,* 1991), which has become widely and successfully applied. It emphasises the House of Quality (HoQ) matrix tool, which in many industries has become synonymous with QFD. The term is catching, but is not always helpful to the novice. The HoQ is sometimes mistaken for being the QFD approach in its entirety. Those who think QFD is merely a matter of building a HoQ will be left wanting for something else to happen in between the phases. Any belief that QFD is solely about numerical processing and that it can somehow automate the design process is also flawed. The HoQ helps bringing out the requirements at each development stage, but not necessarily any design details. The QFD team will periodically refer back to the HoQ for evaluation and visualisation of requirements; but there is in fact a lot more creative working going on, in order to establish the details that are needed as inputs into the HoQ. The project team will spend most of its time outside of the house. Other tools and techniques are applied to the work outside of the HoQ. Fortunately, QFD integrates with any technique of choice and will normally overlay, to enhance, any existing development methods that an organisation may already use. **The creation of quality occurs when we define a new want and then deploy or develop some system in effectively responding to it.** Although the HoQ tool is thereby an important link in the quality and value creation process, we should be careful not to focus too much of our available time or resources on the activities inside of the HoQ.

There is a lot of merit in a standardised QFD approach. In OEM business, for example, clients want to be assured about the inter-companies methods compatibility and the effectiveness in contract designed products. On a down side, one shoe never fits all. QFD practitioners will often adapt the standard approach to individual situations. It is unsurprising that we can find Clausing's 4-phase model depicted in so many varied forms. The variant shown here reflects the common method of working towards information recording and evaluation, in a HoQ in each of the four phases. The development activities, therefore, are seen to precede the house in each phase. The HoQ then produces the planning priorities for the following phase. The 16-step QFD-based approach taught in the preceding sections of this book is similar to the Clausing model. Only, we have depicted the phase boundaries so that each of the 4 phases starts with a planning activity – e.g. a HoQ. The 16 steps are not actually many, when considering that this spans everything from customer requirements capture, to product and process development, and production planning. However, in smaller projects, two or more adjoining steps may practically be combined into one QFD team sitting – i.e. combining the overall number into less than 16 actual activity sessions. For larger projects, some practitioners may find the 16 steps too truncated and would probably elect to widen the project in some areas, which of course is perfectly in order. For example, for complex product assemblies, the product detailing step in Phase 2 may be expanded with its own additional planning phase, similarly to Clausing's "Parts Deployment" matrix.

The concept of 'context weighting' was introduced by Akao, although he termed it a "*quality planning tool*". The 'what context' may be modified to include different kinds of evaluations, to reflect different markets or different values within an organisational strategy, covering:

- Competitive analysis, representing where we are compared to others at present.
- Quality innovation plan, representing where we want to be.
- Sales point, representing how well a satisfied requirement can help in marketing the product.

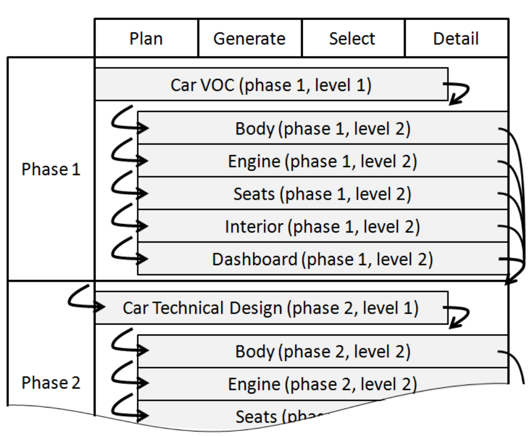
Case Study 2 in the appendix presents an example QFD adaptation in service development

SCALING QFD

In larger development projects, with many component elements in multiple interacting sub-systems, such as, say, a motor vehicle, it would be practically impossible to include everything in a single giant planning matrix. The complexity by multiplicity would simply drown the important information in an ocean of the lesser important – or noise in effect. It would be difficult for the QFD team to visualise how it all fits together and to reliably extract its priority information. So, what is an appropriate number of requirements to manage within a single HoQ-type planning matrix? A very few design requirements, say 2 or 3 only, are so easily resolved that it would hardly make it worthwhile setting up a planning matrix. As for higher numbers, several factors can play in, such as the level of resolution and many-to-many relationships; but as a rule of thumb for a single planning matrix:

5x5 requirements are simple
10x10 requirements are easy
20x20 requirements are comfortable
30x30 requirements are many
40x40 requirements are too many

Like in any other project management methodology that contains an excessive number of requirements to be evaluated and mutually resolved, **the large QFD project is broken down into a hierarchy of interrelated sub-projects**. At the Level 1 QFD (top level) the technical requirements are collected into their functional headings. For (a simplified) example, it may consider the car technical system as simply made up of a body, an engine, seats, interior, and a dashboard. When transferring customer requirements into this Level 1 QFD design requirements, the evaluation and planning matrix tells us, for example, about the relative importance of the seats. It will not give us sufficient details about what is important about a seat, but it will tell us overall how far we need to go in developing the seats, relative to the overall customer requirements. We can now assign the seat development an appropriately resourced and focused QFD sub-team. This seat development sub-team will in turn itself seek a more detailed understanding of seat-specific customer requirements and translate these into the more detailed seat design requirements, such as cushioning, headrest, adjusters, texture, fabric, colour etc, etc.... The car seat QFD is temporarily semi-detached from the parent QFD. In practice, no team can work in total isolation of the wider project. When we come to scoping our QFD sub-project, the seat development team will have set up co-ordination and collaboration with other sub-teams. For example, the seat design sub-team will probably have lots of cross-linking with the interior design sub-team, to ensure that their respective solutions will successfully integrate, to eventually form a whole. On the other hand, the seat design sub-team will probably not need to co-ordinate with the engine development sub-team.



Hierarchy of QFD parent and interrelated child projects

Taking our car example further: If in the Level 1 parent QFD we determine that our existing engine solution, from our already established car range, is competitively capable of continuing to satisfy customer requirements, then in the Level 1 QFD we can define the engine as a 'static' design requirement – i.e. one that does not need to be significantly changed, and one we therefore can give relatively low priority to in the ongoing development. The engine QFD sub-team may then be allocated less, just sufficient resources, to make the relatively minor peripheral design changes – e.g. layout of radiator fixings or maybe a different fuel inlet connection will be needed, to ensure that an existing engine solution is made compatible for the new bodywork engine compartment.

At the end of each 'detail' stage, at the end of a phase, the various Level 2 sub-team outputs re-integrate back into the next phase Level 1 QFD planning matrix. Thereafter, the detailed activities are again allocated down to the QFD sub-teams, and so on. **The referral back to the Level 1 parent QFD at the beginning of each phase is important, as opposed to just letting the sub-teams straight finish their respective projects**. Just because the seat was more resourcing important than the engine in the <u>product</u> development phase does not necessarily mean that the same holds true for the <u>process</u> development phase. For example, the manufacturer's generic seating production process may already be well developed, in a competitive quality and cost sense. It can in this phase, therefore, be defined as 'static'. Unlike the seat, the pre-established engine production process may in fact prove ineffective, in terms of competitively meeting the translated customer input requirements for cost and consistency. In such an example case, we may now need to spend more time developing the engine production process, even though the engine design itself remained practically unchanged.

SHORTHAND QFD

Real life is such that we do never have the luxury of unlimited time and resources. Also, the development starting point is not always the same for every product. These are common project constraints that must influence our practical choice and scope in approach. For example, the company might have well-developed platform solutions, where the new product, therefore, becomes simply a matter of re-configuring or adapting its pre-existing modules. This would significantly shorthand the QFD process for the new product. Or, the company might already, prior to commencing the QFD project, have extensive and very detailed data on customer preferences. This would enable it to shortcut the VOC phase, by making it simply a matter of clarifying the existing data for the project and ensuring that they are visible to the developers. In another example, in the real commercial world, the developing organisation may be severely short of cash funds, and simply cannot afford the resources required to perform an extensive product development project; while on the other hand, it cannot afford the result of developing a poor quality product either. Such an organisation will have to make a necessary trade-off in getting the best possible result for the least possible investment. In one respect, a full QFD could support this scenario. However, at other times it would be tactically clever to do shorthand QFD instead; compared to start doing it longhand and then run out of time or money halfway through the project. A shorthand approach can still bring us some of the QFD advantages in such a situation. In yet another example, it happens that a customer need has sprung-up so suddenly and is so critically important that we are forced to put urgency before perfection.

The emergency response to a natural disaster comes to mind, where it could be perfectly valid to say: *"Quickly, get something basic out to our customers for now. We can discover and fix any issues later"*. In an emergency-type situation, our desperately needy customers would not expect anything differently from us. Where special circumstances demand there is nothing wrong in trading speed for the risk of an inferior result. Again, shorthand QFD could be preferable. If the situation allows, we could return to the QFD post-launch, once the immediate emergency situation has receded, to refine the development work for a longer term improvement upgrade to the original product.

The question is about how to get the best possible out of QFD in a compromised situation. We can more or less shortcut every step in our 16-step approach, or we could combine a couple of steps into a single activity. **What we cannot do, however, is to eliminate any step all together. In the very least, a step must be performed in a team's mental process. Otherwise it becomes a different kind of approach and we will lose the inherent advantages of QFD**. In general, we should try cutting the least corners in the earlier phases. If we get the output from Phase 1 wrong, for example, then everything that follows will be wrong; and it probably becomes more difficult to fix the problem post-launch.

Although the founding of QFD is based on evaluation matrices, as containers for the planning activities, it is perfectly conceivable that the concept of QFD can be implemented without using any single matrix at all. The spirit of QFD lays in a team-based process for maintaining visibility and integrity in the VOC, when translating the characteristics in one domain into characteristics in another domain. In a 'plan' step, we could substitute the HoQ – if we have to – by deploying a smaller translation table or a chart instead. Or we could, in the extreme, simply translate and transfer requirements in a team discussion session, off paper. We should do so in the understanding to the project team that they are about to lose the opportunity of the HoQ bringing out new learning – about the development focus and priorities. The 'select' step may also be performed as an off-paper team discussion, followed by a show of hands. This could be practically achieved in a matter of minutes. In the 'detail' stage we have to do enough work to ensure the product can perform its basic required functions, and that these relate to what the customer wants. However, we may get away with shortcutting some of the optimisation and aesthetics work. Instead of performing a time-/cost-consuming design-of-experiments for determining an optimum mechanical dimension, for example, we could simply and crudely select a known over-design dimension. This is not necessarily a pretty solution, but it would under certain circumstances be perfectly appropriate for purpose of urgency or development time-cost reduction.

Two further things we can never do are: Firstly, we cannot exclude the cross-functional project team from the involved and transparent decision-making process, by leaving high-level decisions to individual designers or by the project leader making planning decisions for him- or her-self. If this happens, then the process becomes a different kind of approach and we will lose some inherent advantages of QFD. Secondly, when sufficient time and resources would otherwise allow the complete process, then we should not simply cut corners just because we cannot be bothered doing the necessary work. Plain laziness is never good, whether it is in QFD or any other approach. The project result will always be thereafter. As for any kind of development, it can be particularly false economy to reduce the upfront analysis and planning efforts. Are we inclined to laziness, or if our personal motivation is at a temporary low, then the project may be better served by handing over the control to someone more able.

Exceptions to completing the full QFD approach are sometimes seen. For example, using our QFD approach Phase 2 alone, within a wider, conventional or unconventional, new product development (NPD) project can yield a localised benefit in the transfer of customer quality and innovation objectives into the design. The HoQ can also be beneficial as a standalone tool for identifying priorities and resolving any requirements conflict, when planning for a product or process design activity – i.e. when using a non-QFD team structure or different design methodology to the generate-select-detail steps.

In another example, the organisation can use our QFD approach initially, but stop short at Phase 2½. This means that QFD Phase 3 is being shortcut, to develop only a rudimentary process definition. The incomplete process is then set in motion to start producing either test products or customer products. QFD Phase 4 is omitted. Under a program of 'kaizen', a philosophy for continuous improvement, it is then left to all employees, instead of the QFD team, to collaboratively and continually improve the process, as they learn about what works and what does not. Although being more risky at the start-up, the promise is that the collective application of talent and the sense of process ownership will eventually yield high quality results. Despite the differing in approach, the thinking is not too remote from the spirit of QFD. The circumstances would have to be right for allowing for such an approach. It may not always be efficient to trial produce or it may not be acceptable to debug an incomplete process using real customer products. For instance, safety authorities and customers would probably not accept the release of a learn-as-we-go-along aircraft build. Safety regulated products will have prescribed requirements for a more control-centric process reasoning approach, where 'kaizen' would only be appropriate once a carefully engineered process has been extensively defined and validated.

Case Study 3 in the appendix presents a
1-sheet shorthand QFD project

PART 2

ASSOCIATED TOOLS

This section introduces a number of tools that are often being associated with or integrated into QFD-based approaches.

TRANSLATION TABLE

There is often more than one functional way of satisfying a customer requirement. In order to attain competitiveness, it is important to identify and develop the one with most advantages over the others. Mankind has reached where it is today, in part due to our ability to draw assumptions from past experience and by copying each other. In some way, we are thereby naturally pre-conditioned to produce stereotypical solutions (while in another way we also enjoy creating new ones). The wider search for and the effective evaluation of viable alternative solutions is essential for optimising the response to customer requirements. The translation table compels the QFD team to think laterally about and record how else a customer requirement can possibly be met. When using the tool, the team will consider other man-made or natural systems where similar kinds of needs are satisfied. They will document the answer to the following question about it: *"What are the functions, features or activity that satisfies the customer requirement"?* The answers should be written in a solution neutral language as is possible. The translation table eventually presents sets of alternative information in a way that stimulates new thinking across them, as well as presenting it for evaluation and selection.

The selected design requirement (right column) can be either:

a) New-found way of fulfilling the customer requirement, or
b) Combining an existing solution with a new aspect, or
c) Keeping or strengthening an existing solution

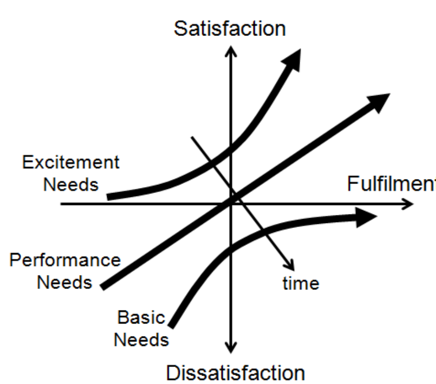
		Example design solutions For each cell ask: What are the functions, features or activity that satisfies customer requirement?					
Customer Requirement	Importance	Existing own solution	Competitors' 'best' solution	Related 'state-of-art'	Abstract analogy	Design rule, standards and regulatory requirements	**Design Requirement**
Not rusting	7	Zinc plated mild steel material	Stainless steel, but at higher cost and more difficult to work	Aircraft grade aluminium alloy	Water system corrosion protecting by biological antioxidants	None	Anodised aluminium material
Colour red	3	Paint	Paint	Mountaineer equipment is colour coded by anodising. Doubles to rust protect	Flower has in-material pigments	Must not be confused with yellow	Red anodising

Translation table (partial)

In the portion of an example translation table shown here, we have returned to our earlier used example for a "not rusting" customer requirement. It considers what a strong competitor is doing and what a related state-of-the-art response could be. We also try to stimulate lateral thinking by considering an abstract or nature analogy. Lastly, we consider if there are any relevant obligatory or standards requirements that we must adopt. There is no product standard for "not rusting" in this case; but the customer requirement for "colour red" relates to a product safety standard that says the red colour is classed as a warning indicator and must therefore be clearly distinguishable from the lesser alert level indicated by a yellow colour. What we finally select as design requirements should match the business plan ambition and 'difficulty budget' for our design phase. We have to be as creatively inventive or as conventionally conservative as the market and business conditions demand. Developing something new in rust protection, such as using plant-based biological antioxidants to inhibit the galvanic corrosion process, which would otherwise result in rust, could be too far-stretched for our particular 'difficulty budget'. However, just looking at such far-fetched option helps opening up the team's collective mind and makes it more receptive to lateral new thinking. In this scenario, it turns out that 'borrowing' part of the solution from state-of-the-art aircraft design is a more realistic solution. Looking across and down at the example solutions, the QFD team can realise that aluminium (not aircraft alloy grade) is easier to work and that anodising has a dual function of providing both colouring and protection. The selected solution has slightly higher cost that our existing, but it remains more competitive and it will potentially be easier to control in our manufacturing process.

KANO NEEDS CATEGORIES

Noriaki Kano developed a model for classifying needs into three categories, each of which influencing customers in a different way (Kano *et. al.* 1984).



Kano needs diagram

- Basic needs are taken for granted when present, meaning they do not add any satisfaction. Customers may not even think it is necessary to tell us about them in advance. On the other hand, their omission from a design results in dissatisfaction. Basic needs are sometimes also referred to as threshold needs, or expected, or must-be quality requirements, because the customer will likely reject the product if they are not met.

- Performance needs are the attributes or features that customers will ask for and against which they measure their buying decision. The more the product fulfils this need the more the customer is satisfied making the buying choice.

- Excitement needs make pleasant surprises when they are first encountered. The customer will not tell us about these in advance, because they are unexpected. Often they will not be missed if omitted, because customers have not yet realised that they want them. On the other hand, a product without any excitement attributes stands weaker in competition against another product that does incorporate some.

Excitement needs help trigger impulsive wants, enabling fresh customer satisfaction and creating competitive advantages. Excitement attributes are thereby effective in enabling a premium price and profit from a product. However, the promise is worth nothing unless the basic needs are firstly fulfilled, and unless the performance attributes are satisfactory. Kano tells that the excitement effect is only temporary. As the novelty-value starts to wear off and the customer begins to expect the feature as being the norm, the excitement need over time turns into a performance need. With further time it may eventually become a basic need.

Although they represent the longest lasting form of satisfaction, customers tend to be neutral to their fulfilled basic needs. It is the performance and excitement needs that make them choose one particular product over another. Price is a typical performance need, unless it is so low that it excites or so high that it exceeds the basic affordability threshold. The addition of performance and excitement attributes often require a trade-off against price, where we have to judge the extra design cost against how much extra the customer is prepared to pay for it. We can keep adding performance and excitement attributes, but there comes a point where we reach a customer's maximum price threshold. Often it is difficult to achieve a balance that optimally satisfies and maximises the price for all of the customers all of the time. That is why many products are marketed in economy and premium featured versions. Cars are a prime example, were multiple models span from small to large, and each of the models comes with selective add-on luxury features – all at an optionally extra price.

Kano introduces a couple of further terms. Product attributes that result in neither satisfaction, nor dissatisfaction, are referred to as 'indifferent quality' attributes. Also, product quality attributes can be provided in excess, meaning that it interferes with other aspects and results in dissatisfaction. For example, the customer will find satisfaction in an electronically controlled car engine and suspension performance function that can switch between economy or sport drive modes. If the car manufacturer now adds 10 modes, such as smooth road, rough road, super-rough road, driving in soft soils, or snow, rain or dry weather etc. then the customer may well find the increased amount of choice too complex and interfering. Kano refers to this as 'reverse quality', where too much of the good can make it bad.

FUNCTION COST ANALYSIS

A value-engineering tool for benchmarking the relative cost of each product function and then determining an optimum cost combination for its components relatively to the value perceived by customers. The aim is to reduce the product cost, while maintaining or increasing its functional value. There are a couple of conditions for Function Cost analysis being an appropriate tool. Firstly, there must be practical technical alternatives for fulfilling the product function. If by convention we are forced to select a standardised solution, for example, then there is little purpose in performing the analysis. Secondly, customers have to have little or no direct interest in the product features, but instead are motivated mainly by the benefits they will receive when using the product – e.g. when saying*: "I don't care how it's done, I just want the product to be comfortable in use"*. The more cost sensitive the product is the more there is to be gained from an analysis.

	Own existing product					Product B						Product C			
		Strap	End hooks	Slide buckle	Riveting		Strap	Pad material	Clip hook	Hook D-rings	Stitching		Strap	Press lock	Stitching
Function	Cost	0.35	0.42	0.18	0.52	Cost	0.22	0.38	0.91	0.08	0.71	Cost	0.30	0.47	0.32
Ergonomic shape	0.09	1/4				0.38		1				0.06	1/5		
Strong strap	0.24	2/4	1/6			0.63	1		1/4		1/4	0.29	2/5	1/5	1/4
Strong fixing	0.77		5/6	1/4	2/3	1.29			3/4	1	3/4	0.49	1/5	2/5	3/4
Length adjuster	0.39	1/4		3/4	1/3	0						0.25	1/5	2/5	

Function cost analysis

The method is to create a matrix of matrices, one for each product to be compared, with functions listed down the left-hand column and components listed across the top. Enter each actual component cost at the top. Estimate the proportion of each component cost that can be attributed to fulfilling each of the individual functions. Add-up the rows, to obtain the function costs. The various solutions can now be analysed, and an optimum or a new combination identified.

TRIZ

The ‘theory of inventive problem solving’ (in English). The theory and its associated knowledge-base tool were developed by Genrich Altshuller. Together with a large team of helpers, he initially screened hundreds of thousands of patents, and subsequently in-depth analysed tens of thousands of the most inventive solutions to problems. Altshuller generalised the result into 39 engineering parameters to be solved and 40 inventive principles. His knowledge-base tool consists of a 39x39 matrix, referred to as the ‘table of contradictions’, where the 39 engineering parameters are pair-wise correlated. The intersecting cells in the table represent a ‘technical contradiction’ and list any relevant numbers from the 40 inventive principles that have proven successful for analogues challenges.

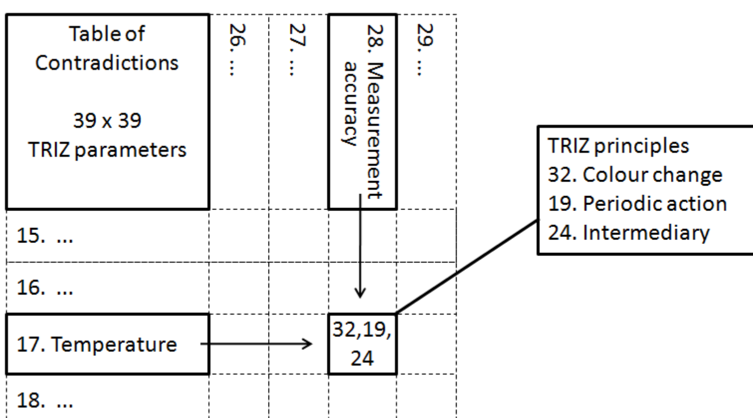


Table of contradictions

In an example, of a real life case, we have an electronic pressure sensor used in a feedback control loop for regulating the gas flow rate through an electromagnetic variable orifice control valve.

The design problem is that the valve operation generates heat, which in turn influences the sensor measurement system. The engineering parameters in conflict are 17-Temperature and 28-Measurement accuracy. Looking them up in the 'table of contradictions' gives us the following inventive principles to think about: 19-Periodic action (replace continuous action by a pulsed one or change its frequency); 24-Intermediary (insert an object to transfer or carry out the action); and 32-Colour change (increase contrast or make easier to see). In this example, TRIZ principle number 24 led us to solve the problem by inserting a length of tubing in between the sensor and the measurement point. This in turn created separation between the sensor and the heat source (the valve). Applying TRIZ principle number 24, allowed the sensor to be sited in a location where a constant ambient temperature exists. The new solution proves more cost-effective and reliable than the initially engineered solution, which was to measure the temperature and to build an individually calibrated algorithmic correction factor into the valve control software.

PUGH'S CONCEPT SELECTION

A decision-matrix method, invented by Stuart Pugh, for comparing a mix of objective and subjective criteria. The method is to create a matrix that has the criteria, or requirements, listed on one axis and the competing alternative solutions on the other axis. One solution is arbitrarily selected as the baseline. For each criterion, we ask for each of the alternative solutions: *"Is this solution better or worse or the same as the baseline"?* We mark the intersecting cell accordingly. When the comparison is done, we can subtract the number of 'worse' marks from the number of 'better' marks, to give us a total count. If the resulting count is positive, the alternative can be said to be better than the baseline.

+ = better
s = same
- = worse

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Counted				Weighted		
						Better	Same	Worse	Total	Better	Worse	Total
Importance	8	3	5	7	2							
Concept 1	Baseline											
Concept 2	s	+	+	s	-	2	2	1	1	8	2	6
Concept 3	-	-	s	+	s	1	2	2	-1	7	11	-4

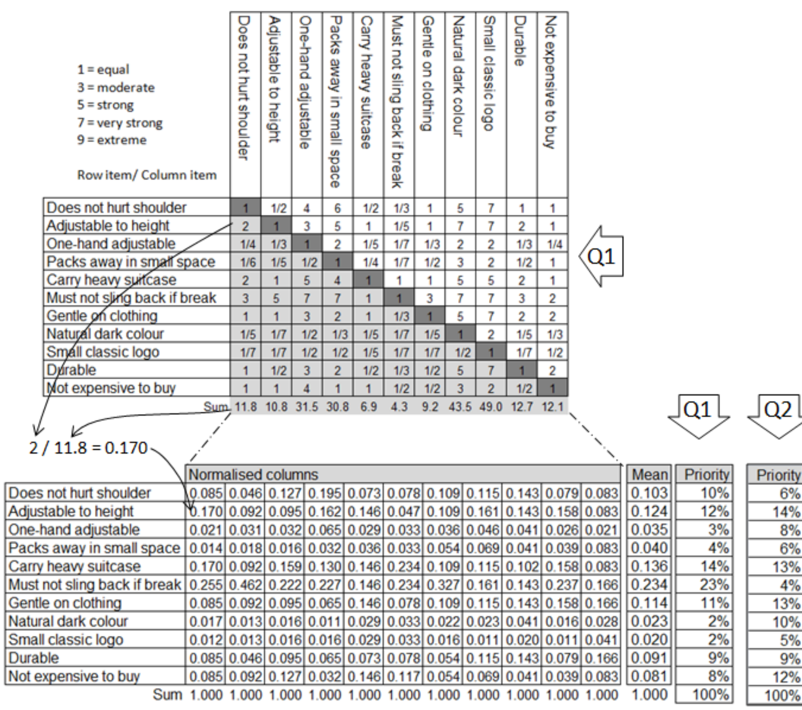
Pugh concept selection

Sometimes it may be preferable to weigh the marks by the criteria importance values. The decision-matrix can then be used to test how much a subjective criterion has to change before it starts influencing the solutions ranking. This can help give us confidence about the sensitivity and robustness of our decision; for example when things are likely to change over time.

ANALYTICAL HIERARCHY PROCESS (AHP)

A selection or decision-making tool, developed by Thomas Saaty, for ranking priorities in situations that contain uncertainty or are complex by multiplicity. AHP decomposes the decision-making problem into simpler pair-wise comparisons between each of the candidate elements. Judgement is subsequently synthesised by mathematical processing, to produce the overall set of priorities. The pair-wise comparison can be either qualitative (expressed in words) or quantitative (expressed numerically). The AHP matrix can be scored in a team session, in a similar way to the QFD HoQ matrix.

In a first stage, the method is to create a matrix with the elements to be priority ranked repeated on both axes. Then perform a systematic pair-wise comparison of each elements pair, by asking: *"How much more important is element A compared to element B"?* The score is on a scale from 1/9th to 9, with the mid-point 1 meaning that both elements are equally important. The row element is the priority and the column element is the alternative. For example, if a row element is 5 times more important than a column element the fractional score is 5/1, or just 5. If, on the other hand, the row element is 5 times less important then the score is 1/5. It is not necessary to score the diagonally lower half of the matrix because this half is simply the reciprocal of the upper half.



Row item/ Column item	Does not hurt shoulder	Adjustable to height	One-hand adjustable	Packs away in small space	Carry heavy suitcase	Must not sling back if break	Gentle on clothing	Natural dark colour	Small classic logo	Durable	Not expensive to buy
Does not hurt shoulder	1	1/2	4	6	1/2	1/3	1	5	7	1	1
Adjustable to height	2	1	3	5	1	1/5	1	7	7	2	1
One-hand adjustable	1/4	1/3	1	2	1/5	1/7	1/3	2	2	1/3	1/4
Packs away in small space	1/6	1/5	1/2	1	1/4	1/7	1/2	3	2	1/2	1
Carry heavy suitcase	2	1	5	4	1	1	1	5	5	2	1
Must not sling back if break	3	5	7	7	1	1	3	7	7	3	2
Gentle on clothing	1	1	3	2	1	1/3	1	5	7	2	2
Natural dark colour	1/5	1/7	1/2	1/3	1/5	1/7	1/5	1	2	1/5	1/3
Small classic logo	1/7	1/7	1/2	1/2	1/5	1/7	1/7	1/2	1	1/7	1/2
Durable	1	1/2	3	2	1/2	1/3	1/2	5	7	1	2
Not expensive to buy	1	1	4	1	1	1/2	1/2	3	2	1/2	1
Sum	11.8	10.8	31.5	30.8	6.9	4.3	9.2	43.5	49.0	12.7	12.1

	Normalised columns											Mean	Priority (Q1)	Priority (Q2)
Does not hurt shoulder	0.085	0.046	0.127	0.195	0.073	0.078	0.109	0.115	0.143	0.079	0.083	0.103	10%	6%
Adjustable to height	0.170	0.092	0.095	0.162	0.146	0.047	0.109	0.161	0.143	0.158	0.083	0.124	12%	14%
One-hand adjustable	0.021	0.031	0.032	0.065	0.029	0.033	0.036	0.046	0.041	0.026	0.021	0.035	3%	8%
Packs away in small space	0.014	0.018	0.016	0.032	0.036	0.033	0.054	0.069	0.041	0.039	0.083	0.040	4%	6%
Carry heavy suitcase	0.170	0.092	0.159	0.130	0.146	0.234	0.109	0.115	0.102	0.158	0.083	0.136	14%	13%
Must not sling back if break	0.255	0.462	0.222	0.227	0.146	0.234	0.327	0.161	0.143	0.237	0.166	0.234	23%	4%
Gentle on clothing	0.085	0.092	0.095	0.065	0.146	0.078	0.109	0.115	0.143	0.158	0.166	0.114	11%	13%
Natural dark colour	0.017	0.013	0.016	0.011	0.029	0.033	0.022	0.023	0.041	0.016	0.028	0.023	2%	10%
Small classic logo	0.012	0.013	0.016	0.016	0.029	0.033	0.016	0.011	0.020	0.011	0.041	0.020	2%	5%
Durable	0.085	0.046	0.095	0.065	0.073	0.078	0.054	0.115	0.143	0.079	0.166	0.091	9%	9%
Not expensive to buy	0.085	0.092	0.127	0.032	0.146	0.117	0.054	0.069	0.041	0.039	0.083	0.081	8%	12%
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	100%	100%

Analytical Hierarchy Process example of prioritising customer requirements for a shoulder carry strap

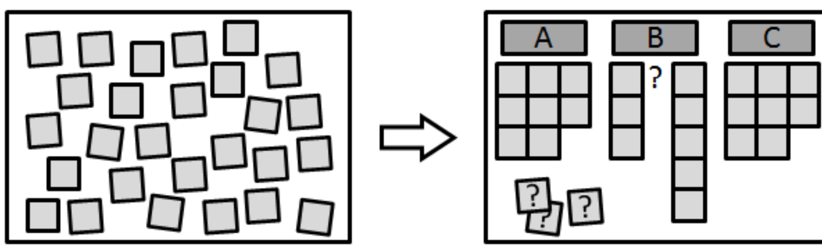
The second stage is the mathematical processing into resulting priorities. There are a number of approaches for doing this. The easiest is the ‘normalised mean values’ approach, which can be done by hand or in a computer spreadsheet. First, the columns are normalised into a resulting matrix and, second, the priorities are established by averaging the row values. The calculated row averages may be shown as percentage values, for ease of visualising and applying. The last stage in the AHP is a sensitivity test, where doubtable input scores are modified within their possible ranges and their effects observed. If changes do not alter the priority rankings then the result can be considered robust.

Our example AHP here shows a relatively simple 2-dimensional matrix with 11 elements. The resulting priority ranking under the label Q1 is what we obtained by the product engineering team asking the standard question: *“How much more important is element A compared to element B“?* The safety feature “must not sling back if break” turns out highest priority, with a score twice that of the second highest priority. Looking at the output priorities, from a purely engineering perspective, they seem about right. They are probably how most of us would prioritise requirements for a carry strap in engineering industrial use. However, the priorities are not all that helpful from the perspective of a product designer in the retail market. The third place ranking is more or less shared by about half of all the elements, which may be truthful of customer requirements, but it does not really help singling out any best item for ‘exciting’ the customer. Literature presents a number of different AHP scoring methods, which varies from the conventional 1 to 9 scale. For example, if we square the decision scores, before normalising, then we are creating more contrast between the final priorities – i.e. helping to spread out the 5 similarly prioritised elements. But contrast is only half the issue to the designer here. Kano tells us that “must not sling back if break” is a basic need, which the customer takes for granted and therefore does not greatly influence their buying decision. Just because the product does not break when used with a heavy suitcase, and just because of an assurance that if it should break by some accident then the belt buckle will not sling back into someone's face, does not automatically make the customer satisfied with owning the product. The low priority ranked "one-hand adjustable" and "natural dark colour" are excitement and performance needs. These are therefore much more likely to influence a buying decision and longer term satisfaction with the product. Our AHP in this case has prioritised for a well-engineered solution, in terms of preventing dissatisfaction and litigation from a use accident. It has not priorities for a solution that will sell well in the shops and satisfying users in the longer term. The AHP tells us something that is useful to know, but we have not necessarily prioritised for 'true' satisfaction, in a Kano model sense. Because the carry strap product is intended for a retail consumer market, where luggage products are somewhat 'fashionised', we would want to redefine the AHP output, by increasing the priority for some of the excitement needs. We can do this by rephrasing our scoring questions to, say: *"How much more important is element A compared to element B, in terms of exciting the customer at the point of sale and over the life of the product"?* The new resulting priority ranking, shown under label Q2, now better reflect retail consumer priorities (the score workings are not shown here). As it is also said for the QFD HoQ, if the output does not look right then it probably is not right. If it does not look right then we have to, first, double-check that our scores are correct (did we ask the wrong question, or did we make an entry error?) and/or, second, factor the output according to some relevant influencing context – similarly to the HoQ context weighting.

AFFINITY DIAGRAM

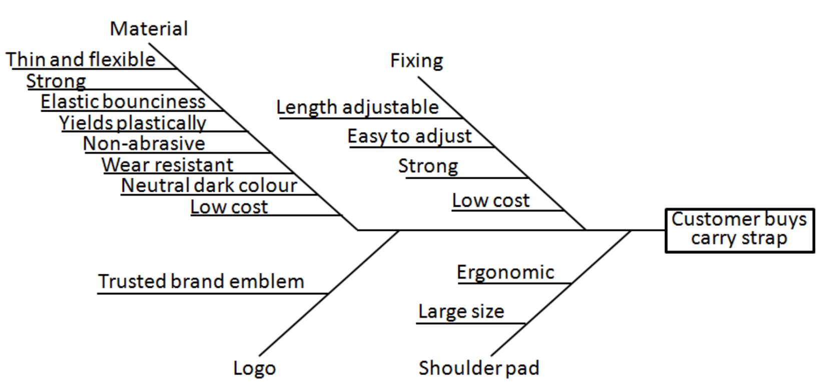
A hierarchy diagram for sorting and visualising the structure of interrelationships between groups of ideas or qualitative statements. The diagram is built from the top down and will help identify omissions or flaws in source data.

The method is to firstly record the ideas on note-papers. Then spread them out on to a surface. Move them around to discover related groupings. Sort them into final groups, until all notes have been used. In large systems, the process may be repeated for each group, to sort it into sub-groups for better overview. The final diagram can reveal ideas or statements that probably do not belong to the subject; or it can identify sub-groups where the content is slight – i.e. something is probably missing.



CAUSE AND EFFECT DIAGRAM

Also called fishbone or Ishikawa diagrams, the tool helps to visualise and think through the potential factors causing an overall output or effect.



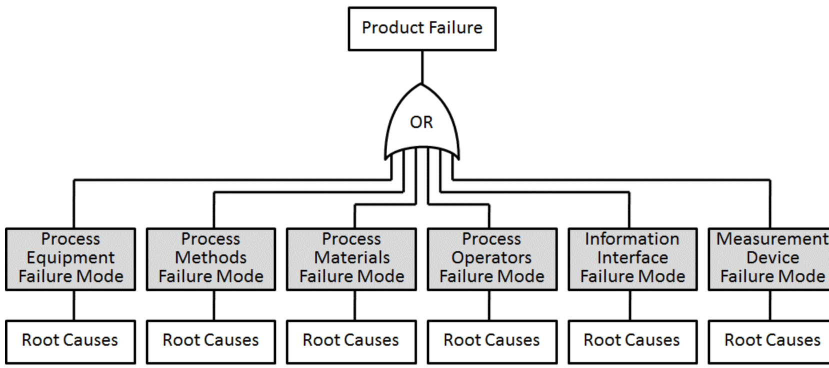
The cause and effect diagram brings together and contextualise the often many, sometimes non-quantified or conflicting, ideas or opinions within the analysing team. The causes are usually grouped into categories, or sub-causes, to identify their sources. We can further distribute probability scores, to help visualise the relative importance of sub- and root-causes.

FAILURE MODE AND EFFECT ANALYSIS (FMEA)

A universally recognised charting method for systematically analysing potential failures and their effects on a system, and for facilitating the development of countermeasure to prevent these effects from being realised. The term system, here, includes either or both designed products and processes. Failure probability and the effect on a system can only be reliably estimated by seeking to understand the failure mechanism. Although the FMEA is inherently a forward reasoning approach, it relies on knowledge being transferred from current and past experiences. The FMEA is undertaken as a team activity, ideally including people with experience in the type of system being analysed.

When performing the FMEA during the design phase, as opposed to post-design, it will help us guide design decisions. It is good practice to start an FMEA early in the design development phase, to obtain a preliminary analysis. Then regularly review and evolve the analysis as the design progresses. The information contained in an FMEA chart is preserved as valuable learning for future systems analysis and specification.

The FMEA method is to, first, clarify (mentally or document) the function of each system component. Then investigate the potential failure modes or deviations from the intended performance, over the full life of the system. Ask: *"What could potentially go wrong"?* A Fault Tree Analysis (similar to the cause-and-effect diagram) can further help identifying potential failures and their root causes.



Fault tree for stimulating a systematic thinking across all of the possible areas of failure modes and their root causes

The definition for failure is a "*shortfall between performance and expectation/standard, or loss of ability to perform to some defined performance criteria*". Failures can be type classified by the way in which they happen:

- Degradation: Gradual drift in performance.
- Intermittent: Alternating between non-failure and failure.
- Sudden: Not anticipated, no sign of prior degradation.
- Catastrophic: Sudden and complete.
- Dormant: Component failure not causing wider system failure until it enters into combination with another fault.
- Random: Equally probable in any time interval.

We are considering single-failure modes and cascade-events only, meaning we do not consider the additive "what if" for two or more independent (i.e. unrelated) failures occurring at the same time. This would be far-fetched and results into much work.

Failure Mode Effect Analysis (FMEA) Worksheet								Last review date	01/12/2015				
System	Television model XYZ12345							Owner	Development Manager				
Severity: 1 = failure effect is negligible (no harm done); 10 = devastating (catastrophic harm is done) Likelihood: 1 = highly unlikely (practically impossible); 10 = highly likely (occurring frequently) Detection: 1 = obviously detectable for easy/timely action; 10 = undetectable before action is too late Score: Above 100 = intolerable; below 100 = moderate; below 40 = tolerable; below 20 = negligible									Urgency of actions should reflect the risk score. Consider it irresponsible to operate systems under intolerable risk				
Original condition (assuming no controls)								Countermeasures and resulting condition					
Description	Failure Mode	Effect	Root cause	Severity	Likelihood	Detection	Score	Controls	Actions	Severity	Likelihood	Detection	Score
Remote Control	Button press doesn't make change on TV	Customer dissatisfaction. Complaint. No repeat purchase.	Battery power loss	2	10	8	160	User manual advises to check	Add battery low warning indicator transmitted to TV for display on screen	2	10	1	20
			Dirt ingress onto PCB contact pad	4	4	7	112	Rubber button pad designed to wrap over PCB to create seal	None	4	1	7	28
			Firmware program/data memory error.	4	2	9	72	Best 3 of 5 EEPROM read/write routine	Continual creeping program checksum, with auto-reset	2	1	9	18
	Unintended selection	Customer dissatisfaction. No repeat purchase.	Button symbol worn away in 36 months. Inappropriate marking solution.	3	5	2	30	Marking validated to established design standard	Improve design standard when opportune. Review solution accordingly	3	3	2	18
		Uncomfortable loud sound. Complaint.	User misinterpret the button symbol	4	2	2	16	Use 'harmonized' terms and	None				

FMEA chart for higher level components analysis

Investigate and record the important effects on the system for each failure mode. Then further investigate to determine their root causes. The generalised root causes of failure can be:

- Design: Intrinsic weakness not resolved or introduced.
- Process: Mistake or variability in actions and materials.
- Wear out: Mechanism that increases at the end of product life.
- Misuse: Operation outside intended function or stress.
- Primary: Not resulting from an earlier failure.
- Secondary: Consequent of an earlier failure.

Evaluate each root cause potential in terms of severity, likelihood and ease of detection. The 3 characteristics are scored on a scale from 1 to 10 and multiplied to produce a Risk Priority Number (RPN), which signifies the magnitude of risk and effect potential.

- Severity rates the adversity of the failure effect (if it occurs), where 1 = failure effect is negligible (no harm done) and 10 = devastating (severe harm is done).
- Occurrence relates to the likelihood that the root cause of the failure mode will occur, where 1 = highly unlikely (almost impossible) and 10 = highly likely (frequent).
- Detection relates to the difficulty in catching the failure before it reaches the customer, where 1 = not difficult at all and 10 = undetectable beforehand.

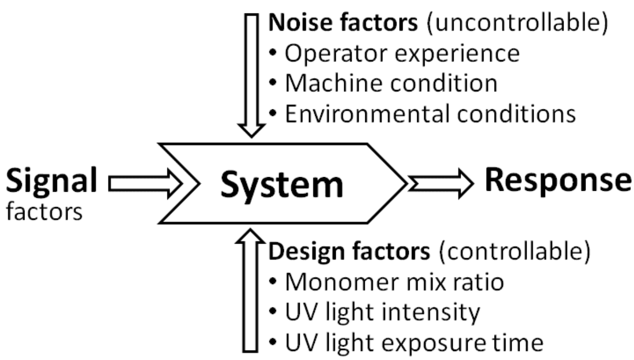
Countermeasures are devices, controls and change actions aimed at reducing the RPN score. The order of preference for the development of controls is:

1) Eliminate or reduce the root cause of the risk, by developing a failure robust design.
2) When the risk cannot be otherwise eliminated, introduce protective devices, checks and alarms to guard against the risk occurring or to improve detection if it does.
3) Accept irresolvable residual risk as tolerable, but appropriately inform or warn users about it.

Record the countermeasures and re-assess the resulting RPN for the failure now being realised. An RPN of 20 or less is generally acceptable, but it does depend on the kind of system under review. If severity is high, say a full 10, then we would want to assure that sufficient controls are put in place to make likelihood of occurrence and detection scores their lowest. If, on the other hand, severity is negligibly low then we can practically tolerate investing less in the associated controls, with a higher score for occurrence and detection. Residual risks are those remaining after the control measures have been implemented. For certain important risks it may be prudent to validate that countermeasures have their intended effect and to periodically monitor whether they remain effectively implemented.

ROBUST ENGINEERING DESIGN (RED)

A method for using statistical experimentation to determine the response effects from changing the controllable design factors, under varying conditions of normal noise factors. Noise is the uncontrollable variability that influences a system response. The term system encompasses products or processes. For products, for example, we are not always in control over how or where the customer uses the design. For production processes, for example, normal machine wear or differences in operator skills can be outside the product designer's on-going control. We would want to best possible make the design robust to such variability.



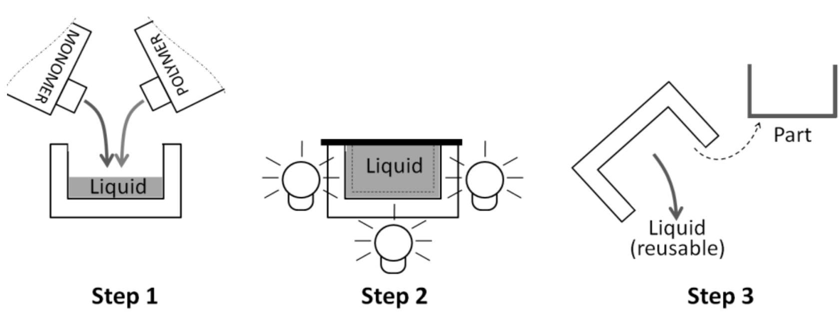
Parameter diagram example, for a
UV curable plastic enclosure production process

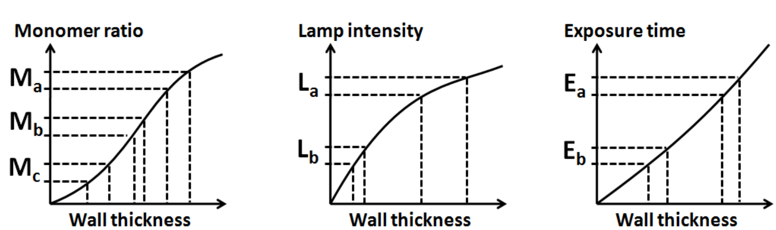
When analysing the experiments we will find that varying the operating point for an individual design factor tends to have one of the following effects on the response:

1. No effect.
2. Dispersion in consistency of response.
3. Moving the mean of response.
4. Dispersion and mean (points 2 and 3 simultaneously).

The aim of RED is to find a combination of design factors that produces a system response at the desired target location, with the least or a tolerable dispersion under normal variability of operation – i.e. making the system robust to noise, without seeking to control the noise itself.

The RED concept is illustrated here by an example for achieving a most consistently exact wall thickness in a UV curable plastic material. The process is used in producing low quantities of small custom shaped enclosures for electronic circuitry. If the resulting plastic wall is too thin, then it offers insufficient strength of protection. If the wall is too thick, then it encroaches on the inner space required for the electronic circuit. The UV curable material is a polymer-monomer mix, similar to what is commonly seen used by dentists to build-up or clad teeth. The material is cured by using a powerful UV light source that is shone through a translucent mould, where a liquid polymer-monomer mixture is allowed to solidify on the wall of the mould, before the still liquid centre is poured back out to create a hollow.





The design factors for the depth of cure – i.e. the enclosure wall thickness – are 1) Monomer mix ratio, 2) UV light intensity, and UV light exposure time 3). A number of test enclosures are produced, in experimental runs that combine the various design factor settings (labelled a, b and c in our graphs here), under various noise conditions such as using different machines and operators.

The wall thicknesses produced from the different experimental runs are analysed for variances. The analysis graphs, in this example, teach us that:

a) The monomer mix has an optimum ratio, M_b, where it results in producing the most consistent (narrow dispersion) wall thickness.

b) A lower UV lamp intensity setting, L_b, results in a more consistent wall thickness than a higher lamp intensity does.

c) UV light exposure time mainly has the effect of moving the mean shell thickness; with minimal effect on dispersion of the response (right-hand graph approximates a straight line).

For the process being robust in producing consistent quality in wall thickness, we would first of all select monomer mix M_b and lamp intensity L_b. We can then adjust exposure time until we get the target wall thickness that we want. We will perform a confirmation run, to assure that our prediction for robustness is correct.

VOICE OF CUSTOMER

A well-defined VOC is in some respect the most important, but also a difficult activity to get absolutely right for a product development project. It is about understanding and clearly defining what customers need and what they want, and also what they could tolerate less of and what they do not want at all.

MECHANISM FOR VOC

We can research customers in two ways:

1. Primary research collects and analyses original new information from the actual intended market, with regards to the planned new product.

2. Secondary research analyses available pre-established information, including some that might have been originally collected for purposes other than the topic under investigation, but is somehow validly transferable.

The two types of research can further involve different modes:

a) Qualitative research explores what customers think and experience, and why. This helps to identify the strengths of customer demands and what excites them the most.

b) Quantitative research produces statistical data, relating to the proportion of customers who think something. This may help identify something that has not been considered, but it will not necessarily tell us why.

Various methods for obtaining customer information have different strengths and weaknesses. It is generally advisable not to rely on any one method alone:

Opinion surveys, in form of interviewer- or self-administered questionnaires	
PROs	CONs
• Reliable statistical information. • Can be analysed quickly. • Gets the views of non-users. • Tracks changes over time, if the same or similar questions are repeated at a later time.	• Poorly designed questions can give misleading results. • Temptation of question writer to reflect organisational agenda, rather than customer priorities. • Some customers do not like criticise the product in front of an interviewer. • Can overlook needs and expectations of important trendsetting minority groups.

Complaints monitoring and analysis	
PROs	CONs
• Helps identify recurring problems and product weaknesses. • Provides both qualitative and quantitative information. • Can save time and money.	• Difficult to extract the positive information that is required to expand demands (see Kano). • Some complaints will relate to effectiveness of sales and product handling system (not always design). • Is unreliable if it involves an uncontrollable middle party (e.g. reseller), who will naturally try to either deflect or cover up any blame.

Customer suggestion scheme	
PROs	CONs
• Obtains positive as well as negative information. • Demonstrates commitment and openness to customers. • Information is recorded instantly when customers use the product.	• When received piece-meal, it can be difficult to interpret quantitatively and is time consuming to analyse. • Relies on customers making the effort, and may only obtain the views of customer groups with a certain attitude.

User trails. This involves observing and/or asking the opinions as a user engaged in the whole process of using the product (or a similar one); while recording any critical observations or inadequacies encountered.	
PROs	CONs
• May identify shortfalls which the user is not aware of, had we asked. • Information is recorded instantly when customers use the product.	• Time demanding. Subjects being observed may not be representative of all customers and non-customers. • No quantitative information.

Focus Group	
PROs • Opportunity to explore views and test ideas with people who knows what is happening on the ground. • Helps concentrate on issues from a customer perspective.	CONs • People tend to say different things when in a group, to what they will actually do when faced with a buying decision in private. • Little quantitative information.

User panel. Often used by software companies, where select users receive and reviews prototype product versions. Also in medical equipment development, where reliable expert users and opinion leaders are consulted on usability and new needs	
PROs • Relatively quick information. • Concentrates on issues from a customer perspective. • Enables exploration and testing of new ideas. • Can help promote good relationships with market opinion leaders.	CONs • Panel members can form association with and start to think like the organisation. • No quantitative information. • Risk of important minority groups being under-represented.

Consult customer and/or industry representative organisations	
PROs • Independent information. • Opportunity to explore views in depth with people that have good relevant knowledge. • Can indicate both qualitative and quantitative information. • Relatively quick and cheap. • Can get the views of important minority groups.	CONs • Information may be flawed by a hidden, uncontrollable political agenda of influential individuals within in the ‘representative’ organisation.

Analysing features and sales performances of competing products	
PROs • Quick and cheap. • Can tell what features and the parameter values that customers are selecting, or not selecting. • Indicates the conclusion of a competitor's market research work.	CONs • May not identify any gaps between the true customers’ needs and what the competitors are providing. • The competitor's conclusion may be flawed or influenced by some hidden organisational limitations.

Customers express their needs in their own words and may not be very explicit about them. If a customer asks for zipped pockets in a bag, for example, what is really meant is that the pocket should be easy quick to open and close, and that nothing should fall out of it. A zip solution can have weaknesses in a particular design context. There may in fact be other more effective ways of meeting the root needs. Instead of specifying a zip, therefore, it would be better to specify the solution neutral features. How we record the customer need should not prevent us from exploring differentiation or discovering something that is observably better that a zip. This is in part what innovation is about.

In saying that we should leave room for being imaginative about how we meet a customer need, such openness of specification should be balanced against the risks of introducing something that is too alien in concept. Be mindful not to select something that we think customers need, but that they are in fact not ready for. People tend to possess a short 'horizon-span', where they see their needs and wants mainly in relation to products they already know. Comfort, or nostalgia, attached to the 'good old wants' often favours subtle, merely incremental improvement to existing concepts. Generally, we have to design something of interest. However, sometimes, for some products, the customer is simply most receptive to a copied 'me too' solution. This kind of 'trapping of the mind' is demonstrated in the classic student experiment, where a chocolate bar is randomly handed out to one half of the class and a coffee-mug is handed to the other half, with no further explanations other than *"here is a gift for you to keep"*. The students will initially find the gifts unusual. They may wonder how they randomly ended up with the one or the other object. After about 10 minutes, having grown used to their objects, the students are advised that, if they want, they are in fact free to exchange for the other type. It turns out that, in the main, very few want to make such an exchange. In their minds, people have constructed a reason why their particular object was the better for them and now they do not want a change.

Customers tend to express their wants and are often not aware of or ambitious enough about their needs. If we are to excite customers towards our product then we have to answer to needs that are not yet fully realised – in effect turning needs into new wants. On method for doing this is to create a table of what we think customers really need, against what we think they currently want. We can then select a happy intermediate position, where the proportion of elements of the new need and the remaining elements of the pre-existing want can be accepted by most customers. Just be reminded that some customers can be rather conservative about their wants. They do not necessarily want them changed – just because we have found they could need something else. The success in convincing the customer is based on a degree of trust, where stronger brands will find it easier to lead customers to accept new solutions – further reinforcing their brand strength in the process; and where weaker brands can be treated with more suspicion and rejection.

Although the end-customer always is king, we cannot afford to lose sight of the needs and ways of our own organisation, suppliers, sub-contractors, stockists and resellers – they are also customers and often need something distinct from our product. Another abnormality in defining the VOC is that sometimes we are forced to try making the customer want what we can realistically provide them with, from our capability or marketing perspective. If, for example, our company makes lawnmowers and have created a differentiating selling point based on the "twin-mover" brand name, then we simply cannot detach ourselves from the original idea of only using twin-cylinder engines. Whatever engine characteristics the customer needs for a new lawnmower model, we will have to somehow create benefits from and convert it into a want for a two-cylinder design. The design requirement could end-up being suboptimal for one particular new lawnmower model, but in the context of the wider marketing plan, for the complete range in our products catalogue, the differentiation will serve the company overall well in competition.

WHAT DO CUSTOMERS REALLY WANT?

We have all heard someone explain: *"My head said no – don't buy it; but my heart said yes, so I did"*. Some needs go beyond the rational, materialistic. Clearly, products will appeal to both the head and the heart. What appeals to the heart is often indefinable and, probably, impossible to copy from somewhere else.

This section is not intended to be a text on psychology. However, we cannot get around the fact that customers are humans. Behind every human buying decision is a thought. Every thought-process is driven by a desire that is rooted in a complex evolutionary psychology of wanting to succeed as biological beings. Other than following trends and testing the market with many variant product examples, which would be an impractically slow and expensive strategy, there is no way of forecasting new needs other than through psychological analysis. Although psychology has a reasonably large core of established knowledge, its frontier is not as well defined or advanced as we might have liked. Psychology has multiple branches of study, each having its own perspective on the same root matters. Even when the different branches share an opinion, their language can be diverse and difficult to correlate. They may also be in disagreement over the evidence used in their respective analysis – because like all analysis it is performed by an inexact individualistic human mind. Human psychology is not and may never become an exact science. It will remain extensively theoretical and often even speculative, where different people in different places will come up with different solutions to the same human needs.

A bower is a thatched avenue with an external court at one end. It is built by the male bowerbird for the sole purpose of attracting females. It has no other function whatsoever – not as shelter, nor for raising chicks. The bower building process is untaught. It is something the male bird just does and it consumes a large part of his life. When a female is attracted into the bower, it creates a fixed viewpoint onto the court where the male is making a display of himself – flashing his crest and picking up unusual objects that he has been preparing in advance. The court is laid with stones, bones and other grey objects, carefully arranged by size to create a distorted geometric perspective making distant objects appear smaller. This visual illusion makes the male appear larger and more colourful. It is uncertain whether the female values his building skills or his (interpreted) large size, or if it is simply because his focused display holds her attention for long enough to create interest; but evidently the untaught instinctive behaviour makes mating and off-springs more likely for the male.

EVOLUTIONARY PSYCHOLOGY PERSPECTIVE

Customers are humans, or an organised collection of humans, who are fundamentally driven by the same survival and legacy imperatives as any other kind of biological organism. Most contents and processes in the human brain are hardwired subconscious adaptations to our environment. We are thereby pre-programmed with largely common instinctive urges – many of which were evolved for a long gone ancestral environment. For example, in some basic respect, the human male behaviour is not too dissimilar to that of the male bowerbird behaviour (previous page). Just as it can be imagined for the bowerbird, a large factor in the human buying decisions is based on how a product will make us look to a prospective mate or how it can otherwise strengthen our ability to compete for power and territory. Even if we do not always like to admit it, our sub-conscious imperative drives us to want that our possessions outwardly signal attributes such as health, beauty, intelligence, fertility, skills, strength and wealth. For certain, no-one wants to be seen having bought a product that makes us look any of the opposites – except when using the human social strategy of self-deprecation.

Human product needs have their rationale in 3 areas:

1. Baser reason (instinctive)
2. Taught reason
3. Influenced reason

The baser reason is an untaught, pre-programmed, powerful influencer on our product choices. It resides and is independently managed in hidden thought-processes within our subconscious mind. The outputs from such processes can range from physical reflexes to instinctive behavioural urges. We do not always understand or know in advance what decisions the baser reason it is going to produce for us; but we can feel compelled to stimulate its hidden urges. Taught reason is cultural and something that is learned in the past. Influenced reason is similar but learned in the present. These two reasons are conscious thought-processes based on selected knowledge that is remembered or freshly communicated to our intellect. Thought-processes can sometimes result in poor reasoning, such as when based on irrational or false knowledge made-up from incomplete information, a lie or superstition.

An example of rationally 'false', yet very powerful taught reason, is how product design or naming aspect based around the number '4' can be difficult to sell in East Asia. This is because cultural learning has taught consumers that this number is associated with deadly bad luck. On the other hand, an aspect based around the number '8' can be associated with good luck, and therefore easier sell at a higher price – whether or not there is any practical functional difference between the two products. Other cultures sometimes attach similar connotations to the numbers '13' and '7'. For example, some people may reject buying a ladder that has 13 steps or won't attend an event on Friday 13th.

In co-habiting societies we are rewarded when collaborating and resisting certain baser urges that conflict with the collective goal. If the subconscious mind urges to do something disingenuous or uncivilised, then the conscious mind overrules it and tells us not to – at least this is true while other people can see what we are up to. Sometimes products can be successfully designed to incorporate subtle features that appeal to the underlying, sometimes selfish, private urges, which customers do not always realise that they have. For example, think of how the ordinary family car has evolve an increasingly aggressive and muscular look. This outwardly signal the driver's strength and power, to help 'depose' weaker drivers in the competition for road space. However, there can be a fine line in making such selfish feature too obvious and causing the 'civilised' mind to reject it.

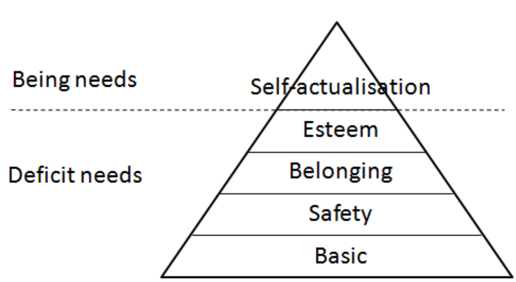
Another evolutionary trait that we share with the bowerbird is the need to stand out from the crowd. The products we choose to buy are tools that help projecting our attributes for others to see; or they are to help us hide weaknesses that we do not want others to see. Adopting the latest fads and fashion is trendy. Deliberately adopting our own counter style is called cool. Generally, others admire cool over trendy; but cool is difficult and risky. An ill-conceived attempt at being cool can make one look like a clown. Today's cool can become tomorrow's trendy, unless it flops – as is mostly the case. For most people, trendy is the safer bet. People, in general, like being seen to stand out as trendsetters. A product with true novelty, meaning something that no-one have never thought of or seen before, can only really target the cool market. However, this market is very small and it prefers to make up its own new ideas. Trying to design for cool is therefore not a recipe for product success. The better market strategy is to design products that incorporate something that is in an established safe transition from cool to trendy, for the larger trendsetter market to buy into. Be careful not to copy someone else's trend too exactly, because trend-following is distinctly un-cool. People are pre-programmed with a cheat-avoidance imperative in baser reason, which finds fakes repulsive. Emulation of top brands may appeal to the rational mind looking for a cheaper price, but we are compelled to mostly want the real thing – not just for our own first-hand experience, but also because of the importance in what other people may think of us.

We can also overload the story that a product tells about its owner, and make it fall into the category that Kano refers to as reverse quality. Human psychology is great at sniffing out things that are not what they claim to be, such as the pretentious. A misplaced overstatement or false self-confidence is suspiciously recognised as a sign of someone trying to hide a weakness. On the other hand, understatement and self-deprecation can be recognised as a sign of strength. Many products succeed because they dare to be simple. For example, it is a current trend, today, amongst American football coaches to wear oversized communication headsets; apparently because of its masculine attributes and bold assertion about who is in charge. It is foreseeable that one day someone will defy this trend and wear something slick elegant, making a statement saying: *"I am strong enough not to need such overstated display"*. If this person gains respect for the choice then the others wearing oversized headsets will soon look gimmicky and ridiculous. The trend will then cease.

So we have to be mindful that trends can both change and they can be overstated. Products that have a long life-span in use are sometimes best served by being neutral and simple in design. One way of determining an appropriate level of novelty is to define the customer group and then look at what other products they have adopted for use, including what fits into the same baser reason impulse band. Then, work backwards to the innate psychological principle, or deficit anxiety, in the need that these products fulfil. Now we have an unbiased picture of the customer group needs.

KANO MEETS MASLOW

Abraham Maslow, 70 years ago, proposed a 5-level hierarchy theory on human needs and their relative order of priority. Although not universally accepted in the field of psychology, the model presented by Maslow's triangle of needs is widely adopted for predicting and explaining human motivation.



Maslow's triangle of needs

1. Basic needs, or physiological needs, are those required for the human body to continue to function, such as water, protein, air, warmth and sleep.

2. Safety needs are about stability and self-protection (e.g. shelter or health insurance), including collaborative devices (e.g. one's own conformance to mutually protective road traffic laws).

3. Belonging includes a need for love, affection, children, family, group and social relationships.

4. Esteem needs are about feeling content with ones achievements, reputation, dignity, or even maintaining respect and ability to dominate.

5. Self-actualization is an instinctive human need to strive to make the most of our abilities, by pursuing new experiences, knowledge and understanding about ourselves and the world around us. It is also about intimacy or oneness with naturally attractive things, such as beauty, art, music and nature.

'Deficit needs' is a domain where when you do not have enough of something then you become anxious and feel an urge to do something about it. Maslow refers to this as a self-regulating homeostasis principle – e.g. if we become cold then we seek warmth and when we become hot then we seek cold. Once we have reached a level of comfort then the anxiousness ceases and we stop thinking any further about pursuing the particular need. There are cases deviating from this norm, where the anxiety about a particular 'deficit need' can become distorted by traumatic events or other influences driving people to falsely and irrationally overcompensate their true need. Also, different strengths of motivation can occur at different times.

Circumstances brought on by environmental conditions – e.g. culture, religion, national wealth, natural disaster, war – can change the dominance in different places of the hierarchy of needs, in the subtle to the extreme, momentarily or longer term.

'Being needs' differ to 'deficit needs' in that they do not involve the balance of homeostasis. In the 5-level triangle of needs, 'being needs' are synonymous with 'self-actualisation'. These are needs for continual personal growth that – unless suspended by the priority of an unfulfilled 'deficit need' – are continually demanding more. The subconscious goal is to become the most complete "you", or as Maslow puts it: *"What a man can be, he must be"*. All humans want to self-actualise, but not all want it equally much all of the time. Very often our daily life is filled with the pursuance of our more pressing 'deficit needs' and we simply cannot let the pursuit of self-actualisation get in our ways.

The basis for the Maslow hierarchy is that we are generally motivated by a need only if the lower level needs have been met. Basic needs such as thirst, for example, tends to take priority, unless your safety is immediately and seriously endangered, during which the fulfilment for the thirst can wait a while – but not indefinitely. Eventually, severe thirst will take precedence even over safety. This makes the 'deficit needs' more dominant than 'being needs'. We have to have fulfilled our 'deficit needs' to a considerable extend before we can start realising our 'being needs'. Maslow proposes that in the developed world, where basic, safety and relationship needs are largely satisfied the pursuit of esteem needs is a significant psychological driver. It is where most people's deficit anxiety tends to be rooted. Humans often seek out and buy products that best alleviate their esteem anxieties. In present context, the fulfilment of need corresponds to the elimination of anxiety. Product advertisers often play on people's subconscious deficit anxieties, to help enhance demands for their products. Product developers should do similarly, by making sure to investigate: *"What are the biggest customer anxieties in relation to our type of product, and how can we best alleviate them"*?

At a first glance, there are strong similarities between the Maslow and Kano models – although the terminologies and degree of details differ slightly. Both defines a hierarchy where the basic needs have less value, in a product economic sense, but are essential must-be prerequisites for all else. Where the two models differ is, firstly, that the Kano model expressly incorporates the temporal element. This says that a product feature that initially satisfies a Kano excitement need (~Maslow being need), over time becomes associated with Kano performance needs. It is the same product feature, but over time appealing to a different order of needs. Secondly, Kano's excitement needs have a somewhat materialistic feel, whereas Maslow's equivalent self-actualisation is of a higher, nearer spiritualistic order. The English common translation into "excitement needs" is not always helpful here. In other common translations, such as "attractive" and "captivating" quality, Kano can infer cognitive, aesthetic or self-actualisation needs; but the common English translation does not expressly say so. Kano identifies that over time the appeal becomes less exciting. Similarly, Maslow says that once a 'being need' is fulfilled then we will be looking for something else, more. In this respect, self-actualisation is a moving target. But even so, when the appeal of a fulfilled 'being need' diminishes the self-actualisation value that was obtained will in fact stay with us forever. This mechanism is not well represented by the Kano model. Inferring that the Kano model perhaps is limited to being more materialistic is not a criticism. Fact is that we are in the main developing products for purpose of addressing the more materialistic 'deficit needs'. Maslow himself, in his time, believe that only about 2% of the world population are sufficiently free from the conflicting demands of 'deficit needs' that they can truly devote themselves to the pursuance of their 'being needs'. Saying that, the experience that we take away from a relatively ordinary travel product, when we buy a holiday visit to a foreign land, for example, contains a large proportion of Maslow's being attributes. Some of these attributes have a temporary fulfilment effect. The initial high excitement from the first time we experience new foods or smells will diminish the longer we stay in the foreign place; and over time they will become normal to us. However, we will learn things on our travel, about food, language and culture, which widen our horizon and grow us as beings. The holiday will come to an end, but the resulting change in our person that we have gained from it will stay with us and be valued for life. The same can be said for a university degree course, for example. If the experience is profound then its result will persist in time. This tells that not everything about the Kano excitement needs is in fact temporal. Some aspects will remain fulfilled on a more permanent basis. Although, once fulfilled, we will feel less of an urge for repeating them and more of an urge for experiencing other yet unfulfilled ones.

Products are a collection of multiple attributes, which can simultaneously address both deficit and being needs.

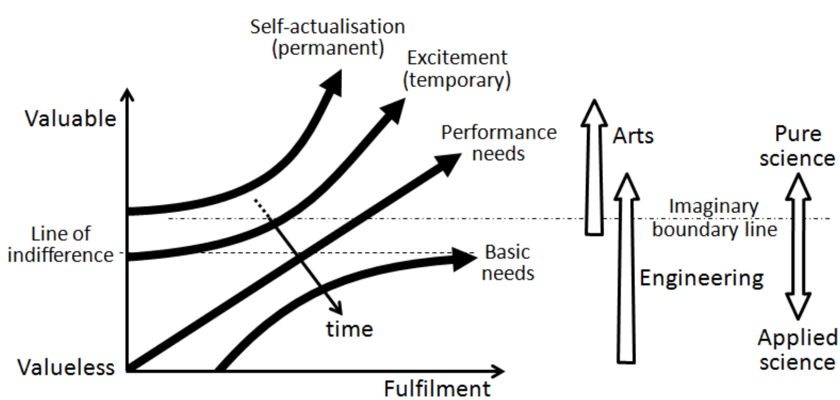
Kano	Maslow	Smartphone product example
Basic	Basic Safety	Enables an emergency call for help. Enables communication and information transfer.
Performance	Belonging Esteem	Enables us to 'belong' more widely and at a distance. Esteem building tool signalling wealth, skill and knowledge.
Excitement	Self-actualisation	Realising and learning about new features. Beautiful to look at. Growing yourself by exploring and discovery (e.g. using internet)

If we for a moment try taking a materialistic view on the art world, where $50 worth of materials plus 50 hours of work can sometimes sell for $100,000+, even though the product has no utility or necessity function, then we realise that **we should not neglect any opportunity to design excitement and being needs fulfilment into our products – where it is possible.** People are paying good money for products such as university courses and skydiving. These are products that improve esteem, but also move us towards self-actualisation. If someone could formulate and market a complete self-actualisation, as a product – whatever it might look like – then it could be of priceless high value to wealthy buyers. There are people who give up all of their worldly goods and sacrifice all but the most essential of basic needs in pursuit of the never-ending self-actualisation. For example, around-the-world leisure sailboats are more about fulfilling a self-actualisation dream than they are about utility and necessity. As another example, in 2013 more than 200,000 people applied for 8 places on a one-way trip to Mars project. It demonstrates a human readiness to pay everything, as common sense knows it, for a uniquely new self-actualisation experience. However, customers willing to exchange absolutely everything for a promise of fulfilling a dream are still more the exception than the common norm. They do not make up a big market.

When saying that we should never neglect any opportunity for adding excitement and self-actualisation attributes to our products, we should simultaneously not forget that most product consumers simply exist for the day-by-day pursuance of their 'deficit needs'. Some products are purely for utility or necessity, and simply cannot be made up with self-actualisation attributes. We buy them to increase the efficiency in meeting our 'deficit needs', in order to free-up more of our time to pursue our other needs. Even when a product does not directly fulfil any 'being needs' we can still look at it in terms of how its use experience adds to our wider overall life-process and enables pursuance of self-actualisation. Complicating utility functions with unnecessary features equates to what Kano terms 'reverse quality'. We want products that increase our efficiency, to gain us more time, and not to slow us down. Maslow says that self-actualising people have not got time or patience for the pretentious or artificial. Instead, self-actualising people find satisfaction in simplicity, intellectual stimulation, self-sufficiency, meaning, beauty, honest truth, un-forced choices, and naturalness. This is achieved mainly by the basic needs being just right – not excessively made up, but not in any way falling short either.

ENGINEERING VERSUS ART

In our QFD context, design is about applying engineering and arts in creating or improving function, usability, ergonomics or aesthetics, to make products more marketable or their production more efficient. For purpose of illustrating the engineering and art domains' contributions to the customer perceived value, we are for a moment taking liberty in adapting Kano's work into a value diagram containing a self-actualisation need. It serves to illustrate relativity between engineering and arts.



Engineering versus art value diagram

Art is defined as *"a deliberate arrangement that excites or influences the senses, intellect or emotions"*. Engineering is defined as *"a discipline for acquiring and applying science"*, where science is *"systematic knowledge gained through study"*. Pure science is about deducing new scientific knowledge. Applied science is about adopting pre-existing scientific knowledge for solving practical problems. Although good engineering can be beautiful to the intellect – i.e. an art – it is in the vast majority of products concerned with the nuts and bolts hidden from view. Engineering based on pure science has greater potential for value creation than applied science has; but it still remains value-limited compared to the arts. We can draw an imaginary boundary line below which the needs fulfilment is mostly about finding engineering solutions to basic and performance needs. Above the line, activities are mostly about finding art solutions for creating temporary excitement and permanent self-actualisation values. In the main, good engineering is essential to assuring the foundation for product value – i.e. to avoid devaluation by insufficiency or failure. However, it is the art contents that create the higher levels of product value. Products that grow or widen the horizons of the self-actualising customer are of the highest long-term value.

In a real life example, a specialist manufacturer of architecturally matched door handles (30% engineering and 70% art contents) makes four times higher sales profit than a specialist manufacturer of advanced life-support machines (90% engineering and 10% art), when both are supplying to the same hospital. The products are equally niche and the hospital makes a significant – not too dissimilar – investment in both types. The developers' knowledge domains in the two products clearly impact on users in different ways. Evidently, even when making adjustment for the product total life-cycle revenue, the door handle manufacturer, supplying a product with a proportionally greater art contents, can obtain the bigger reward.

QUALITY AND ASSURANCE CONCEPTS

Note the word “and” inserted into the section header above. Quality practitioners now-a-days tend to treat the term “quality assurance” as being too narrow for purpose and prefer instead to talk about “quality management” or “quality systems”. History shows that over-emphasis on the term “assurance” can drive a limited kind of quality, which would not necessarily deliver satisfaction. In our context here, QFD is the wider quality system, which incorporates the customer and market needs up-front. When using the narrower term assurance, we are referencing here to the devices and controls that are established in the final stage of the QFD project, in order to best ensure that the designed system keeps delivering to specification – i.e. avoids production defects and dissatisfaction.

WHAT IS QUALITY?

It depends on who we ask and how they feel at the particular time when we ask them. Quality is an individual experience, which probably has near as many meanings as there are customers. We all have different perceptions of the characteristics that determine quality. We also tend to change our preferences according to the circumstances under which we encounter products and services. The meaning of quality differs between industry sectors, from a voluntary social support organisation to a commercial mass producer, for example. The definitions or meanings of quality, therefore, can have just as many interpretations and practices, as there are customer-supplier relationships. Such notion is of course impossible to even start thinking about for practical application. We therefore need to approximate some generalised standards for quality. Some of the classic standard definitions include:

Manufacturer view:
Quality is conformance to specifications.

Service sector view:
Quality is to satisfy or exceed customer needs and expectations.

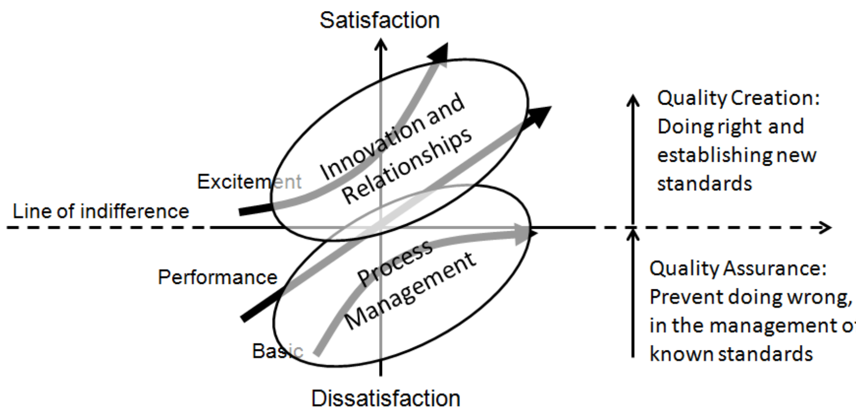
Utility view:
Quality is fitness for purpose.

Value-based view:
Quality is what the customer is prepared to pay for.

ISO 9001 quality management standard:
Quality is the degree to which a set of inherent characteristics fulfils requirements.

Transcendent view:
Quality cannot be defined, but you know it when you see it.

Elaborating on the ISO 9001 (ISO 9000) quality definition, the standard further describes that "characteristic" means a *"distinguishing feature that is inherent or assigned, qualitative or quantitative, physical, sensory, behavioural, temporal, ergonomic or functional"*. "Requirement" means *"need or expectation that is stated, generally implied or obligatory"*. ISO 9001 further recognises that quality is not something static, but is subject to continual change. Instead of trying, with difficulty, to apply all of these disparate and dynamic definitions for quality, we can substitute for thinking in terms of quality by instead considering and working on the 3 drivers that produce quality. The overlay of these 3 drivers on to the Kano model illustrates how they cover the various needs fulfilment.



3 drivers for quality

1. Innovation adds novelty excitement and stimulates an impulsive or sub-conscious desire. It raises performance to new levels, which creates new quality and value.

2. Relationships (personal/social attachment) is a particularly important component in the service sectors, but it can also feature directly and indirectly in manufactured products. For example, people are generally influenced more by the salesroom experience than by the technical specification when buying a car. Separately, they can come to think about their car in humanised relationship terms, including giving it a name and talking to it whilst driving. It can therefore be important to design the car with ‘personality’.

3. Process management ensures that pre-existing requirements are identified and that things are done correctly – to prevent dissatisfaction. ISO 9001 is largely a process management standard, with the important addition of a required commitment to opportunities and improvement.

The Kano model tells us that a strategy based solely on removing dissatisfaction – i.e. by controlling existing quality to avoid complaints – can over time never really result in satisfied customers. In order to create truly satisfied customers it is important to continuously improve the satisfaction with performance needs and to periodically also add fresh excitement needs to our product. The "line of indifference" is the point where the customer is neither satisfied, nor dissatisfied. Activities above the line of indifference are concerned with creating quality; whilst activities below are about preventing dissatisfaction – also known as quality assurance. Innovation and relationships can be managed effectively in a systematic process. Most successful innovators are in fact process driven. However, the most important element in creating quality is people, as only they have the intellect to create and be innovative, and only they have the empathy to care for relationships. There is always a practical operational need to generalise the customer groups and product specification. Once the tangible product is designed and fixed, it is the social interaction aspect or innovation in the product delivery process that has the greatest potential for adjusting to individual customer needs. Care has to be taken that tight process controls, for purpose of preventing dissatisfaction, does not act as a straightjacket to the part of the system that creates satisfaction. There has to be sound controls in place, to prevent doing the wrong things, but they must not get in the way of simultaneously enable doing the right things.

When it comes to innovation, care has to be taken that the new concept is not too alien from the customers' pre-conditioned thinking about what they like and value. If the customer cannot obviously recognise the value in a novel product or feature then it will not satisfy them – not immediately anyway. Sometimes we need to remember that it is possible to be too clever with novel ideas. Innovation only counts when it is successfully adopted in the market.

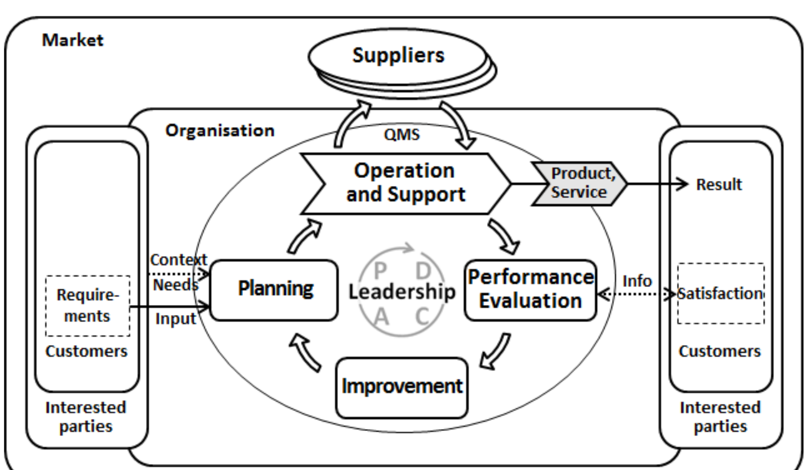
Quality management and ISO 9001

Ideally, quality is naturally inherent in the product design and operating processes, in a way that poor quality is simply never an issue. In the real world, however, organisations and their operating environments are dynamically complex. Everything that interacts has variability. It is utopian thinking that poor quality can never happen. At best we can maintain variability at such a low level where our customer can easily tolerate the trivial or occasional minor flaws. Commercial and non-commercial organisations are established and exist to provide value to customers, for which they receive an economic compensation in return. This exchange is essential for the organisation sustaining itself, to maintain the repeating cycle of providing value. Without the longer term continual ability to produce value to customers, there would be no basis for an organisation's existence. Standard ISO 9000 defines quality management as *"coordinated activities to direct and control an organisation with regard to quality"*. Any organisation that has activities intended to assure customer value, or simply to limit any poor quality reaching customers, can therefore be said to have a quality management system (QMS). Some organisations maintain a dedicated quality management function and operate to internationally recognised QMS standards; while others may simply use a few informal controls seeking to limit the amount of bad products. The QMS, whether formal or informal, is fundamental to succeeding in business and practically all commercial organisations have one. The degree of quality management effort is often a commercial decision, weighing the perceived costs and benefits.

The international standard ISO 9001 on requirements for quality management systems belongs to a family of standards, including ISO 9000 on the fundamental concepts and principles of quality management and vocabulary; and ISO 9004 on the quality approach to managing for the sustained success of an organisation. The (current) family of standards defines seven quality management principles, which are:

- Customer focus.
- Leadership.
- Engagement of people.
- Process approach.
- Improvement.
- Evidence-based decision making.
- Relationship management.

The world around our products and services does not stand still. Competing offerings continually improve and customer expectations evolve. Just because our product delivery system is state-of-the-art today provides no guarantee that we will not have to change it tomorrow. It is therefore of central importance that the system is continually improving, to at very least keep pace with or, better, to get ahead of requirements. The standard presents improvement as the spin-off that occurs from applying the Plan-Do-Check-Act (PDCA) cycle within the QMS.



QMS model (adapted from ISO9001:2015)

The ISO 9001 standard provides a descriptive (as opposed to being prescriptive) model for an end-to-end process-based system for achieving an organisation's policy and objectives through continual improvement.

The quality management system elements are:

<u>Leadership</u>
Drives the effective implementation and ongoing execution of the PDCA cycle across the system. Sets a unified direction and promotes the coherence to planned objectives. Unblocks any obstacles and maintains conditions for achieving the objectives.

<u>Planning</u>
Determines the customer input, any mandatory requirements and their organisational context, for translation into planned objectives. The context influences the objectives for making maximum use of opportunities for improvement and efficiencies as they arise. Planning also considers and incorporates countermeasures to risks of deviation from the objectives.

<u>Operation and support</u>
Organises and controls the multiple activities and linkages in the processes-chain and resources, for the purpose of the producing the planned result – e.g. transforming the input requirements into a corresponding output. The support element develops and maintains the appropriate competencies, capability and capacity in people, equipment, infrastructure and work environment.

<u>Performance Evaluation</u>
Measures, investigates and analyses the processes, product and outcomes, including customer satisfaction, for purpose of verifying that planned results are met and for identifying new risks and opportunities. Periodic audits objectively measure effectiveness and verify conformity to requirements.

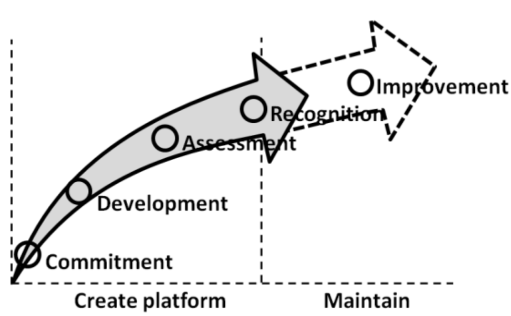
Improvement

Reactive and proactive activity for assuring the ability to meet requirements and for enhancing the satisfaction of customers and other interested parties. Improvement relies on evidence-based decision making.

The claimed benefits from adopting the ISO 9001 standard have included:

- Improving productivity and efficiency, reducing costs.
- Increased customer confidence and satisfaction potential.
- Wider market access.
- Competitive advantages.
- Statutory and regulatory compliance.
- Strengthened platform for innovation.
- Self-esteem and recognition.
- Reduced burden of inspection. One periodic third-party assessment instead of multiple lesser coordinated client and/or regulator audits.

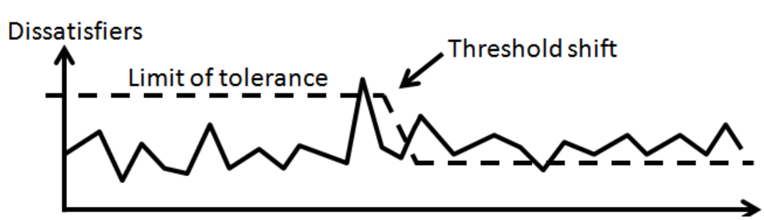
Most organisations tend to adopt the ISO 9001 QMS standard, or one of its industry specific variants, because its customers demand it. Adopting the standard is not a one-off activity, but has a life-cycle for improving the value provided by the organisation to its customers and stakeholders. Initially, the adopting organisation creates a platform for conforming to the standard requirements, and from which it can continually improve.



Whereas the standard presents a model for a quality system, it does not necessarily resolve all ills within an organisation. Quality has a reduced chance if the organisation, and its top management in particular, does not believe in its guiding principles. Attempting to bolt an ISO 9001 QMS on to an inherently dysfunctional organisation that is incapable of changing its poor practices can possibly make matters worse, by introducing an added burden of work and complexity in pursuit of something the organisation will not be able to meet or properly maintain anyway.

WHAT LEVEL OF POOR QUALITY WILL CUSTOMERS TOLERATE?

The following observation was made some years ago, while being responsible for a company quality management system. One of the QMS functions was to resolve and measure customer complaints, including compiling 3-monthly reports for management reviews. The particular company produces a complex mix of customisable products, for business-to-business trade, counting about 125,000 units per annum. The production generally operated well, when considering the inherent level of products and process complexity. We were rigorous in soliciting and recording anything that customers said they were unhappy about. Each 3-month period accumulated about 10-20 customer complaints. Then, one day, a supply difficulty made the order fulfilment time slip from the normal 3 days to 5 days. At one stroke, we suddenly received hundreds of complaints about all manner of variability issues. The same issues would have existed in our products and services when the delivery time was normal, but they had only become a problem now that our delivery time had slipped. In the particular sector at the time there were 3 key competitors. In less than 2 weeks, some customers had become so unhappy that they defected away from us. They only came back when their collective flight had overloaded the competitors, who eventually also ran into supply problems and started to mess-up on their delivery times. However, it still took a long time for conditions to normalise again and it had been a very costly process. The hard lesson learned is that while customers on the whole are satisfied and while they like us as people they can tolerate a degree of the odd small dissatisfier. At times it can feel as if we can do nothing wrong. However, as soon as the limit of tolerance is exceeded then everything – even the slightest deviance from expectations – becomes perceived as bad. It will suddenly feel as if we can do nothing right. The effect is strongest when it is concerned with non-fulfilment of a (Kano) basic need – i.e. something customers have learned to take for granted. The limit of tolerance is thereby dynamic. When the organisation just once peak above it, it can suddenly and immediately shift downwards to reveal a multitude of issues that no-one realised matter much. The rate of threshold recovery is comparably slow and can become trapped in a self-perpetuating dissatisfaction. It takes a long time, measured in months or years, for the limit to return to 'normal'. For some customer that felt let down things will in fact never again become what they used to be.



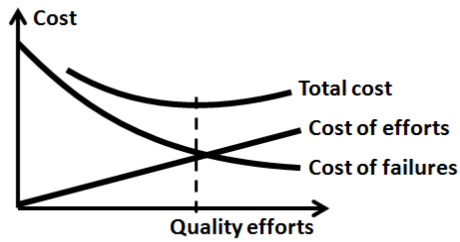
Shift in the customer's limit of tolerance to dissatisfiers

Most customers will tend to switch their supplier only following a poor experience. Staying clear of the limit of tolerance, for both poor design and execution, will therefore naturally tend to help increase customer numbers over time. This makes it important to be positive about understanding any form of perceived shortfall – not just receiving the formal complaints. It enables gauging the limit of customer tolerance to dissatisfiers. When we improve quality, or if our competitor does it, then customers come to expect the new capability and the limit naturally moves downwards. Continual quality improvement ensures that we keep up with expectations and do not suddenly get caught out by a moving threshold limit. If by improving our product we can instigate a downward shift in the threshold limit, while maintaining our own quality level well within it; and if this catches out our competitors, then we can in a relatively small step create a significant competitive advantage. Just beware, our competitor will be forced to respond and may in return do the same to us. The customer limit of tolerance is never clear cut, but more of a grey area. It is always worth investing a little extra effort on quality, to maintain certainty of a clear margin to where we perceive the limit to be. We would not want to take too much risk with quality, with attitudes such as: *"Let's cut a corner and hope nothing happens"*, or *"let's send out the sub-standard production batch, because the majority of customers won't complain and we can always fix it for those who do"*. Playing it too close to the limit of tolerance, and misjudging it, can have a potentially catastrophic cost effect.

COST OF QUALITY

We sometimes hear the saying that *"quality is free"* or in fact saves money. This is normally true, up to a point. Expenditure on quality efforts will eventually reach a point of diminishing returns, beyond which the cost of quality effort increases at a faster rate than the cost of failures reduces. The excess cost this creates has to be passed onto the customers, who will see relatively less value in return for what they pay.

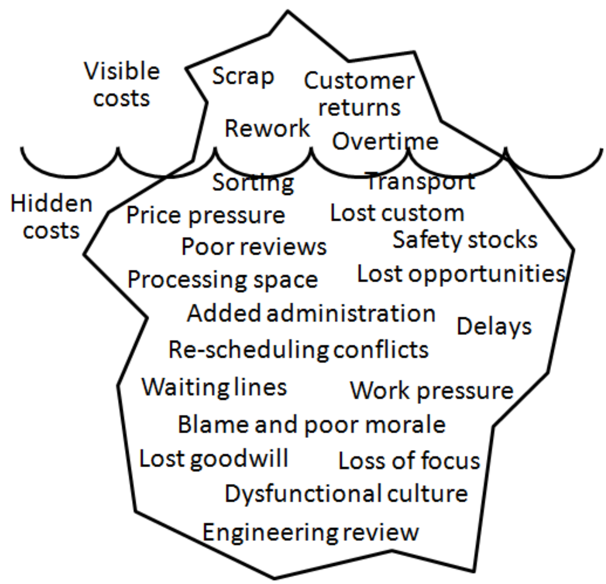
The cost of quality is the total summed cost of efforts and failures. In practice we add-up 4 cost areas, namely prevention, appraisal, internal failure and external failure costs. Its principle use is about finding the best balance for minimising this total amount.



Cost of quality curve

Cost area	Example costs
Prevention: Costs of efforts to prevent poor quality in products or services	• Quality planning activities • Product design verification • Quality education and training • Preventive maintenance • Process improvement
Appraisal: Costs of measuring, evaluating or auditing products or services to assure conformance	• Incoming goods acceptance inspection • In-process inspection and testing • Final product inspection and testing • Test equipment and calibration • Quality audits
Internal failure: Costs of making good defects caught before reaching the customer	• Scrap • Downgrading • Rework • Re-inspection and re-testing • Production re-scheduling
External failure: Costs of making good defects that have reached the customer	• Complaints handling • Warranty claims • Product recall • Product liability • Lost sales

When we do our sums it is easier to estimate the cost of efforts, than it is to estimate the costs of failure. This is because of the iceberg analogy telling us about a large element of hidden failure costs. This adds reason to erring on the side of always doing more prevention that we may think is obviously worth the cost of effort. Fortunately, there is an infinite space of yet undiscovered, low cost solutions for improving quality. It is simply a matter of being clever in finding them and to start implementing.



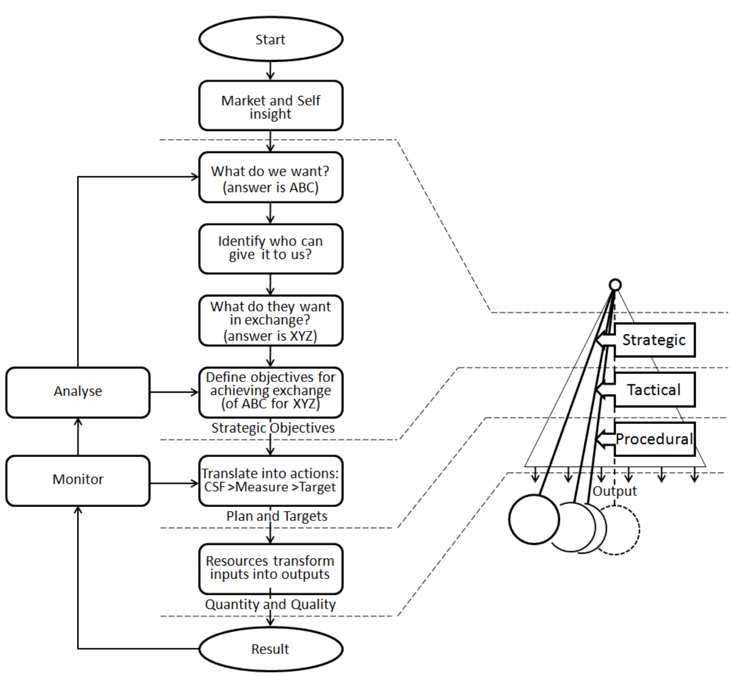
Iceberg analogy to hidden costs

PART 3

STRATEGY CONCEPTS

STRATEGY PROCESS

Strategy is a hypothesis on the causal links between initiatives and their effects. Strategy development and deployment is a process that cascades down a set of derived objectives and policies for implementation. The inputs into the strategy are frequently incomplete and invariably based on a degree of assumptions – the quality of which depends on the organisation's insight into the market and itself. The forecasted effects of initiatives can often not be entirely validated in advance of implementing the strategy and will therefore need continual monitoring and correcting.



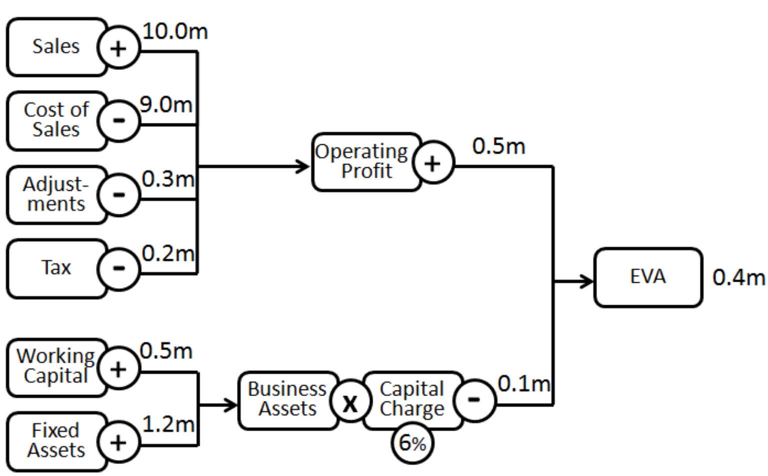
Strategy development and deployment process

The strategy process starts by asking the fundamental questions of: *"What is it that we want"? "Who can realistically give it to us"?* And, *"how can we get them to give it to us; what of equally perceived worth would they want from us in exchange"?* Once we have determined the answers then the process is to define a set of objectives for making the exchange happen. The strategic objectives are subsequently cascaded down for implementation at a tactical level. Deploying the objectives involves identifying their 'critical success factors' (CSF), to which are attached measures and targets – sometimes termed 'key performance indicators' (KPI). The success factors may also define changes to be developed in detail and implemented, such as new products or delivery systems, in order to establish a new direction or meet new performance levels. Finally, the procedural activities are managed against the KPI targets, which involve measuring the system output quantity and quality against the plan. The strategic level receives monitoring reports from both the tactical and procedural levels, to enable its continual validation, or re-thinking, of the original strategy assumptions. The pendulum analogy tells us that a single unit of work effort that is performed at the strategic planning level can have significantly more impact on the organisations output performance than any similar single unit of work effort that is put in at the procedural level. This analogy is similar to when in QFD we say that time spend planning the development work is more than saved when it comes to implementing the actual development activities.

Once the strategy process owner, who when it comes to organisational strategy tends to be senior management, has determined the organisation's objectives and policies then the tactical and procedural activities must align themselves with these. This includes any product development project, which of course does not exist independently of the wider organisation. This fact of reality impacts on the QFD-based project. Firstly, the QFD team's ambition must match the ambition in the organisation's strategy objectives. It would be pointless developing something that is less than what the strategy requires. It would also be pointless investing excess time and resources in aiming for something that is (significantly) more. Secondly, if the QFD team's direction gets out of alignment with the wider organisation's objectives, then one of two things has happened. Either an assumption used in the higher strategy process is proven wrong and needs changing; or the QFD team's decision is wrong and needs changing. The QFD team leader would therefore need to check with the strategy process team to resolve the issue.

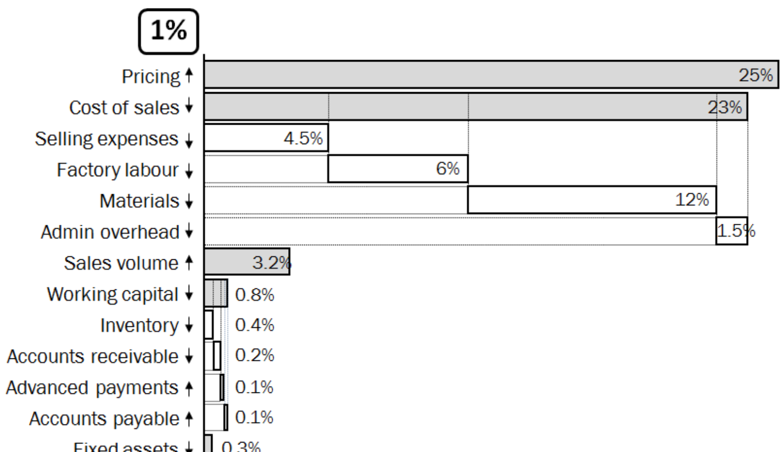
Economic Value Added

The principle aim of any commercial organisation is to grow or to protect its Economic Value Added (EVA), with regards to both the shorter and longer term. EVA is the measure of true profit that is made. Different companies may use other similar measures for the return on their investment.



Economic Value Added calculation

Now imagine that we could increase our sale price by 1%, while all else remains equal – e.g. without any effect on cost or quantity. ‘Sales’ in our EVA chart will then become 10.1m; Net Operating Profit 0.6m; and EVA 0.5m, which equates to a 25% improvement in true profit. The bar graph below reflects the example effects of EVA levers for a not atypical product manufacturer. Reducing cost by 1%, all other things being equal, has a 23% improvement effect on EVA. Cost is broken down into its 4 main centres, which can be addressed independently. How much price and how many units we can sell of a product have inherently something to do with the customer-experienced quality, which is largely a function of product design. How much it costs to produce the product is also significantly influenced by product design. The amount of total inventory that the organisation has to hold is also influenced by product design – e.g. degree of components shared across products and the size of reliability safety stocks. Design is therefore an organisation’s principal creator of wealth and the choice in its approach to design, such as QFD, is a significant success factor. Other organisational processes, such as sales and marketing, cannot create value – not sustainably in the long-term anyway; but they can waste value by under-selling a product.

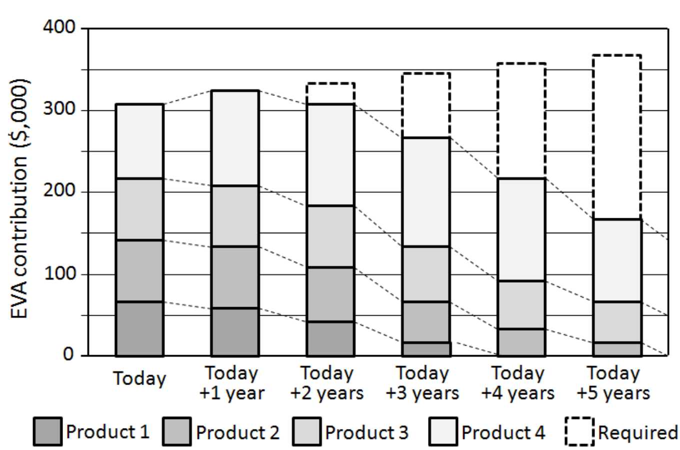


Effects of the EVA levers

The bar graph for the EVA levers teaches us that whereas cost optimisation is good, it should not compromise the ability to obtain a good price. Elements of the product that the customer interfaces with – what gives it the look and feel – are particularly important in conveying value. So, if we have to cut cost then in the first instance we should do it on parts of the product that the customer does not see and where it does not result in a disappointing quality problem. The engineered technical solution has to be satisfactory, but equally important is to optimise the user interaction experience. This is what the customer buys into and is continually reminded about paying for.

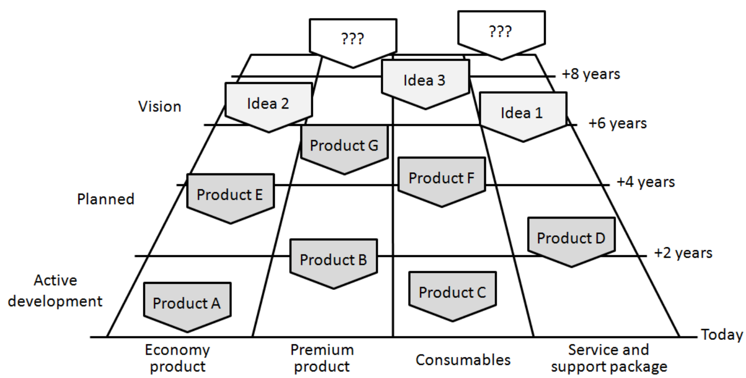
PRODUCTS PLANNING

An organisation's ambition for its product development is, as minimum, to replace the naturally diminishing future EVA in its existing aging products range. A commercially more realistic ambition is to maintain a roadmap for developing products that keep improving EVA.



EVA forecast showing a requirement for renewal

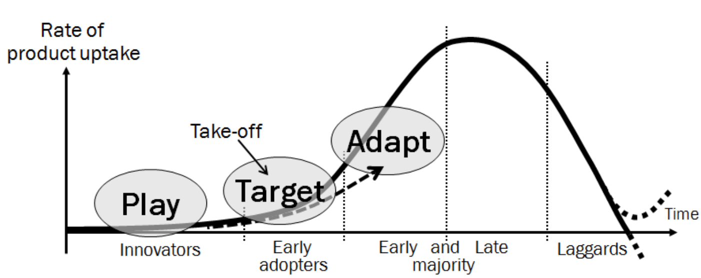
The products roadmap has a number of time horizons where the plan refines and becomes more firm as the timeline approaches. It is healthy to look several years ahead to maintain a vision for what may come, so that we can think about direction and compatibility in the decisions we make regarding products that are in development today.



Products roadmap

DEGREE OF INNOVATION

The rate of uptake in highly innovative new technology tends to be initially slow, while only the 'innovators' pay attention to it. This is because innovators have special ideas, which the masses cannot yet recognise any value in and therefore do not yet want.



Rate of new product uptake

Products at the 'innovators' stage tend to require frequent revisions, due to the evolving new technology and evolving ideas about how to apply it. The initial novel product can either flop; or it can evolve so much that it demands further unplanned investment in a revised generation; or it is superseded by a fast-following competitor. Entering the market with a product at the 'innovators' technology stage severely risks not producing sufficient sales quantities to payback the necessary high investment. In addition, break-through innovation is resource demanding, which can detract focus away from operating the organisation's core cash generating activities. Innovation is therefore often economically unappealing, because of the associated risk of destroying EVA. Brave companies embarking on new direction innovation projects rarely get their just rewards. Looking at some of the greatest and most successful innovations in history, the organisations that ended up capitalising on new technology are rarely those who did the original invention. Many companies therefore make a conscious decision to ignore break-through innovation and instead specialise in being fast followers. In the main this works well. For example, GE, Siemens and Philips did not invent or were not first to market with the medical MRI scanner. Instead they followed only once the need had been commercially established. This hasn't prevented them from taking the biggest portion of the rewards. Such strategy, however, relies on someone else actually creating the innovation to begin with. There is something of a dilemma in saying that we cannot afford to innovate, while simultaneously we cannot afford a situation where there is no innovation either. We cannot entirely ignore working with the innovators, because in the least we need to maintain an understanding about what and when the next big idea is about to take off, to prevent someone else locking us out of the emerging new opportunity. The optimum solution is that we work cleverly and efficiently, to enable us 'playing' with the innovators as much as we can economically get away with.

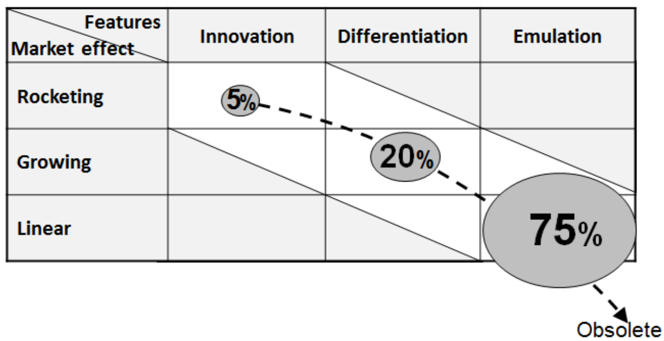
Calculating companies tend to mostly target new product features that are at the take-off point in the 'early adopters' stage. Getting to market fast and first is important to such strategy. Often the development of a first generation product has to compromise on optimisation for speed. Fortunately, the early adopters have a short attention span and tend to be motivated more by novelty than by optimised reliability and cost. Optimisation first becomes significantly important once we 'adapt' the product for the larger sales quantities within the mass market.

We can aim for our new product features to target different market-effects:

- Innovation is defined as *"something novel of commercial or professional value"*. Innovative features have potential for creating a rocketing market effect, significantly growing the sales quantities and/or the obtainable price.

- Differentiation refers to features that make us stand out from the competition. These features can help us establish a growing market effect (i.e. growth in sales). We can only differentiate on features where it can help us promise the user an advantage over competing products. Differentiating something for the sake of being different, without the difference offering any advantage, can sometimes risk going against the product – in particular in linear markets where customers may look for standard commoditised solutions.

- Emulation refers to commoditised features, which are no more or less what may be found in any similar type product from any other producer. These features produce mainly a linear market effect, meaning they will not contribute anything to growing the sales quantities or the obtainable price. However, thinking back to Kano for a moment, the promise of innovation and differentiation are worth nothing unless the basic needs are fulfilled.



Product features and market effects

By the definition of innovation, as being both novel and valuable, and by further recognising that rocketing market effects cannot be created by emulation, product features can only really exist within the non-shaded zone in our table for ‘product features and their market effects’. The illustrated sizes of the circles here represents a suggestion for where to invest new product development efforts for a not atypical growing technology company (but it could look differently for a company with different ambitions), namely: 5% on innovation, 20% on developing differentiation, and 75% on emulating/copying known standards. And even then, what we marketing consciously in the commercial world define as ‘innovation’ is in fact often no more than synthesis of elements of existing knowledge that we relatively simply have transferred from a different product field. It is rarely radical break-through innovation. Calculating companies tend not to let their innovation programmes stray outside their already established competencies and core business

– unless the core is in a desperate decline. It is about investing for the biggest assured economic return. The rationale for our distribution of focus here relates to the conservatism in market uptake and to the risk of failure from innovation. By necessity, we simply have to largely inhabit the linear market emulation model, in order to generate the 'bread and butter' business income that will enable us to afford the risks cost of investing 5% of our development time and resources on innovation. In static markets, where buyers mainly consider their well-defined needs, innovation is best focused on enhancing and creating excitement around the responses to (Kano) basic needs – i.e. do not try deviating from the fundamentals of the accepted product model, but try instead enhancing the fundamentals.

RISK AND OPPORTUNITY

There are disruptive trends and opportunities going on all around any organisation all of the time. It is bad, but not uncommon, when organisations concede: "*It would have been a fantastic thing to do; but just not right now because we currently have other issues to sort out first*". It can become kind of a perpetual excuse of the never-ready organisation for not maximising its opportunities. The organisation has to prepare and protect the capability of its resources to use opportunities. Inaction, in a changing market, is the greatest risk of them all.

Although not truly the reciprocals of each other – because there can be opportunity without risk and vice versa – risk and opportunity often have to be considered together.

Inability to exploit opportunity can present a risk.

Ability to control risk enables exploitation of opportunity.

Risk-based thinking means to ensure that risks are identified, considered and controlled by a proactive approach. An opportunity is a set of circumstances that makes it possible to do something positive. When the market as a whole is disrupted the strongest, best prepared is able to take advantage. This in part is about making the organisation's systems robust in handling disruptions, without seeking to control the (uncontrollable) disruptions themselves. Investments in resilience can give an organisation a competitive advantage over those who are unprepared. Resilience is about being able to seamlessly adapt to evolving changes in the operating environment. To put this in context of the quality thinking presented in the previous chapter, it is about controlling what can go wrong, while simultaneously maintaining or enhancing the capability for doing right. The system is thereby said to simultaneously have both defensive and offensive modes:

a) The defensive mode is about establishing preventative and protective devices, to prevent failures or setbacks from unmanaged risks.

b) The offensive mode is about maintaining adaptability and scalability, to be readily poised to take advantage of new opportunities.

BIG DATA

Refers to information that is high in volume, velocity (near real-time) and variety. When combined in new deductive methods of analysis, 'big data' can improve learning about relationships, dependencies and behaviours. It proves a cost-effective way to enhance decision-making in the product strategy process, for the benefits of producer, product users and society in general.

Quantifying features usage and user behaviours, together with the context in which they occur, is valuable information in the planning of new product evolutions and in marketing. It will also enable producers to understand individual customer preferences and personalise products. Developers should consider all conceivable ways of embedding sensors and usage data recorders into their products. Generally, if something can be measured then the information will have some sort of use, and value, to someone.

We need to be aware that data gathering consent and privacy protection become important additional customer requirements. In this respect, stronger brands can often be at an advantage. If you are unable to gain customer trust then data gathering features may risk counting more against the product than the benefits they can bring.

Eventually, virtually everything is expected to one day interconnect. Many billions, if not trillions, of devices will connect to the 'internet of things', all generating data to support new understanding of our living environments and about ourselves – for example, in predictive healthcare. The network of interconnected technologies promises to revolutionise products and delivery processes. New information streams give rise to new features, increased usability and productivity, improved forecasting and planning, self-checking inventories, self-diagnosing faults before failure, optimised movement and transport, and reduced natural resources usage.

SUPPLIERS RELATIONSHIPS

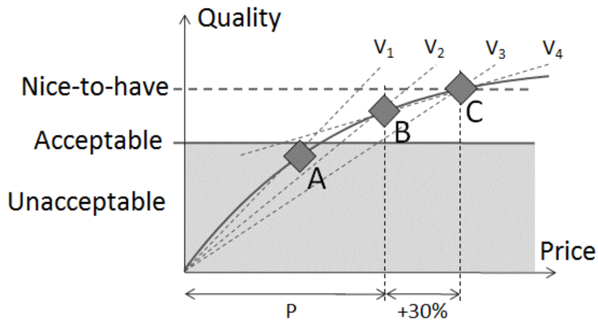
A well-managed supply chain provides for a stable flow of goods and services. Even if they are not part of the organisation itself, those suppliers who have a significant influence on the final product to customers should be considered with equal importance to the organisation's own systems. In fact, in some sectors, the supplier can have a greater influence on outcomes than the organisation's own resources have. The organisation would want its suppliers to continually improve, on both quality and price. Practically all sectors experience cycles of change that results in economic pressures within the supply chain. The chain should share this pressure with a degree of equity. Bad or selfish organisations, pushing all of the pressure up the supply chain, cannot expect to have good suppliers. A skewed relationship, where one party sets all of the conditions and reaps all the rewards, is not a recipe for long-term success. The unfairly subordinated party is unlikely to invest their best effort in such a relationship.

The success of supplier relationships depends on:

1. Finding the right supplier, who 'matches' the organisation.
2. Be clear about what the organisation wants from its supplier.
3. Understand sensitivity to quantity and time commitments.
4. Negotiation for mutually benefits (both fulfilling their needs).
5. Monitor and manage relationship performance.
6. Replace when at risk of failing – before failing.

The right supplier shares the organisations value (quality-price) strategy – e.g. has either an economy or a premium product focus, or something in between. The aim is to avoid buying too little quality or paying excess for needless quality. 'Quality' here is the combination of product/service performance, desirability and the supplier's technical, environmental, safety and professional ability. The 'acceptable' level of quality is what the organisation has determined as necessary for succeeding in its purpose – e.g. for satisfying its particular customer group and interested parties.

'Value' can be defined as the ratio between quality and price. The supplier's investment in quality efforts will eventually reach a point of diminishing returns, beyond which the cost of quality increases faster than the rate of improving customer satisfaction.



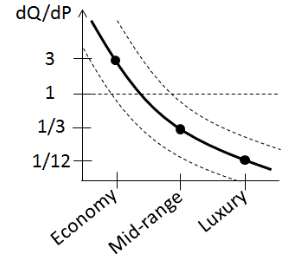
Value lines and 'natural law of pricing' curve

The supplier's pricing, as a generalised rule in the mid-range, says that for every +10% of luxury expect about +30% of added price. In the example graph above:

Product 'A'	has the highest 'value' (line V_1), but fails the threshold quality/performance requirements. It cannot be relied on for satisfying needs.
Product 'B'	is lowest price item that fulfils the 'acceptable' quality requirements. Best value line (V_2).
Product 'C'	contains more 'nice-to-have' quality benefits than Product 'B', but is lower in value (V_3). The difference between Products 'B' and 'C' can represent exceptionally poor value (V_4).

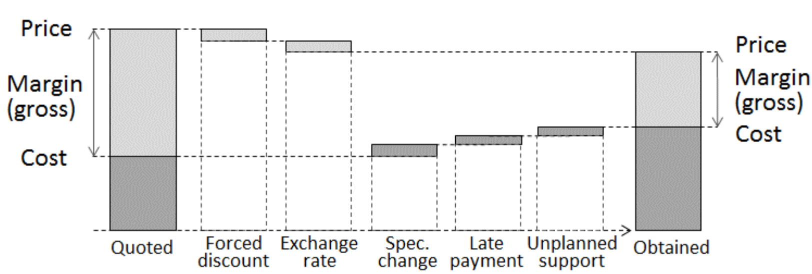
The natural law on pricing is represented by a curve – i.e. it isn't universally linear across the market. For an 'economy' product, a relatively small change in price (dP) can support a higher rate of change in quality (dQ). When the ratio dQ/dP goes below '1' then it is generally not 'worth' investing further in quality, because the net value to customers reduces. There are exceptions. When we can afford it, and when our customers can, then we all tend to prefer to feel good about buying a degree of non-essential luxury.

	dQ	dP	dQ/dP
Economy	30%	10%	3/1
Mid-range	10%	30%	1/3
Luxury	5%	60%	1/12



Rate of change in quality-price ratio

Price and cost are the two single most important matters to a commercial supplier. Nearly everything that a supplier does evolves around estimating them right and optimising their difference, without losing the customer. Suppliers know that the margin in the price they quote is not necessarily the one that they will finally obtain. They must factor-in risks to the 'obtainable margin'. Buyers invariably end-up paying for this risk, in one form or another. The organisation, in order to get the best value price, should help mitigate the supplier's risks by knowing what it wants, paying on time and committing to quantities.



Supplier risk to obtainable margin

Think about how your processes and approach to relationships can adversely impact on your suppliers, but demand the same consideration in return. Know where the organisation can be flexible on the features in what is being supplied to it. Negotiate fairly, with equity. However, do not tolerate unreasonably poor quality or pricing. Replace poor suppliers or seek to adopt an alternative solution to fulfilling your needs.

INTELLECTUAL PROPERTY (IP)

IP is any form of original creation of the mind, which can be bought or sold. This includes inventions, literary or artistic works, names, symbols, images, and designs in commerce. IP is an asset that the originator can claim exclusive rights to and legal ownership of. This means that others cannot commercialise the idea without the owner's prior agreement, which usually involves a financial compensation. IP protection can be essential to recovering innovation investment costs. It is therefore important to establish clarity about ownership and to protect the IP from misuse or theft. In most countries the world over unauthorised use of someone else's IP rights is a crime, comparable to stealing any other type of asset. Common ways to formally claim or protect IP rights are:

- Patents for novel technology in products and processes.
- Registered designs for the way products look.
- Trade Marks for branding of goods and services.
- Copyright for literature or artistic works.
- Licensing.
- Confidentiality agreement.

The first 4 methods tend to be standard in most countries. There are also means of protection that covers regions or globally, such as European and World patents.

Licensing to an established market player can be a fast and secure way to start earning money from IP, where the originator does not have the means to bring the IP to market by himself. This may involve multiple licensees; or a single exclusive licensee; or a shared partnering model.

Confidentiality agreement, or Non-Disclosure Agreement (NDA), is a written agreement that records the conditions under which IP related information can be disclosed "in confidence", to enable its secure sharing with potential partners and collaborators. Sharing information under a confidentially agreement does not constitute putting the original idea into the public domain.

The quality characteristics of the different ways to set up protection for IP rights are:

a) Clarity of ownership.

b) Robust claims, meaning that a patent or agreement covers all possible variations in language use and it does not conflict with any prior art.

c) Wide claims, meaning that they cover related features or areas, to best set up a protective zone around an IP.

d) Fast. The 'patent pending' period, for example, is not recognised in law and does not prevent anyone from (temporarily) exploiting your idea. If it takes 3 years for a 20-year patent to be granted, you practically have 17 years to exploit the IP commercially. If it takes 5 years, due to a weakness in a poorly drafted patent application, you then only have 15 years to exploit. Slow process reduces the value of IP.

e) Secure. If someone else finds out about an idea, before ownership has been formally recognised, then the basis for new originality is lost and the IP rights can become unclaimable. This includes if others in the public domain learn about the original claim through accidental distribution or illegal theft of information, such as from computer systems and by intercepting emails.

f) Cost efficient.

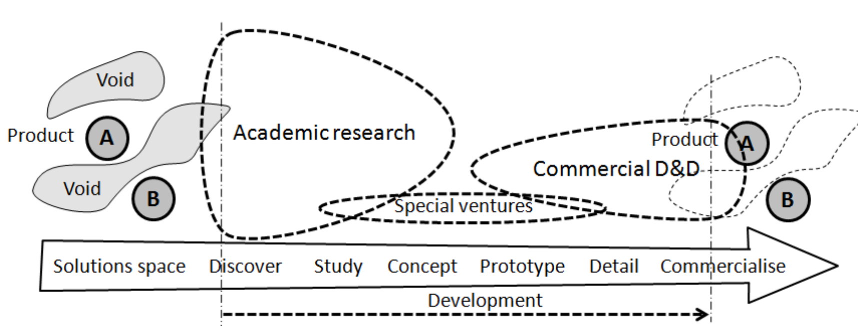
g) Financial backing. IP rights can be worthless without the financial means to defend them.

IP is a complex and important subject that often requires specialised expert advice, tailored to the idea originator's particular circumstances. Advice is generally available from the national Intellectual Property Authorities, but often expert IP lawyers prove essentially necessary and invaluable.

PRODUCT DEVELOPMENT CONCEPTS

HOW DO IDEAS COME ABOUT?

Before a new original idea is discovered it can be thought of as in fact being in existence already, just that it exists within a yet unknown 'void' in solution space where it has not yet been found, studied and defined. Simultaneously, the same solution space holds defined products containing known developed ideas, such as the labels 'A' and 'B' on our pathway here, where the voids co-exist alongside these established products. A newly discovered, previously unknown, idea goes through a development pathway, before it is released back into solution space as a known idea. The solution space can be thought of as wrapping around the idea development pathway, with the same space in fact existing both before and after idea development. Solution space has near infinitely more undiscovered voids than it has discovered solutions. The future promises to reveal many yet undiscovered ideas to us, on the basis of which we can discover yet even more.



New idea development pathway

It is worth distinguishing that R&D and D&D occur in different arenas on the pathway graph, where what we term an idea uses a different route to market. Academic research is largely concerned with looking into the voids on the left-hand side of the development pathway graph, for purpose of discovering and studying new original ideas. The dashed line drawn around "Academic research" is shaped with its gravity towards the yet undiscovered, to reflect where the most money and brain-power is spent. Academic reward and prestige come from making new discovery. The academic researchers therefore tend to let go of ideas before they reach a concept stage, to refocus their efforts on making yet more new discovery.

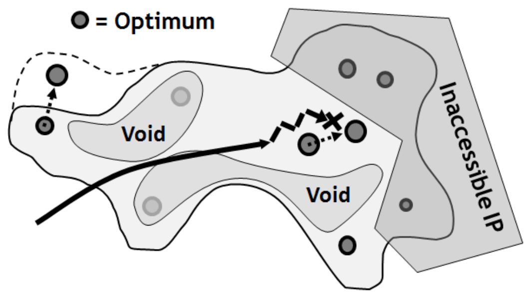
Commercial D&D, being risk adverse to developing novel original ideas, tends on the other hand to be biased for reusing existing know solutions. A commercial D&D project is largely concerned with looking at existing products, based on mature ideas in the right-hand side of our development pathway graph, to take them back into development for rework and improvement. Occasionally, they may by deduction come up with new ideas, by looking at narrow gaps between existing products, such as the small strip of void illustrated here between the labels 'A' and 'B'. However, this is not the same new frontier discoveries that academic researchers are aiming for. In the main, commercial D&D tends to stay well clear of the solution space voids, because these are too investment demanding and too risky to be economically viable. The commercial strategy also reflects what its customers are asking for – namely the already known. There are examples of academia and commerce stretching their reach sufficiently to meet up, but these are the exception rather than the norm. In many fields, where society has an interest in promising new ideas being successfully taken across the divide, various public funding initiatives and grants competitions exist to support collaborative knowledge transfer. 'Spin out' to universities science parks and Capital Venture companies can exist as a knowledge transfer bridge in this area; but they are relatively low in quantity. Generally, it can therefore take a very long time for original new ideas to evolve and reach the commercial market.

In some respect, the discovery of a truly original new idea, which has no similarity to anything preceding, can only happen by chance or accident. It is possible to set up conditions for increasing the chance of discovery. However, the kind of creativity that we mostly apply in product development is the inquisitive transfer or association synthesis, recombination or evolution, of largely pre-existing ideas and knowledge. The generalised types of thinking involved in creating new ideas may include:

- Random search, including by an automated idea generator.
- Trends analysis.
- Group stimulated search (brainstorming).
- Systematic testing of many potential relationships, to find new ones between previously unrelated ideas.
- Exploring analogies to similar technical knowledge.
- Exploring analogies to natural systems.

NAVIGATING SOLUTION SPACE

Solution space is abstract multi-dimensional and non-convex (not necessarily a nicely gradient surface). The space contains known and partially explored optimum solutions. It also contains unchartered 'voids'. An optimum, and the space around it, can move, grow or shrink in ways that are not always easy to predict. For example, customer desires can change, and thereby reduce the value of an optimum. Or, a new related discovery or a sudden safety concern can completely destroy an optimum. Part of solution space is inaccessible to us, either because someone else have established IP rights to it or because it is outside our design or production capabilities.



Navigating a changing solution space (2D representation)

In our design process, we set our eyes on a partially optimised solution that we judge, by analysis and evaluation, to be effective in meeting market needs and is within our capabilities. Once we have committed to our solution, we start a metaphorical hill-climb to get us as high up the optimum as we can get, within the project time and resources that we have available to us. We have to be mindful about a number of wasteful navigational errors that can be made in solution space:

1. Choosing a wrong target solution that has less potential than another optimum in the same space. Once we have started the ‘hill-climb’ and made investment in a solution it then becomes difficult to abandon it again. Sometimes, if we are unsure about our options, it can be justified to spend a little time wandering the solution space and make a few small exploratory climbs at different optima, to better appreciate their individual potential or difficulty. The learning (from failures) is often transferable.

2. Choosing and developing a target solution, only to find out late that someone else has already claimed the IP rights to it.

3. Rigid early design specification, which does not allow us to track a moving optimum. When combined with a long project timeline, our final product may thereby completely miss its

target market – which has moved on. Project plans need flexibility in accommodating unforeseen changes in the market and product functional requirements.

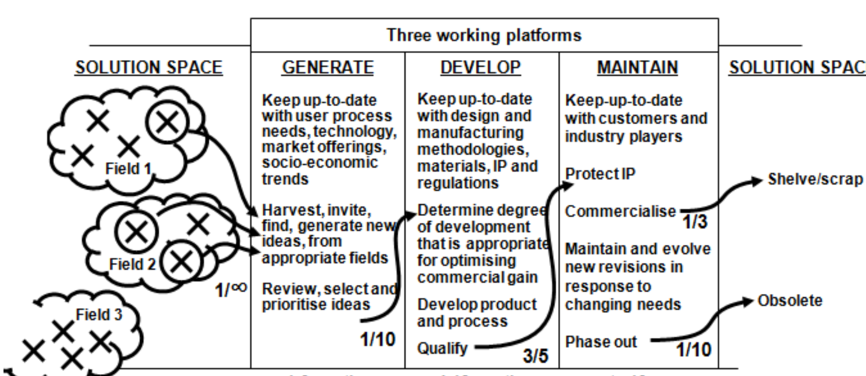
4. Wandering into unchartered space and picking an optimum that stands within a knowledge or competencies void. To a commercial enterprise these are 'black holes' sucking in excessive time and cost, while producing something that customers have often not asked for anyway.

5. Inappropriate assumptions about our production system capabilities. The prospect for attaining the necessary production capabilities for new technologies or fine design tolerances needs early consideration.

Successful navigation of solution space favours a systematic approach, such as QFD.

ORGANISATIONAL MODES

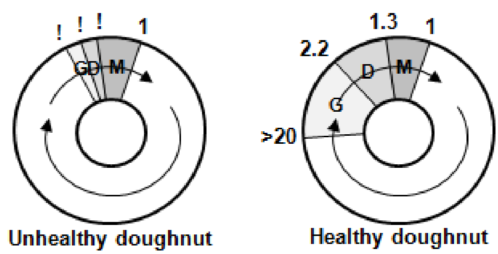
The product life-cycle functions within an organisation can be thought of as operating on 3 working platforms.



Product life-cycle model with working platforms

The product life-cycle model indicates that of the ideas on the ‘generate’ platform only about 1 in 10 gets prioritised for progressing into development. This reflects that many of the ideas we get or hear about, once we start thinking them through, do not yield sufficient potential to merit development. An idea can have a lifespan of 1 to 6 months, from inception until we have decided what to do with it. In reality, some ideas can reside for many years within an organisation, just waiting for circumstances to become right for them, but they are not continually active during such long time. Of the ideas that progresses on to the ‘develop’ platform only about 3 in 5 makes it through the development process. This is because sometimes priorities will change and a project will be put on hold, or scrapped. Other times, in spite of best efforts, we come up against a technical or regulatory difficulty that does that we cannot successfully qualify the product for release into the market. Products that succeed in their qualification are flowing into the ‘maintain’ platform. Even here, some are never successfully commercialised or they turn out to only have a relatively short lifespan. Sometimes the market rejects a product – maybe because a competitor introduces something that is significantly better and cheaper; or maybe some unforeseen patent conflict bars us from selling the product in certain places. Lastly, there comes a point where we can no longer continue to revise or renew the product, where it eventually comes to its end-of-life and is phased-out.

If, hypothetically, we say that a product has a 10-year lifespan; and our organisation has 10 products in the market. Then we will need to top-up the ‘maintain’ platform with 1.3 new products every year. The added 0.3 relates to the proportion that we can expect being prematurely shelved or scrapped. In order to achieve the 1.3, we will have to, on average, start 2.2 development projects per year. And, we will have to harvest and evaluate at least 20 new product ideas every year. Because of the way that discovered and undiscovered solutions co-exist in space, where the scrapped or obsolete products effectively return to space, we can wrap-around the platform model into a doughnut shape. If we do not satisfy the proportional balance between the platforms quantities (20 -> 2.2 -> 1.3) then we have an unhealthy doughnut. We then risk being forced to either, or both, market outdated products or push through incomplete developments based on under-developed ideas – overall diminishing the organisation's chance for success.



Doughnut analogy to sizing the working platform activities

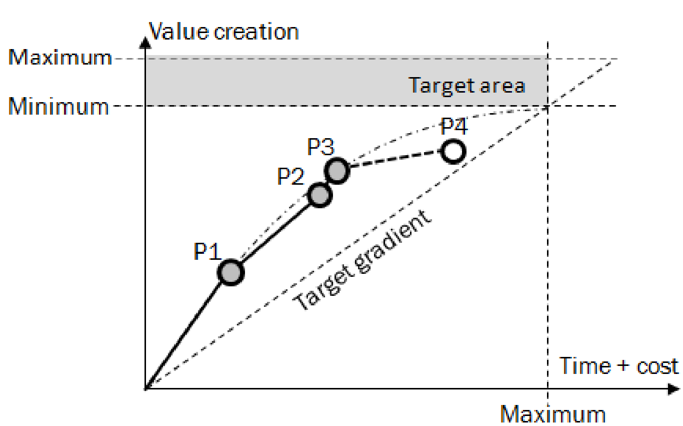
Establishing and maintaining the right quantities balance between the working platforms is one thing. Another is to establish the right organisational modes within them.

Platform	Activities	Organisational mode
Generate	Keep up-to-date with the market and solution space. Harvest solution space and creative minds for products ideas. Select and prioritise the best ideas, to go forward into the development platform.	• Manage breakthrough • Entrepreneurial • Experiment and learn • Allow for multiple, small failures • Agile and responsive
Develop	Keep up-to-date with technologies, regulations and IP. Plan and perform product development actives. Market test and qualify new products.	
Maintain	Keep up-to-date with changing market needs. Protect IP. Commercialise new products. Make post-launch revisions, in response to customers, markets and supplier changes. Phase-out obsolete products.	• Manage volume and cost • Conserving • Incremental change • Consistency and control

Large organisations tend to have different teams of people, with different behavioural talents, within each the 3 working platforms. This can be good for maintaining constancy of purpose; but it often lacks integration and results in ineffective over-the-wall relationships between the working platforms. In small organisations it is the same team of people that operates across all 3 working platforms. This, firstly, requires that people behave with some kind of split personality. People are generally not fluent in switching between the modes and tend to bring only a half-way attitude to either mode. Secondly, the 'maintain' platform, which feeds today's customer and makes today's money, will always shouts the loudest for attention. There will always be product maintenance tasks demanded for today, at the risk of perpetually putting off the new product development work until tomorrow. When there is only one team available, for all 3 platforms, it demands strongly disciplined resource planning.

DESIGN PROCESS EFFICIENCY

It is the measure we get when dividing the value creation by the time plus cost of development efforts.



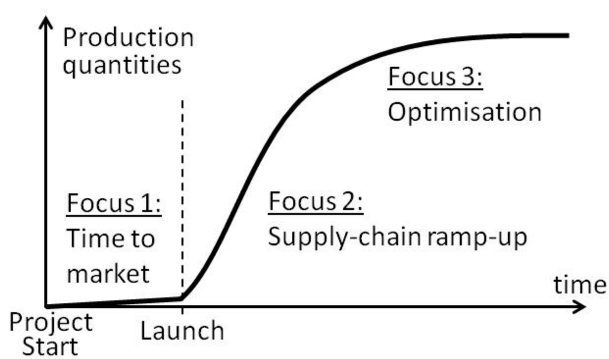
Design process efficiency gradient

The design project will have a minimum value creation target and a maximum allowable time plus cost. As part of managing the project, we should continually understand the prospect for process efficiency. When we indicate that a project may also have a maximum for its value creation, this refers to cases where a product has to fit in with other products in a wider value range. For example, if our task is to design a mid-price-range car model then it must have more value than the economy range car model, or else it will not sell; but it must not have so much value that it starts 'cannibalising' sales from the premium range car models. The final design value in such case, therefore, has to fit within a minimum and maximum target range.

The graph here (previous page) illustrates a target gradient line that starts at the graph origin and ends at the point where the minimum value meets the maximum allowed time plus cost. Development work that results in the actual project progressing above the target gradient is more efficient than planned. It proves generally easier to maintain a feel of value creation earlier on in a project, while the development team is more highly motivated by the novelty and where we have not yet reached the detailing stage. A project team has to be careful not to become complacent due to its early perceived successes. There comes a point towards the end of a project where the 'law of diminishing returns' will set in and the actual process efficiency gradient starts levelling out. Our graph here illustrates the process efficiency through example stages, which are probably not atypical to real-life project cases. Project stages P1 and P2 progress more or less as can be expected of a typical project. P3 achieved only a relatively small value creation step, but its time and cost investment was proportionally even smaller, so P3 was well justified. Now the project team is faced with a decision to embark on the proposed P4 plan, which does not look good. Proceeding to P4, as the plan in the illustration stands, will result in the project remaining on the good side of the target gradient; but when looking at the trend, in respect of the 'law of diminishing returns' gradient, it should warn us that the plan will probably fail in terms of a future P5 or P6 reaching the final target. The project team, in this case, must go back to the plan to find more ambitious options for increasing the value creation potential of P4.

DESIGN AND ENGINEERING OPTIMISATION

Optimisation is the process of improving and refining something to its best practical level. There are many methods for choosing what and how to optimise, which we will not go into here. Instead we will take a higher level view on when to optimise.



Product development project life-cycle focus

From the product developers' perspectives, unless they are designing something as safety or reliability critical as a spacecraft, the initial development focus tends to always be on 'time to market'. This is because, firstly, of the necessity for the project investment to start earning money to pay itself back. Secondly, we often cannot afford to miss a timing opportunity in the competitive market. As soon as the product gets to market the next focus becomes about ramping up the supply-chain to enable it produce the quantities being demanded. While quantities are small and while product success is yet unproven it is more difficult to justify investment in optimisation. In many situations, the engineering optimisation often has to wait until the product is in the market and is starting to reach sizable production quantities. It is here that optimisation has the biggest positive impact. A potentially positive aspect of delaying the optimisation is that it enables prior learning from the product being in the market. We thereby gain a better idea of how to prioritise the optimisation against other design aspects that we found might need changing. The difficulty with delaying is that many of the design decisions made earlier on, when the main focus was on time to market, risk not having left sufficient scope for successful optimisation. There will therefore be certain features and parameters that simply cannot wait for a delayed optimisation. For example, anything that impacts significantly on the customer experience must be right at the outset, or else the product sales ramp-up has a diminished chance of success. Costly production tooling investment, which we cannot afford to waste, is another aspect that we would want to get optimally right at the very outset. The development project plan must therefore clearly prioritise what can and what cannot be delayed for post-launch optimisation. The prioritising should consider the risks from sub-optimisation adversely impacting on the sales ramp-up and risks of waste from having to substantially undo earlier costly design decisions. Early design decisions should consider their future compatibility with foreseeable later revisions.

Any new product must at least offer some new benefits in terms of performance, quality or cost. Otherwise it would be a pointless development. Often customers can tolerate a degree of sub-optimisation, because of these new overall benefits that the new product brings them. This is not because customers like to experience product weaknesses, but because they recognise that the developer has to get the new product out to them as well. Customers want the excitement of getting their hands on the new product. Software development is an area that springs to mind, where the early adopters are not surprised by product bugs. In fact, to a (very select) expecting minority the struggle with software bugs somehow adds to the early adopter's pioneering badge-of-honour – although this is a needlessly bad design policy to try recreate deliberately.

SUSTAINABILITY

Global populations and urbanisation are forecast exponential growths for several more decades to come. Demands for materials, water, energy and land are growing at similarly elevated rates. Natural resources are becoming subject to ever greater competition, with increasing levels of supply disruptions and price volatility to be expected. The increasing population densities also increase the importance of cleaner technologies, over the complete product life-cycle.

Practically every Government the world over have now established policy regimes for assuring productivity and waste reduction of key resources. The associated Regulations are progressively being tightened and strengthened, in ways that continually threatens to force the pre-mature obsolescence of yesterday's designs. It therefore becomes increasingly important to consider both the immediate and longer term sustainability aspects in the design decisions that we make. Successful designers include those who can make their products and processes resilient to these effects, such as by being more productive and flexible in natural resources usage.

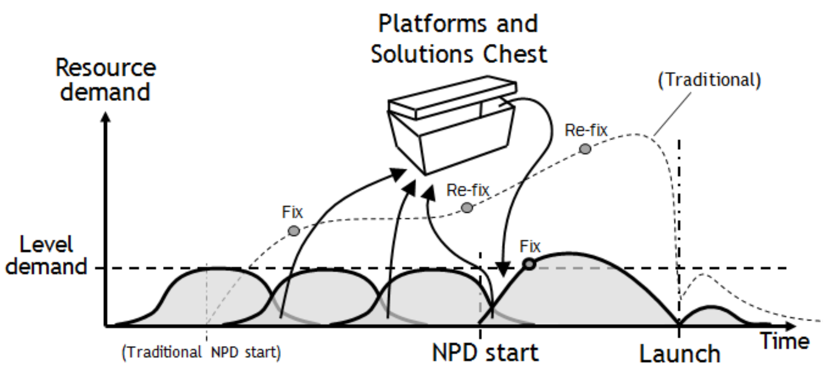
The intensifying competition for increasingly scarce and harder to reach natural resources is giving rise to the concept of a 'circular economy'. This is a currently evolving term, emphasising ideals such as:

- Keep end-of-life products in a productive loop by reclaiming reusable components, refurbishment/remanufacturing (returning to its original specification), recycling of raw materials or energy recovery (e.g. use waste materials that have net energy production for incineration).
- Design of products with more value, for smaller amounts of energy and materials usage.
- Substitution of 'precarious' materials, to mitigate the potential supply and regulatory volatility.
- Design for longevity with in-built change resilience and upgradability.
- Design for servicing and reconditioning.
- Personalisation of products, for purpose of avoiding wasted materials usage in otherwise redundant features (and also because it can make good sense for customer satisfaction).
- Products for shared ownership, to maximise their productive usage.
- Cleaner, quieter factories that that can be built in more densely populated areas. Process waste energy being used for heating residential and public buildings. Closer proximities will demand more collaborative interactions between suppliers, producers, workers and consumers.
- In some areas, competitors collaborate on shared resources and process facilities – for example, on a shared backup system that no-one could afford to maintain individually, to mitigate sector supply disruptions.

Sustainability creates a multitude of challenges, but also has sizeable opportunities for those who are able to stay ahead in the game.

PLATFORM DESIGN AND REUSE

Market requirements and the solution space tend to change in unforeseeable ways. We sometimes have to change our design targets with them, mid-flow during the product development project. The shorter a time that we can achieve between the design specification 'fix' and the product launch the greater is our chance for optimally matching the current customer requirements.

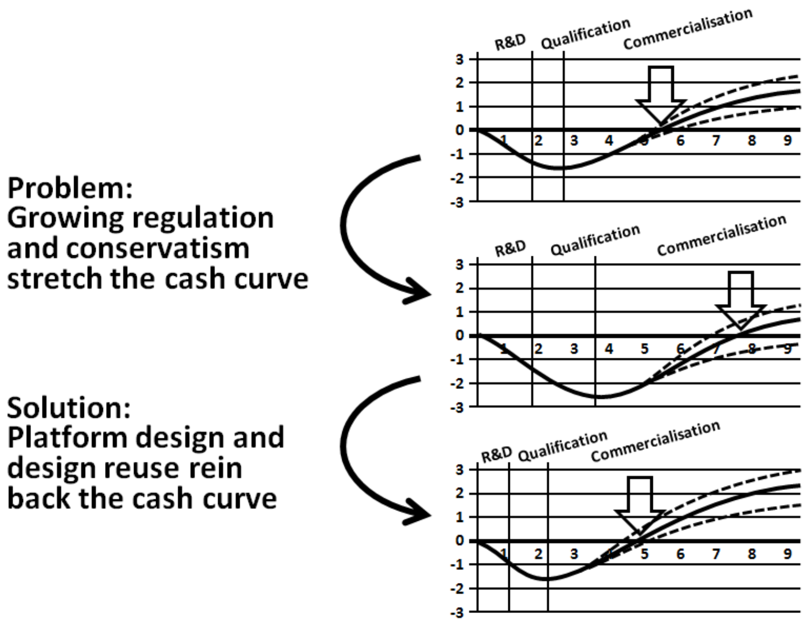


Resource demand from the product development approach

In a traditional development cycle, as illustrated by the dashed resource demand curve in our graph here, the up-front early planning work will 'fix' the design specification relatively early on in the development project. As result of the changing needs dynamics we have to occasionally calibrate and 're-fix' our design specification, which makes part of our earlier development work wasted. The result is a growth in the remaining resource demand for getting the product to market in time, which in turn can drive us to take rush shortcuts in the final product qualification phases. This increases the probability of the product being released containing flaws; which in turn have to be resolved significantly more costly in a post-launch situation. The design team, in effect, performs a final post-launch ‘re-fix’ of its dynamic VOC.

Platform design is an alternative model, where we can seek to level out the resource demand by continually developing sub-modules for integrating into designs. The platform modules are added to an inventory ‘chest’ of pre-qualified solutions. When a marketing demand for a new product arises, the development becomes concerned with simply integrating an appropriate selection of the pre-existing platform solutions. In one example from industry, we maintained an inventory of 4 enclosure designs, 3 electronic platforms that were software driven and configurable, 5 actuator component options, and 2 brand names. The platforms mix and configurability enabled us to market in excess of 50 product variants, targeting different market segments and pricing sensitivities. Integrating and configuring a new product combination would take no more than 1 week in engineering time. In the background to configuring new products the development team is continually renewing, improving and re-qualifying the various platform modules, to ensure the products range appears forever fresh new and is technically up-to-date. Furthermore, platform design assures more sharing of component parts across the products range, which supports economy of scale and reduces complexity in the supply-chain.

The generally growing products regulation and the conservatism (risk adversity) in certain sectors result in increasing product qualification time and cost. This in turn stretches a product’s cash curve, which diminishes the attractiveness of its business case – due to the later payback time becoming more unpredictable and less assured. The re-use of pre-qualified modules in platform design helps reduce both development and qualification time, reining back on the cash curve payback time.

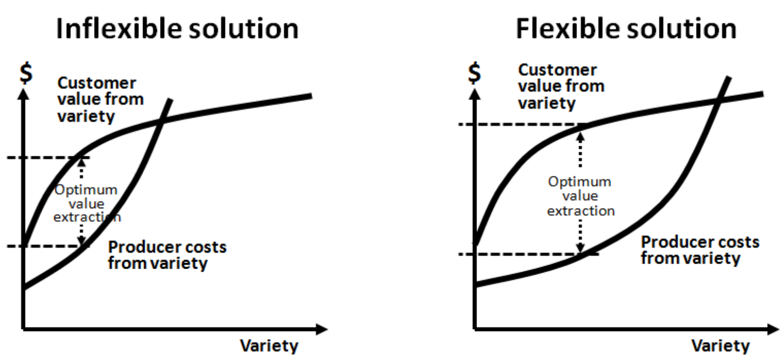


Cash curve effect from platform design

Platform design also has potential drawbacks. Firstly, it deliberately focuses on a sub-set of solution space. While this is not a problem initially, the cross-compatibility between platforms and multiple product variants can make it more complicated to adapt the whole to significant future changes within solutions space. Secondly, the platform has to carry all of the features for all of the possible products configurations, which means that the lower-price-end variants will carry a cost of redundant features. It is therefore important either to have multiple staged platforms, each carrying a varying degree of cost-features, or to make the platform module cost-feature scalable through some other means.

FLEXIBLE DESIGN

Products variety enables access to a wider customer-base in more markets. Also, specially adapted or customised product variants have higher customer perceived value. A producer offering more variety can thereby extract more value from the markets. However, variety also carries an added production cost, including from increased stock and scheduling complexity. There is an optimum degree of variety where the producer can extract the most net value. By making the designed product and the production process robust in flexibly handling a larger degree of variety, the producer can improve the value extracted from markets.

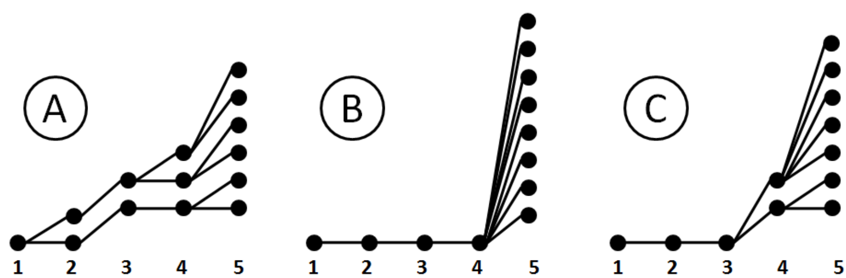


Increased value extraction by flexible design

FORM POSTPONEMENT

The concept is defined as the delay of the final product variation process until customer orders are received. We achieve this by producing standard generic products for as long into the production and stocking process as is possible. The benefits from form-postponement are:

- Increased capacity for supplying variety.
- Reduced production complexity.
- Reduced stock complexity, with less risk of shortages.
- Reduced safety stock levels.
- Reduced inventory holding cost.
- Less stock obsolescence risk.
- More flexible supply-chain forecasting.
- Easier production planning.



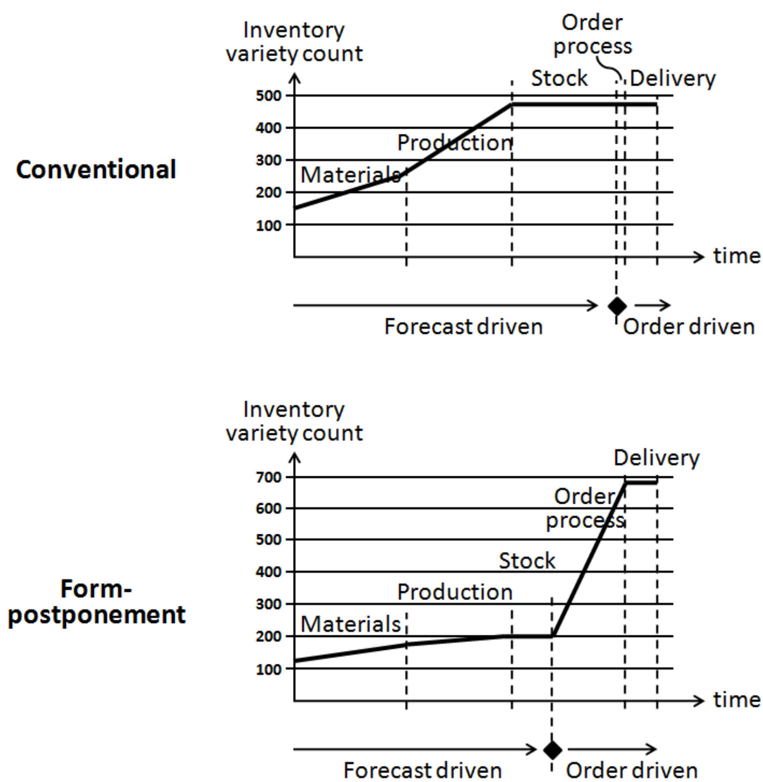
Example products variety differentiation during production stages

In our graphs here, scenario 'A' represents a conventional production system, where the product variant differentiation starts early and gradually proliferates, until we eventually hold 6 different finished product variants in stock by stage 5. Scenario 'B' is form-postponement, where we produce a generic form until stage 4, after which we stock only this single variant. Stage 5 is delayed until a customer order is received, by which time we perform the configuration into 1 of 8 final forms just before shipping it to the customer. Scenario ‘C’ is a hybrid solution, where we produce and stock the most common variants in their finished form – represented here by the 2 lower parts in stage 5. This enables faster order processing for these common variants. All other ‘minor quantity’ variants are configured to order from a generic stock held at stage 4.

Imagine, for example, that we are a producer of socks, as in the clothing item, and that our customer-base would ideally like us to supply products in 30 different colours. However, the cost-pressures on the clothing industry makes it practically unviable for us to stock the materials and finished goods for any more than the 10 most popular colour variants. The 20 lesser popular models would be too slow moving and more unpredictable to forecast for. They would simply be too expensive to produce.

If on the other hand we produce and stock only white socks, together with 30 dye colour agents, then we can colour the socks to requirements as and when customer orders are received. The reduced cost of materials, production and stock would make it viable for us to perform all of the additional colouring variants. The only drawback is that the order process now takes longer to complete. The design art here is to optimise the configuration process for speed. Alternatively, in the hybrid model, it may still be possibly to finish and pre-stock a smaller amount of the most popular colour models, to improve the chance of satisfying any exceptionally urgent customer requests.

In another example, the ideal scenario would be to perform the variant configuration of a machine product post-shipping, in the customer’s domain. This will make it possible to stock the machines and ship them to different parts of the world in their generic form, together with an appropriately prepared language configuration pack. The people performing the machine installation and commissioning at the final customer’s location can as part of their process attach the language specific labels, power cable etc. The few customers, for whom this solution may not work out, can alternatively have the configuration performed by the machine manufacturer's logistics department, at the expense of the delivery taking an extra 1 or 2 days. The end result is that the machine manufacturing site more efficiently turns out nothing but identical generic types.



Inventory variety count and order lead time effects.
Inventory includes component parts build into and
held in various sub-assemblies and in finished products

INCLUSIVE DESIGN

The concept is about making the product accessible to and usable by as many people as possible, without the need for any special adaptation. The VOC phase should therefore seek to understand and quantify the full range of abilities and skills that exists within a product's total user population.

For example, human sensory and dexterity functions will begin to noticeably degrade when we reach 50 years of age. For the average mainstream product, people over the age of 50 years and those with disabilities will account for about 30% of the potential user population. This significant user segment should not be excluded from or left frustrated by an inability to adequately use the product – such as by visual information being too small to read or because operating controls provide insufficient tactile feedback. 'Non-inclusive' design can be a sizeable lost commercial opportunity. In certain markets, for certain types of products, exclusion on grounds of age or disability is not just commercially negligent, it is also illegal.

The same notion holds true for the product realisation processes. Aging populations mean that people increasingly have to work for longer, into their more senior years. The realisation process has to accommodate senior workers, who are likely to have reduced sensory ability and mobility strength.

When we review new design features, we should ask and resolve questions such as: *"Can it be used by an 80-year old"*? *"Can it be operated when seated in a wheelchair"*? And, when designing the production process: *"Can it be easily put together by a 65-year old"*? It is good practice to conduct prototype usability trails with a wide range of representative customers and operators.

Design for Manufacturing (DFM)

DFM is about integrating product and process design. It is essentially about ensuring that the designed product is easily and economically producible to a consistent standard. Many, if not most, of a product life-cycle's potential problems and costs are resolvable by the decisions made in the early design stages. The thinking behind DFM, about eliminating the potential production problems while the product is still in the design phase, integrates well with QFD. The method is to involve a process expert, such as the process owner and/or the operators, in a product design review. Walk through the planned production system with them, while applying a number of guiding principles. The art lays in best facilitating the guiding principles in the product and process design:

a) Minimise the number of parts.
b) Use standard components.
c) Design new parts for multi-use – e.g. share between products
d) Design new parts to be multi-functional.
e) Develop modular design with standardised interfaces.
f) Use standard sub-assemblies.
g) Use standard process methods.
h) Use standard equipment and tools.
i) Reduce skills and craft requirements.
j) Automate where possible.
k) Standardise and reduce the number of fasteners.
l) Minimise handling – e.g. no need to rotate or turn over parts.
m) Make ergonomic (= less operator concentration fatigue).
n) Minimise assembly directions.
o) Use vertical assembly, for gravity to move and hold in place.
p) Minimise movement.
q) Use straight linear joining movements.
r) Minimise alignment movements in joining parts – e.g. design-in mechanical positioning guides.
s) Eliminate or simplify adjustments.

t) Maximise compliance with mechanical tolerances.
u) Achieve widest possible allowance for tolerances (to assure robustness).
v) Make assembly self-jigging.
w) Make assembly easily accessible.

DESIGN FOR RELIABILITY AND SAFETY-INTEGRITY

Reliability and safety integrity relates to the probability of a failure or harmful hazard being realised. Safety analysis considers critical failures, whereas reliability analysis also includes the non-critical. Reliability, R(t), can be measured in terms of an item's capacity for meeting the required performance over a defined period of time. Related measures are mean-time between failures (MTBF) or mean down time (MDT).

Design principles for reliability and safety integrity:

a) Use components with known well established failure profiles – e.g. through component pre-qualification evaluation.
b) Exceed stress with adequate safety margins.
c) Minimise complexity and unpredictability. Consider using known well-established modules/platforms.
d) Add active or conditional system redundancy or duplication, including a self-initiating error-checking and correction function.
e) System distribution and diversity. Avoid multiple sub-systems relying on a single common critical component that can result in a common-mode failure.
f) Robust engineering design (RED). Determine design parameters through experimentation, to establish best possible immunity to uncontrollable random effects (e.g. component tolerances) and random inputs (e.g. environmental/human noise factors).

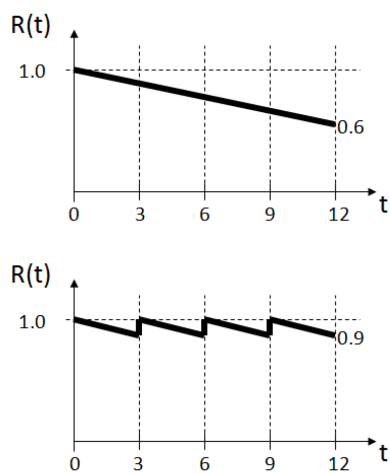
g) Calculate and justify system reliability. Make R(t) subject to design qualification testing. Failure probability and Weibull plots from accelerated life-cycle tests can help quantify and qualify the probable failure modes.

h) Assess safety risks (e.g. by FMEA) and assure they are reduced to within tolerable levels.

i) Define preventative maintenance requirements and maintainability. Good design should minimise maintenance time, ease condition monitoring and diagnostic.

Without any preventative maintenance, R(t) is 0.6 after 12 months

With quarterly preventive maintenance, R(t) is 0.9



Other reliability and safety-integrity activities:

In production:

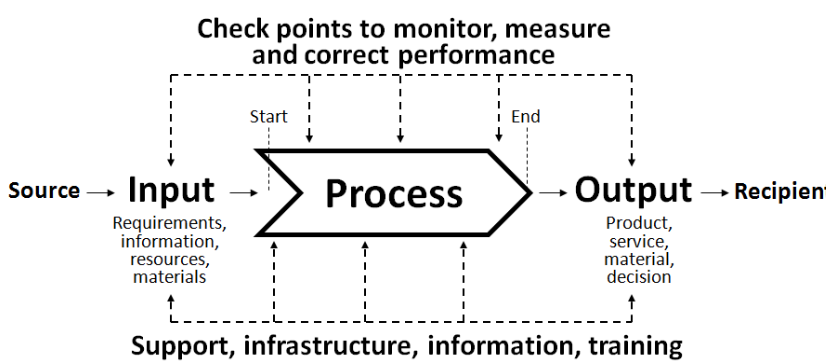
- Control of materials, methods and changes.
- Control of processes and standards.

In field use:

- Adequate user instructions and training.
- Field feedback for design review learning.
- Maintenance and spares strategy.

PROCESS DEVELOPMENT CONCEPTS

A process is a set of interrelated or interacting activities that transform inputs into outputs, using resources and is managed against a set of planned objectives and criteria. For example, the input could be a customer request for a particular product that is required in a specified time. The output should be the matching finished product on time. The process is supported with infrastructure, information and training.



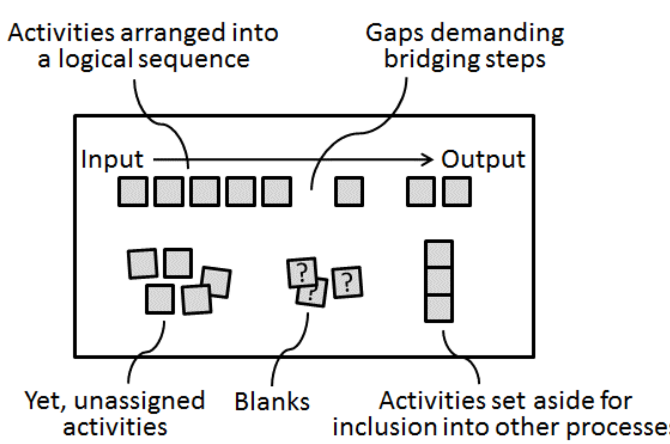
Process model (adapted from ISO 9001:2015)

By nature of changing needs and expectations, and an organisation's reliance on satisfying its customers, most processes are under-going continual incremental improvement. There will be times, however, where demands or conditions of business have changed so significantly that more fundamental process re-development is required – beyond the incremental.

PROCESS DESIGN

The following guide is a simple approach to process design or re-design. The approach may be expanded or refined with other tools and techniques – although this could reduce its desired simplicity.

Start by defining the needs of customers and interested parties. Determine what activities are required to deliver and satisfy these needs. Record all the activities to be performed on to cards or labels. These represent the tasks that the process has to perform. In a group discussion, arrange the activities into a logical sequence that makes sense, from the input to the final output of the process. Apply best possible a set of guiding principles for process effectiveness and efficiency. Have some blank cards ready, because a new activity may be needed to bridge two steps or if we need to duplicate some (e.g. if data is recorded in several stages, and we initially only made one card for this). Consider also that some activities may have to transfer to specialist supporting or parallel processes (e.g. remote IT backup) where they – possibly – have a better or more economical fit. Document the final process, including its inputs, resources, criteria and outputs.



Functional activity cards being logically arranged

Guiding principles for process effectiveness and efficiency:

a) Avoid dividing a process into multiple specialised tasks. Instead, create 'case workers' or cross-functional self-steering 'case teams' for completing the full job. This reduces complexity of interfaces and eliminates the need for hand-offs, thereby increasing speed and responsiveness.

b) Directly connect the source and the user of something. This assures that the transfer between them is always complete and correct, to the user's requirement. This is sometimes referred to as 'end-to-end principle', which says that intermediaries (including managers/supervisors) introduce an uncontrollable degree of variability in a transfer. Where an intermediary is unavoidable (e.g. a goods courier or an information communication network), the two ends must have checks and balances in place to assure completeness and correctness in what is received at the user end.

c) Have those who use the output of a process also perform the process. This extends somewhat on points a) and b). For example, teams could make their own purchases, manage parts inventory, and carry out equipment maintenance. This eliminates the need for co-ordination and controlling functions (supervision), and reduces organisational barriers where one team has to wait for others, who are not always readily available to come in to support.

d) Maximise capacity and skills for parallel processing, for increased speed and work flow flexibility. Flexible work units enables flow 'takt time' balancing for improved efficiency. For example, if step 1 takes 2 minutes to perform, and step 2 takes 1.5 minute to perform, then the capacity (operator or machine) at step 2 stands idle for 25% of the time. Ideally, we would want to move some of the work at step 1 to step 2, to balance the times to become equal. Coordinate the parallel activities, instead of blindly integrating their results. Late integration is a common cause of results mismatch and rework. The early linking facilitates a continual coordination.

e) Concentrate on the value-added. Reduce bureaucracy. Reduce non-value-adding support processes. For example, let operators perform their own preventive and corrective – instead of calling in a costly and difficult to schedule resource.

f) Capture information once – at source, to avoid re-entry work and its associated increase in error probability. Use robust data entry methods, such as barcodes or data tags. Merge information processing work into the real workflow that produces the information. People who collect information should also be responsible for processing it. They are more likely to recognise an error or abnormality.

g) Put decision points where the work is being performed. Recognise that the workforce can be trained and made knowledgeable. Open up for information transparency. It is in fact easy to provide teams with access to all of the relevant information. This results in a more responsive organisation.

h) Maintain quality self-checks, as opposed to separate inspection functions. Build controls and mistake-proofing devices into the process, to prevent faults from being accepted into or travelling out from a process step. This raises personal responsibility and accountability.

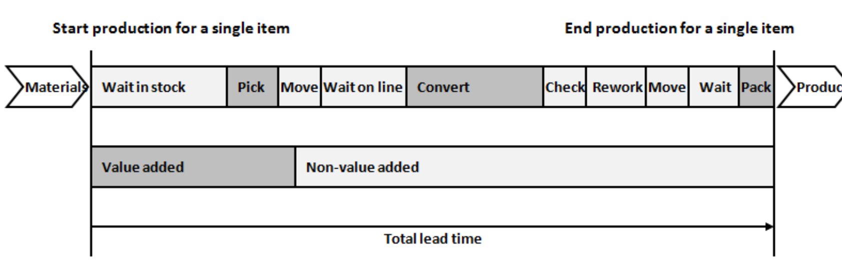
i) Standardise processes and process equipment across the organisation, for reduced skills specialisation and greater flexibility.

LEAN PRINCIPLES

The concept is a systematic approach to identifying and eliminating non-value added activities waste, through the continuous perfecting of the work flow to the pull demand of the customer.

- Value added activities are those that are worth paying for having done.
- Non-value added activities are those that nobody can see any worth in paying for.
- Non-value added required are those that do not add value but must be done – say, for legal safety reasons.

The most basic way to look at lean principles is that whenever an item is being worked on it creates value; while when an item stands still (waits), is being carried or transported, is checked or reworked then value is being destroyed. This does not mean that value creation and destruction occurs at the same rate – but just that it occurs. Typically only about 5% to 30% of activities time in a production system can be defined as value adding. The remaining majority of activities are non-value adding and can be counted as waste.



Process-chain summing up the
value and non-value added activities

Lean principles distinguish 8 wastes and their typical causes, which should be targeted for reduction.

Waste	Causes
1. Inventory Any supply in excess of what is needed for the single next customer order	• Poor forecasting and scheduling. Not operating to pull demand/kanban. Traditional MRP is not lean. It is utilization and not cycle time focused, resulting in large static batches and scheduling at each supply chain stage. • Lack of stock visibility • Large batches or in-process inventory • Safety stock buffers against inefficiencies and problems • Unreliable supplier shipments
2. Transportation Moving materials, products and documents within the facility, from suppliers and to customers	• Poor layout • Poor process flow • Larger than necessary facility • Distant suppliers • Distant warehouse • Distant customers
3. Motion Any movement by people or machines at a work station, which does not add value to the product or service	• Poor workspace organisation • Poor housekeeping • Inconsistent work methods • Lack of individual tools and equipment, where operators waste time in searching for the shared tools/equipment
4. Waiting Idle time waiting for parts or waiting to commence the next task	• Unbalanced workload and takt time • Unplanned maintenance • Quality problems • Unreliable suppliers • Poor scheduling • Lack of visibility about what is next • IT problems

Waste	Causes
5. Defects Bad parts, mistakes and rework	• Weak process definition • Tolerance of poor quality • Bad suppliers • Inadequate maintenance • Inadequate training • Poor morale • Lack of or diluted responsibility - e.g. in a multi-phased system • Poor equipment • Poor housekeeping
6. Over-processing Effort that adds no value to the product or service, from the customer and organisation's point of view	• Poor communication • Unclear customer requirements • Bad directions • Redundant inspections • Redundant approvals • Excess unnecessary information and copies
7. Over-production Making more than required, earlier than required, or faster than required – and then risk it passing its sell-by-date	• Lacking confidence. Unnecessarily planning for 'just-in-case' • Long process setup • Poor scheduling • Unbalanced workloads • Redundant inspections • Lack of visibility and responsiveness
8. Under-utilized people Not making the most of people's mental, creative and physical abilities	• Poor recruitment practices. Over-capacity of the wrong skills • High staff turnover. Always inexperienced people in the system • Command and control management (only do what and when you are told!) • Sub-ordination to systems • Blame culture where good intentions risk-taking is punished

CAPACITY MANAGEMENT

The concept is the process of recognising the level of work demanded, for then determining the necessary people, equipment and other resources needed to accomplish it. There are two main strategies for meeting demand and usually capacity planning is about finding an optimum combination of the two:

1. Level-capacity is about setting the production rate at an aggregated average output level, to smoothen out the demand over time. This brings peaks and troughs to the delivery time, which can sometimes results in an order backlog and missed promises.

2. Chase-demand production varies the capacity in response to order fluctuations – through flexible work shifts, overtime, hire/fire, sub-contracting, and maybe adjusting demand through pricing.

A necessary trade-off has to be struck between the wastes associated with too much or too little capacity. Pareto's 20/80 rule tells that 80% of costs from waste tend to be hidden. For example, failing to deliver to the customer on time can have indefinable longer term costs from loss of trust. This hidden element means that it is not always obviously easy to determine the optimum trade-off point.

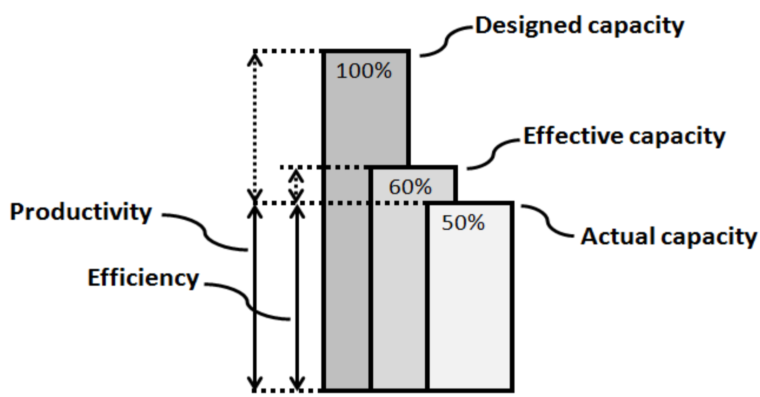
Capacity optimisation is an important aspect of effective planning. In order to achieve optimisation, we have to recognise and consider the 3 levels of capacity:

1. Designed system capacity is the rate of output that the technical system could theoretically produce under continuous ideal conditions.

2. Effective capacity is the realistic output, given the foreseeable product mix, scheduling complexity, flow control,

bottlenecks, operator skills, stability, work tools, facility availability and necessary down time for planned equipment/vehicle maintenance.

3. Actual capacity is lower than the effective capacity due to unforeseeable, unplanned problems such as equipment breakdown, quality defects, supplier shortage of materials, operator sickness and industrial relations.



The 3 levels of capacity

Productivity and efficiency are both measures of the actual output, but using different references. In the chart above, efficiency is 83% and productivity is 50%. Effective capacity acts as the principle limiting factor to productivity. Efficiency improvement, while not un-important, has less actual effect on the overall productivity gap.

Commonly expected EFFICIENCIES for operations involving:	
Continuous processing of jobs that have repeatable balanced 'takt' times – e.g. a factory assembly line.	75-85% efficient
Dynamic job scheduling situations – e.g. responsive field services with some peaks and troughs in demand.	50-75% efficient
Under-utilised and/or evolving new activities that have not yet reached full demand – e.g. time of day in a shop.	<50% efficient

The optimum production system is not necessarily the one with the highest designed capacity. It is conceivable that a system with high designed capacity translates into a lower actual capacity, by the way it influences the various detractors for productivity and efficiency. **Capacity improvement should focus on the design of products, processes and technology for achieving the highest effective capacity**.

The determining factors of effective capacity:

a) Job size or batch quantities. Frequent start-stop, change-over and set-up time detracts significantly.

b) Product design can have significant influence on capacity. High similarity, standardisation of methods and materials can lead to greater capacity. A greater the mix of components manufactured at different rates of output will reduce capacity. DFM provides the guiding principles.

c) Process design and quantities capability, such as machine cycle time, is an obvious determinant. Lack of mistake-proofing can detract. Unbalanced 'takt' times will detract – e.g. activity 1 takes longer than activity 2 and the resource at activity 2 sits idle waiting for much of the time.

d) Facilities, including layout, heating, lighting and ventilation of the work areas, will affect concentration and how work is performed.

e) Operational factors including scheduling problems, inventory stocking decisions, waiting-lines supervision, supplier delivery reliability and materials acceptance criteria.

f) Location factors such as distance to suppliers and market, labour supply and sufficient space for facility expansion.

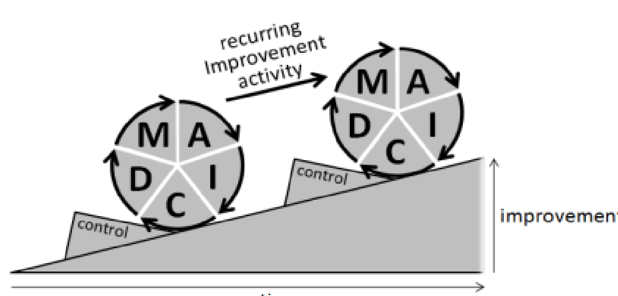
g) Human factors, including performance, knowledge, skills and experience. In manual systems the inherent operator motivation also has an important relationship to capacity.

h) External factors such as product standards, environmental or safety regulations can restrict options in increasing capacity; due to associated pollution limits, liability risks and burden of evidence recording.

SIX SIGMA

In context of a management system, Six Sigma can be thought of as a more statistically analytical, data-centric variant of the PDCA cycle. Due to its statistical technical nature, Six Sigma is often being 'done to' the system by an expert practitioner. This can make it difficult for people to feel involved.

In Six Sigma programs, the PDCA equivalent cycle is called DMAIC (see illustration below), where the 'C' stands for control. The control element is intent on implementing a device for assuring that the system does not slip back into its former sub-optimal ways. This infers an assumption that people cannot be trusted to maintain the implementation, possibly because they do not understand how the expert practitioner's solution was derived at.



The 'Define, Measure, Analyse, Improve, Control' cycle

By comparison, the PDCA cycle relies on the deeper involvement of people, maintaining their ownership of the problem and the solution. This difference does not devalue Six Sigma. The analytical evidence-based technique can yield superior improvement solutions in certain complex scenario. Although it is not universally suited for every situation, Six Sigma is proven by successes in many diverse industries.

MISTAKE PROOFING

The concept involves devices, such as a physical obstruction or automatic failsafe, placed within the process to prevent incorrect working and to assure against any faulty items leaving the process. An example of a mistake-proofing device is the audible alarm that sounds if you start your car engine without having fastened your seatbelt. Similar automated devices can be designed into any work process.

Humans tend to make mistakes when the system they work in is poorly designed. The causes can relate to a lack of technical knowledge, poor information robustness, monotony leading to loss of concentration or some de-motivational stimuli resulting in reduced care of action. Processing errors to guard against are:

- Human mistakes.
- Machine maladjustment or malfunction.
- Materials or component defects.

The best mistake-proofing devices do not complicate or slow down the process, which would otherwise introduce a new potential for mistakes – because people might try to bypass them or because they could add more cost than the benefit they bring. Always review a mistake-proofing device after it has been installed, to check that it achieves its intended purpose and remains appropriate.

PROCESS VALIDATION

The concept is a systematic investigation for purpose of establishing evidence that the process is capable of consistently delivering a quality result. The producer collects and evaluates data in order to judge whether there is sufficient understanding to have a high degree of confidence in the process. This includes:

- Knowing the presence and degree of process variability.
- Understanding the sources of variability.
- Understanding the impact of variability on the process and how this cascade into impacting on product quality.
- Control the variability according to the risks they present to the process and product.

The process validation is performed over a series of staged activities:

1. <u>Process design</u> during which knowledge of the risk factors and a strategy for their control is established (e.g. by FMEA). Process quality attributes are inherited from product design.

2. <u>Process qualification</u> is the validation of facility and equipment installations (IQ); operational stability, capability and sensitivity (OQ); and process performance (PQ). This stage will quantify the risks and qualify their controls.

3. <u>Process verification</u> is the on-going assurance that the process remains in a state of control.

Formally recorded process validation is specifically required in regulated industries, such as medical devices and pharmaceuticals.

Various methods or techniques may be used for collecting and evaluating data at the various stages of the process validation. It is important to the producer that the methods are both reliable in their results and economical in application. The following table illustrates a suggested list, but it is by no means exhaustive.

Qualification stage	Suggested methods	Description
Installation (IQ)	Parameters observation	Record process output and observations. Compare to intended specification. Analyse and conclude whether the process and facility is appropriately installed.
	Fault tree analysis	Analyse causes of deviation.
Stability (OQ)	Parameters observation	Record process output and observations. Analyse and conclude whether the process is stable – i.e. repeatable output with acceptable spread in quality measures.
	Fault tree analysis	Analyse causes of instability.
	Pareto analysis	Quantify significance and importance amongst multiple factors.
	Weibull failure time plot	Identify number and types of failure modes, and whether their pattern of occurrence indicates the process 'burn-in' has been completed.
	Robust engineering analysis	DOE, ANOVA, response surface charts, multi-vari charts, or gauge study helps identify stability problem factors and their relative contributions.
Capability (OQ)	Capability Index (Cp, Cpk)	Process capability measure.
	Distribution histogram	Process performance visualisation.
	Control chart	Process performance visualisation, in time-domain.
	Taguchi Loss Function	'Cost of quality' evaluation.

Sensitivity (OQ)	Challenge test	Stimulate variability (induce noise) in process parameters, and observe for disruptions effect.
	Fault tree analysis	Identify sources of variability faults.
	Robust engineering analysis	DOE, ANOVA, response surface charts, multi-vari charts, or gauge study helps quantify how variability in inputs/materials translates into variability in outputs. Helps define process tolerances.
Risk and controls	Failure Modes and Effect Analysis (FMEA)	Quantifies risk, traces to root cause, and evaluates effectiveness of control.
	Mistake proofing	Failure prevention. Risk control.
Performance (PQ)	Control charts	Process performance visualisation, in time-domain.
	Distribution histogram	Process performance visualisation.
	Capability Index (Cp, Cpk)	Process capability measure.
	Sampling plans	Defines the level of continual forward verification.

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ABOUT THE AUTHOR

Frede Jensen has 20 years of senior management experiences, including with responsibilities for products strategy, innovation, design, quality and regulatory affairs in medical device manufacturing. He also held global roles in the ‘Design for Manufacturing’ and ‘Factory of the Future’ groups within a division of a major multi-national company. He became a Six Sigma Black Belt in 2005. In the last 8 years, he has worked with a mix of commercial and academic organisations, as an independent consultant in product design and quality management. He was first introduced to QFD while studying Quality Engineering Management in 1998. The basis for the QFD approach presented in this book was originally conceived in a study project on service process design. The project titled *“Process innovation under ISO 9000”* won him the EFQM Award for European Best Master Thesis in 2000/01. In the 15 years since the original work he has evolved the variant approach into a more generic design management tool for quality and innovation.

APPENDIX

Case Studies

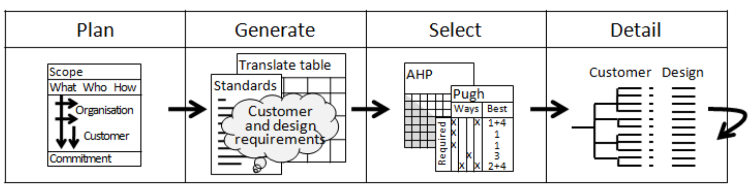
Case study 1: Approach walk-through

This section is a practical walk-through of our standard QFD approach. Although we have titled this a case study it is in fact not a real life case; but instead a hypothetical product example. The product's low scientific complexity and recognisable features makes the design suitable for the teaching purpose.

Product background

The market for large cases, including travel luggage and for heavy but sensitive instrumentation equipment, demands both wheeled and non-wheeled carry solutions. Our product here is a universal shoulder strap device for helping the user hand-carry the non-wheeled product category.

Phase 1: Voice of Customer



The project starts with establishing the customer demands, or the VOC, which will become the foundation for everything that follows. It is therefore highlighted as one of the single most important activities to get right.

PLAN – VOICE OF CUSTOMER

When pre-planning the VOC phase we essentially seek clarity and communicate awareness about:

a) Purpose of the QFD project.
b) Who the customers are, and what we aim to do for them.
c) Who else influences the design or project context, and what their involvement in the project will be – e.g. the QFD team.
d) Project time line.
e) Allocated resources and aids.
f) Responsibility and authority.

Project	Luggage carry device			
Purpose	New device design and development to meet retail customer and end-user expectations			
Scope	Project	Others	Interaction or impact (how)	Involvement
Strategy and policy		Company business plan	Requires $200,000 sales, with 55% gross margin from project	Account for
		Products roadmap	Assure compatibility with other new planned products	Consider
		Marketing	Defines value proposition/price point.	QFD team
Technology		Design and develpment	Product developers	QFD team
Sourcing		Suppliers	Suppliers of any new component parts	Consult
		Procurement	Purchasing, stock and invetory management	Consult
Process		Production	Manufacturers and quality assures the finished design	QFD team
		Packing	Develops packing process. Guide on packing materials	Consult
Customer		Travellers	Qualify and quantify needs and expectations	Investigate
		Equipment users	Qualify and quantify needs and expectations	Investigate
		Retail resellers	Qualify and quantify needs and expectations	Consult
Project time period		Start 1st May 2013, production implement 21st June 2013		
Resources and aids		Design engineer 21 days Marketing manager 3 days Production manager 4 days Quality engineer 3 days Tools and jigs £10,000 Other project expenses £3,000		
Project Manager		John Smith		

The people involved in the QFD team are not necessarily specialist project workers and will come with a background of varied planning experience. It could therefore be off-putting if the very first step in the project appears complicated. The project scoping approach here has to be simple and easy comprehensible, to enable everyone committing to it. Yet, it must adequately address the essential items for consideration. The project scoping form is a simple tool for obtaining agreement and commitment from the QFD team members on the project. It also helps people who are not directly participating, but may be relied on for support during the project, to understand what is going on and become prepared for the possible outcomes. The size of the drawn circles in the form reflects the strength of interaction or impact on the project. Clearly, the customer must be given the most attention (the biggest drawn circle). However, it is also important to involve or consult the key figures in any cross-cutting activity, in order to pre-empt and resolve any potentially conflicting situations. By 'cross-cutting' we mean a function that the project depends on for success, but which simultaneously follows its own separate goal. The degree of involvement should depend on the level of interaction or potential difficulties that can arise between the QFD project activity and the cross-cutting activity. Where it is not possible to fully align the two activities, the QFD team will need to negotiate a best trade-off position that satisfies the overall project and the organisation's wider product.

In larger organisations, in particular, there is likely to be a number of cross-cutting activities, which can all influence the QFD project. Each such activity is pursuing its own objectives, within a wider context, and will inevitably sometimes put limitation on or conflict with the goals of the QFD team. For example, the QFD team designer may consider using a new better component part that is not available from an existing strategic supplier, with whom the organisation's procurement department has established good relationships and a favourable wider discount deal. Selecting the new part could thereby destroy the deal that the organisation benefits from more widely in the many other products it produces. Unless the procurement team can help negotiate us around the problem, the designer may have to accept the constraint of accepting a lesser optimum part decision. In such a situation the cross-cutting needs of the procurement contract may have to be given priority. The co-operation between the QFD project team and the cross-cutting functions is therefore important to success. The procurement manager’s day job, for example, does not stand still just because somewhere else in the organisation a QFD team is engaged in developing a new luggage carry device. The worst that can happen to the project is that the procurement manager cannot prioritise time to support the QFD team when needed, or even worse, deliberately put obstacles in its way to prevent any interference with the unrelated goal of saving the company money in its procurement.

GENERATE – VOICE OF CUSTOMER

Generating the VOC is about surveying and analysing the demand space. It is important that the VOC is obtained from a representative group of customers or, if not, that survey data is adjusted to correctly reflect the total population within the target market. The aim is not purely to identify needs in the existing market, but it could also be to consider potentially new markets or to understand any limits for the acceptance of unique and novel concepts. Various techniques for obtaining the VOC involve different times or costs. Each has their own strengths and weaknesses. It is not normally advisable to rely on any single method for obtaining the VOC. The following is an outline list of some of the most commonly used:

- Opinion surveys
- Complaints monitoring

- Customer suggestions scheme
- User trails
- Focus group
- User panel
- Consult representative organisations
- Analyse competitors' features and sales performances

The following summarises a set of unstructured needs identified from researching our luggage carry device market.

Summary of study published as an article in the "Holidaying" magazine of a major newspaper, into how travellers are let down by their luggage:

- *Every year, nearly 10,000 air passengers miss their flights due to being slowed down by problems and pains relating to their luggage.*
- *Holiday suitcases are simply too heavy to carry by hand.*
- *Holiday air travel is on the increase and airports are getting bigger, with further walking distances.*

A test of various existing aids in the market found that:

- *Un-adjustable shoulder strap reduces effectiveness and can do user harm.*
- *One model snapped and slung back, potentially injuring the user's face.*
- *Strap is more space-efficient and versatile, than wheels and pull-out handles.*

Most regular customer complaints, reported back through retailers:

- *Snapped, broke or otherwise failed, including poor workmanship (48%)*
- *Too expensive to buy (37%)*
- *Cannot adjust to suit user height (12%)*
- *Scuff or damage to user clothing (4%)*
- *Other (7%)*

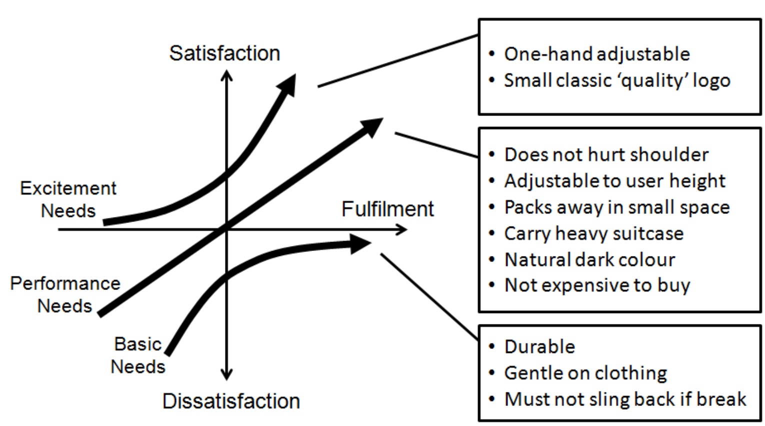
User trail with existing own product model:

- *75% of users are struggling to get the right height adjustment and comfort.*
- *White belt material quickly gets dirty.*

Customer opinion survey, 400 respondents:

- *Top 5 priorities are: Comfort, ease of use, long lasting, strength, low price.*
- *82% preferred black in colour.*
- *15% picked sample illustration with 'executive' style logo*
- *Safety is not voiced as being important*

Exacting the priorities that customers and stakeholders have is fundamental to the product development plan. We have to think about the context of who is saying what here. For example, can we trust the rigor behind the sensationalising “Holidaying” magazine’s study? Can we trust that retailers have not over-emphasised the price importance? A price reduction from the manufacturer, without reducing the product value, makes profit easier to obtain for the retailer. They tend to therefore always tell manufacturers that products are too expensive. It also matters how we ask questions of users and interpret the information we receive. If we, for example, ask a user to rate on a scale from 1 to 10 how important it is that *“the device doesn’t damage clothing”?* The person may then mentally picture her best jacket being scuffed up and will say: *“Absolutely intolerable, 10”*. If on the other hand the question was phrased *“... is gentle on clothing”?* Then the mental picture is not so severely negative and the person may say: *“Yeah, that would be good, the score is 6”*.



It is also helpful categorising the needs into the Kano types. We have to be careful not to miss out or underestimate any basic needs, just because the customer did not ask for them. We should also assure the discovery and emphasis of some excitement needs, to help increase the product competitiveness and pricing.

The Phase 1 ‘generate’ step is further about creatively translating the customer requirements into a corresponding set of optional design requirements. The translation table is one way that we can start generating these options. Its purpose is to prompt the QFD team to break with stereotypical thinking. Already at this stage the table can start generating ideas about the coming design solutions for Phase 2. However, it is yet one step too early for jumping to conclusions. We therefore try to suspend judgement and keep the emerging options solution-neutral for now. Do not complete the right-hand column during this ‘generate’ phase.

		Example design solutions For each cell ask: What are the functions, features or activity that satisfies customer requirement?					
Customer Requirement	Importance	Existing own solution	Competitors’ ‘best’ solution	Related ‘state-of-art’	Abstract analogy	Design rule, standards and regulatory requirements	**Design Requirement**
Adjustable to user height	10	Length adjustable belt	Length adjustable belt	Length adjustable belt	Car seat belt	None	Length adjustable belt
Not expensive to buy	8	Low component count	Standard mass-produced components	Reduced components and processing	Pallet strapping	None	Low cost belt material and fastener
Must carry heavy suit case	8	Strong belt and fastener	Strong belt and fastener	High-tech carbon fibre material	Truck towing strap elastic absorption	None	Strong belt and fastener. Elastic bounce
Gentle on clothing	8	Nothing special. Canvas belt	Nothing special. Canvas belt	Smooth teflon non-stick surface	Artificial ski slope and ice rink	None	Non-abrasive surface
Durable	7	Over-engineer belt and fasteners	Over-engineer belt and fastener	Resilient kevlar or diolen material	Parachute nylon cords and webbing	None	Wear resistant
Natural dark colour	6	White !!!	Black	Dark grey, near black	Dark luggage colours	None	Neutral dark colour
One-hand adjustable	6	Sliding buckle, requires two hands!!!	Sliding clasp, requires one hand	Waist belt holes and tongue buckle	Transport lashing strap with hook	None	Easy to adjust by one hand
Does not hurt shoulder	5	Wide belt	Sliding shoulder pad	High density foam pad	Mountaineer-ing harness	None	Ergonomic large shoulder pad
Packs away in small space	5	Flexible, rolls up. Small fasteners	Flexible, rolls up. Larger fasteners!!!	Netting material – i.e. crunch up bag	Long tape measure	None	Slim and flexible, small fastener
Must not sling back if break	2	Canvas belt is not very elastic	Canvas belt is not very elastic	Use twin strands	Chewing gum necking before breaking	Product liability	Yield plastically
Small classic logo	2	Company brand mark	Quality assurance mark	Trusted brand mark	Top end brand use of marks	Brand trust mark	Small trusted brand emblem

Translation table

Needs were expressed in the customer's own language, which might not always be very explicit. We should try identifying and thinking in terms of the associated features in a solution-neutral language. When a customer asks for a *“shoulder strap with clip hooks at its ends”*, for example, what is really meant is that the strap needs to be attachable and detachable. We do not yet know whether a clip hook is necessarily the ideal solution or whether there can be other more effective ways of meeting the need. It is better to define the need as “packs away”, because this is ultimately what the customer really means for the product to do.

The “brand trust mark” – last item under our design rule column – is a company specific standard that it imposes on itself. This relates to a company strategy objective for never compromising on *“quality at reasonable cost”*. In making the brand trusted in respect of this ethos, the company has an expectation that consumers will attach value to its brand mark. It is not something that customers have expressly asked for, but something they are nonetheless expected to perceive value in when encountering it – which is why we have classed it as an ‘excitement’ need.

SELECT – VOICE OF CUSTOMER

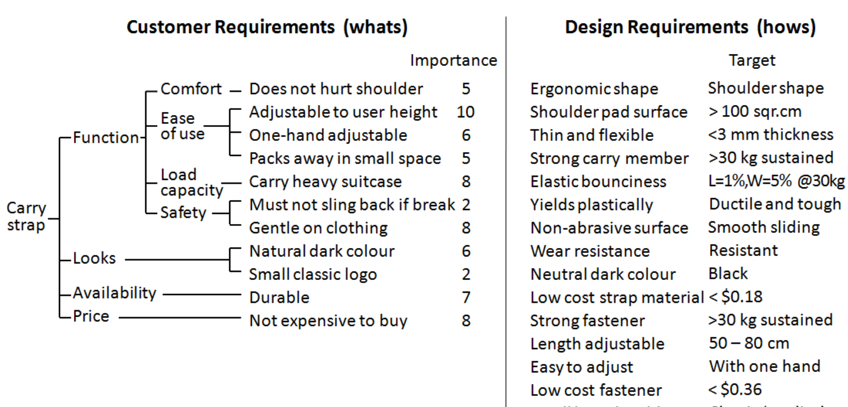
We can now look across the rows in the translation table, to stimulate thinking and discussions about what the final set of design requirements should be. The selection is about combining or extrapolating the best functional ways of satisfying a customer requirement, by evaluating the recorded options and any trends that may be identified from the table as a whole. The final choice will consider one of the following basic cases:

a) Completely new solution.
b) Combine existing and new solution.
c) Keep or strengthen existing solution.

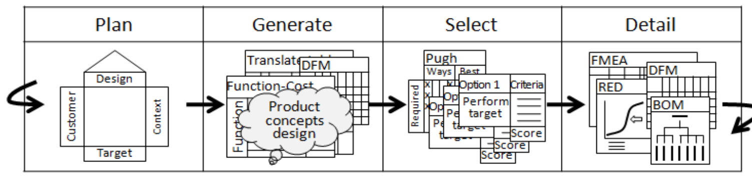
We also give consideration to a balanced translation, where the higher importance customer requirements become associated with a higher number of design requirements. Looking at it the other way around, we generate a lesser number of design requirements in relation to the lesser important customer requirement. We express our final selection in the right-hand column of our translation table, in a solution-neutral design engineering language.

DETAIL – VOICE OF CUSTOMER

Refining customer and design requirements is about sorting, structuring and sifting out any trivial items, to make the project manageable within the time and resources defined in our project scoping form. The final output from Phase 1 is a structured set of relevant requirements. As far as practically possible, and without being solution specific, we determine a technical objective target value to indicate what would satisfy the customer requirements as we understand them.



PHASE 2: PRODUCT DEVELOPMENT



PLAN – PRODUCT DEVELOPMENT

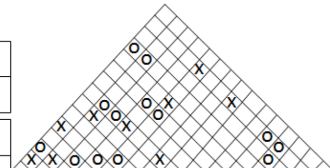
We start by taking the output from the previous phase and enter it into a HoQ. The technical "objective targets" are entered into the technical evaluation area below the matrix. We now consider each customer requirement in turn and assess its relationship with each design requirement. Enter the scores 'blank', 1, 3 or 9 – to represent none, weak, medium or strong relationships – in the intersecting matrix cells. Once completed, visually review and confirm that the translation from Phase 1 was appropriately balanced. Absence of any relationship for any one or more of the customer requirements would indicate that the earlier Phase 1 translation into design requirements has missed something. Absence of any relationship for a design requirement would indicate that the translation might have introduced unimportant or unnecessary items. Likewise, if a customer requirement with a low importance rating is singular in interrelating with a relatively large number of product requirements then it could indicate that the translation maybe has given too much emphasis to this 'lesser' customer requirement. If something looks 'not right' then we can go back and verify the VOC in Phase 1, as necessary. The example HoQ shown here demonstrates an appropriately 'balanced' translation.

Luggage carry device

QFD Phase 2 plan

x = positive correlation
o = negative correlation

Ideal target direction
S=smaller T=Target L=Larger



Customer requirements			Importance	Shape: Ergonomic shape	Shape: Shoulder pad surface	Material: Thin and flexible	Material: Strong carry member	Material: Elastic bounciness	Material: Yields plastically	Material: Non-abrasive surface	Material: Wear resistant	Material: Neutral dark colour	Material: Low cost material	Fixing: Strong fastener	Fixing: Length adjustable	Fixing: Easy to adjust	Fixing: Low cost fastener	Small brand emblem	Policy weight 40%: Own product	Policy weight 40%: Competition A	Policy weight 40%: Competition B	30%: Strategy objectives	30%: Selling point	Weighted importance
Ideal target direction				T	L	S	L	T	L	L	L	T	S	L	L	T	S	S						
Function	Comfort	Does not hurt shoulder	5	9	9	3		9		1					1				2	4	2	5	4	9.6
Function	Usability	Adjustable to user height	10												9	3			4	2	4	2	4	2.6
Function	Usability	One-hand adjustable	6	1												9			2	1	4	2	4	4.6
Function	Usability	Packs away in small space	5	1	9	9									3				4	1	5	1	3	1.0
Function	Capacity	Carry heavy suitcase	8		3	3	9	1			1			9	3				3	2	4	3	4	6.1
Function	Safety	Not sling back if breaks	2			3	1	9	9										2	4	3	5	2	1.9
Function	Safety	Gentle on clothing	8	3	9	1		3		9	1								3	4	3	2	3	3.1
Appearance		Natural dark colour	6									9							1	5	4	1	4	3.8
Appearance		Small classic logo	2			1						1	1					9	1	5	3	4	3	3.8
Available		Durable	7	1	1	3	9	3	9		9		3	9					4	2	3	3	2	1.3
Price		Not expensive to buy	8	3			3		1		3		9	3	9	1	9	1	3	2	4	3	5	7.7
Objective targets				Shoulder shape	> 100 sqr.cm	<3mm thickness	>30kg sustained	L=1%,W=5% @30kg	Ductile and tough	Smooth sliding	Resistant	Black	<$0.18	>30kg sustained	50 – 80cm	By one hand	<$0.36	Classic 'quality'						
Score				115	193	121	161	116	89	77	103	56	95	159	206	92	72	32						
Technical importance (%)				7	11	7	10	7	5	5	6	3	6	9	12	5	4	2						
Own product				2	2	4	4	5	3	3	3	1	2	5	4	2	4	1	Competitive rating (1-5)			(1-5)		
Competition A				5	4	2	2	3	5	4	2	5	4	3	1	1	1	5						
Competition B				2	2	4	5	2	1	4	4	4	3	4	5	4	3	1						
Dynamic design (1-2)				2	2	1	1	1	2	1	1	1	1	1	2	2	1	1						
Bottleneck (1, 1.2, 1.5)				1.2	1	1	1	1	1.5	1	1	1	1	1	1	1.2	1	1						
Weighted score				118	86	7	19	12	33	7	9	19	23	9	49	40	7	23						
Development importance (%)				26	19	1	4	3	7	1	2	4	5	2	11	9	1	5						

The "Technical importance (%)" reflects the pure customer requirements transferred into the technical system. These values are what our designed product will aim to satisfy. For example, from a customer value perspective, it is significantly more important that the final design has a good technical solution for "length adjustable" (12) than it has a "neutral dark colour" (3).

Once the QFD team is in agreement that the translation and transfer through the HoQ makes sense then we rate the 'what context' and 'how context' parameters. The 'what context' percentage policy weights reflect the relative importance of the 3 context modifiers. The elements of our 'what context' in this case study being:

- Competitive rating is the measure of any negative gap between the highest scoring competitor and our existing own product, plus 1 (to avoid a zero for multiplication). The evaluation is made in terms of the customer perceived performance.
- Strategy objectives refer to how important the fulfilment is to the organisation's business, quality and social responsibility plan. For example, the customer requirement "not sling back if breaks" is weighed highly, by a value of 5. This is not because the customer asks for it, but because the company would want to best protect its brand image and avoid any public complaint over its product safety.
- Selling point rates the ability of a satisfied customer requirement being used to increase saleability in the market.

The elements of our 'how context' in this case study being:

- Competitive rating, which is similar to in the 'what context', but here it compares the strengths of technologies, as opposed to comparing customer perception. For examples, we consider whether a competitor is using a technologically more effective or efficient way to address the same design requirement.
- Dynamic design reflects a decision to either re-use a pre-existing solution or to develop something new from scratch (1=static, 2=dynamic).
- Bottleneck rates the potential for overloading a designer's time or capability with the technical aspect development and considers any potential scheduling problems with other work that has to be performed concurrently (1=unlikely, 1.2=possible, 1.5=likely).

The “Development importance (%)” reflects were we shall focus our development attention and resources, when taking into account the contexts modifiers. For example, the “ergonomic shape” has merely a mid-range customer technical importance of 7%, but is given the highest development importance with 26%, out of the normalised 100% being allocated across all of the design requirements. If we trace backwards, we can see in the ‘how context’ that this is because the performance of our current technical solution is particularly weak, while a competitor product is particularly strong. Also, we have determined it to be a dynamic design aspect with potential for causing an engineering bottleneck. Furthermore, the “ergonomic shape” relates strongly to the customer requirement “does not hurt shoulder”, which was boosted in importance within the ‘what context’, from a customer importance of 5 to a weighted importance of 9.6; the competitive rating = ((4-2) +1) x 40% = 1.2; Strategy objectives = 5 x 20% = 1.0; Selling point = 4 x 40% = 1.6; hence, Weighted importance therefore = 5 x 1.2 x 1.0 x 1.6 = 9.6.

For the correlation roof we start by determining whether the ideal value for each of the technical targets is a nominal target value (T), or larger-the-better (L), or smaller-the-better (S). We mark the appropriate cells under the correlation roof accordingly. This in turn helps us assess the correlation between each of the design requirements with the others. Where a correlation is identified we rate it as positive (mutually enhancing) or negative (mutually impeding). We enter the scores into the intercept cells within the correlation roof.

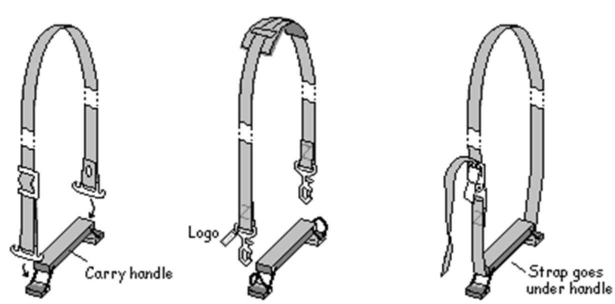
GENERATE – PRODUCT DEVELOPMENT

The next activity is about creatively researching the design solution space, focusing our efforts in accordance to the development priorities identified by our HoQ plan. It starts with the generation of a number of diverse ideas, which could potentially be developed to satisfy the design requirements and help to bridge any competitive gaps. The thinking processes involved in generating new ideas may include:

- Systematic analysis of trends and emerging ideas.
- Random search for new ideas.
- Recognition of new relationships between ideas.
- By analogy to similar objects or areas of knowledge.
- By analogy to nature.

One appropriate tool could be another translation table, similar to that used in Phase 1, but with the solution-neutral design requirements now listed in the left-hand column, and where we now write real specific solutions into the table.

Another tool is a Function Cost Analysis of various known solutions. This can help identifying the most cost-effective way to satisfy a performance requirement.



Function Cost Analysis

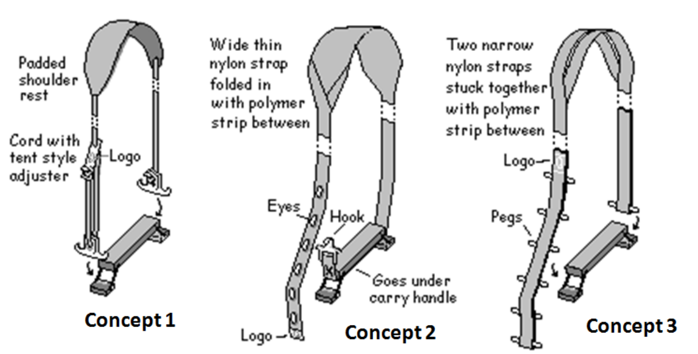
	Own existing product					Product B						Product C			
		Strap	End hooks	Slide buckle	Riveting		Strap	Pad material	Clip hook	Hook D-rings	Stitching		Strap	Press lock	Stitching
Function	Cost	0.35	0.42	0.18	0.52	Cost	0.22	0.38	0.91	0.08	0.71	Cost	0.30	0.47	0.32
Ergonomic shape	0.09	1/4				0.38		1				0.06	1/5		
Strong strap	0.24	2/4	1/6			0.63	1		1/4		1/4	0.29	2/5	1/5	1/4
Strong fixing	0.77		5/6	1/4	2/3	1.29			3/4	1	3/4	0.49	1/5	2/5	3/4
Length adjuster	0.39	1/4		3/4	1/3	0						0.25	1/5	2/5	

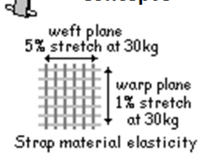
Now is also the stage to start speaking to the process owners of other cross-cutting activities, to establish or start negotiating possible options for an optimised alignment.

The output that has emerged from our 'generate' stage, in this case study, are 3 possible new product concepts (shown below).

SELECT – PRODUCT DEVELOPMENT

The relative performance of our 3 concept designs is evaluated against the customer-derived design requirements and their "objective targets". Pugh's selection technique can be used in this particular step. Here, Concept 2 is selected as the highest scoring candidate choice. This concept is designed to slides under a carry handle and can be hooked-up (fastened) single-handedly.





Pugh Concept Selection

+ = better
s = same
- = worse

	Design requirements																	
	Shape		Material								Fixing							
	Ergonomic	Large shoulder surface	Thin and flexible	Strong material	Elastic bounciness	Yield plastically	Non-abrasive surface	Wear resistant	Neutral dark colour	Low cost material	Strong fixing	Length adjustable	Easy to adjust	Low cost fixing	Better	Same	Worse	Total
Concept 1	Baseline																	
Concept 2	s	+	+	s	s	+	s	-	s	+	s	+	+	+	7	6	1	6
Concept 3	-	-	s	s	s	+	-	s	s	+	-	+	s	+	4	6	4	0

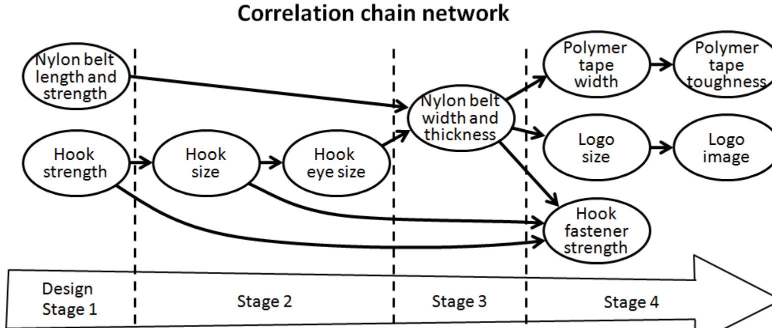
DETAIL – PRODUCT DEVELOPMENT

The selected Concept 2 was not yet an optimum design and it contained unanswered questions. The concept is now further detailed, refined and optimised. Various tools are linked to this product development stage, such as FMEA, DFM and RED.

	DFM principles and considerations																					
Component	Standardised components	Standardised process, known capability	Standardised process equipment	Operator skill (minimise)	Operator accessibility (ergonomics)	Operator visualisation (ergonomics)	Operator movement comfort (ergonomics)	Assembly directions (minimise & vertical)	Make robust to tolerances	Number of fasteners (minimise, standard)	Jigging and/or self-jigging	Travel time, distance (operator, materials)	Component feed hopper	Automation, semi-automation	In-line testing	Reworkability (ease of rework)	Traceability	Standards	Environmental conditions	Components shelf-life constraints	Chemical, biological constraints	Design life (impact of revisions likelihood)
Nylon belt	Y						Y		Y		Y	Y	Y									
Polymer tape	Y												Y									
Hook	Y												Y									
Hook eyes	Y												Y									
Fastener	Y	Y	Y	Y		Y		Y	Y	Y			Y	Y								
Logo		Y											Y									

Analysis of the correlation roof helps identifying what design aspects have pre-conditions and where there is opportunity for concurrent development. The review determines the order in which to perform the detailed design work.

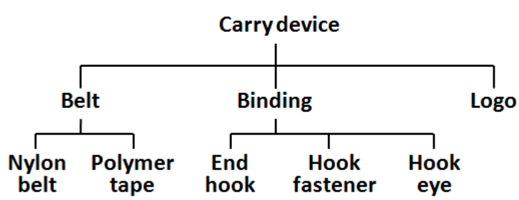
Correlation chain network

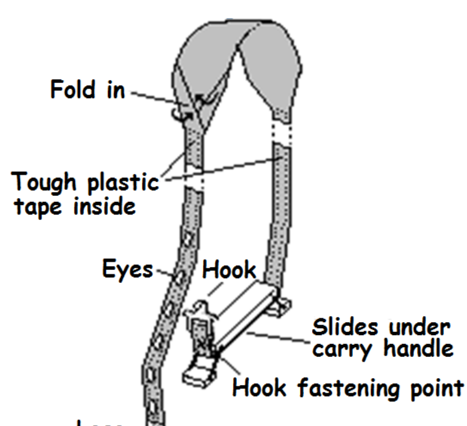


For example, before anything else, we should first identify a belt material and a hook that has the required strengths. Later in the development, the polymer tape, logo and hook fastening can be developed separately and concurrently, because they do not influence each other. The polymer tape is a thin stretchy inlay, which prevent the loose ends from separating if the nylon belt accidentally breaks. It provides user safety in case of failure.

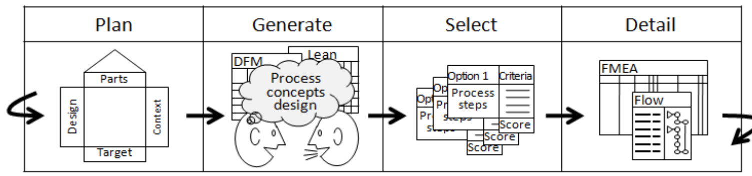
The detailed design output from Phase 2 will consist of bill-of-materials and parts specifications, such as technical tolerance drawings and target values. The designer will also understand how the product is to be assembled – although the production process is not yet developed.

Bill of materials





PHASE 3: PROCESS DEVELOPMENT



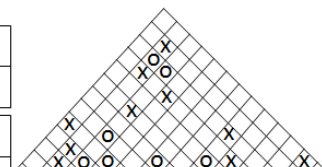
PLAN – PROCESS DEVELOPMENT

Luggage carry device

QFD Phase 3 plan

x = positive correlation
o = negative correlation

Ideal target direction
S=smaller T=Target L=Larger



Ideal target direction				T	L	S	L	T	S	L	S	L	L	S	T	T
Parts and characteristics				Nylon belt					Poly.		Binding				Logo	
Design requirements		Targets	Importance	Length	Width	Thickness	Strength	Elasticity	Width	Toughness	Hook size	Hook strength	Fastener	Hook eyes	Size	Image
Shape	Ergonomic shape	Shoulder shape	7		9	1	1	9								
	Shoulder pad surface	>100 sqr.cm	11		9											
Material	Thin and flexible	<3 mm thickness	7		9	9	9	3	3				1	9	3	
	Strong carry member	>30kg sustained	10		1	1	9	3	1		1		3	9		
	Elastic bounciness	L=1%,W=5% @30kg	7	3		1	3	9								
	Yields plastically	Ductile and tough	5				9	1		9						
	Non-abrasive surface	Smooth sliding	5		1		1							3		
	Wear resistant	Resistant	6		1	3	9	3			1		3			
	Neutral dark colour	Black	3											1		1
	Low cost material	<$0.18	6	9	1	3	9	3								
Fixing	Strong fastener	>30kg sustained	9				1	1				9	9	3		
	Length adjustable	50 – 80 cm	12	9				1						9		
	Easy to adjust	By one hand	5								3	1		9		
	Low cost fastener	<$0.32	4								3	9	3	9		
Small brand emblem		Classic 'quality'	2		1										9	3
Organisational difficulties				N	N	N	N	N	N	N	N	N	N	N	N	N
Technical targets				1900 mm	75mm (unfolded	<3 mm thickness	>0.4 Nmm²	L=1%,W=5% @30kg	<20 mm	>30% flex at 1kg	<7.5 mm	30kg load	30kg load	<8 mm inner dia.	10 x 20 mm	Company logo
Weighted score				183	256	123	348	232	31	45	43	122	148	387	57	15
Technical importance (%)				9	13	6	17	12	2	2	2	6	7	19	3	1

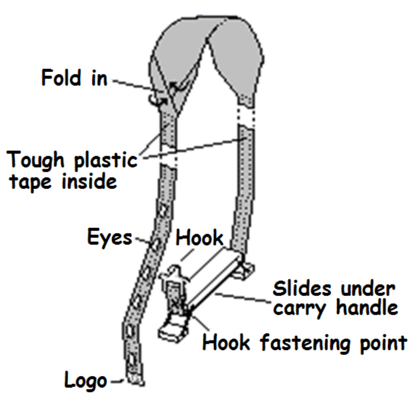
This planning activity follows the HoQ evaluation method, as in Phase 2, with the exception that there is no need for any context weightings in this case study. The "Organisational difficulty" evaluation is an estimate of whether we are straightforwardly ready to achieve the required technical targets or whether we need to pay attention and be mindful of potential difficulties. This evaluation is placed below the main matrix for visualisation purpose. It does not influence or adjust the bottom line "Technical importance (%)" in this case. This variation in the arrangement demonstrates how we can tailor the application of the HoQ to focus on whatever is most relevant in our particular project.

GENERATE – PROCESS DEVELOPMENT

The next activity is about creatively researching the process solution space. It is concerned with creating a number of process options, based on the principle approach of the same stage in the previous phase. DFM or Lean principles can be valuable sources when determining the process elements. In looking for suitable process activities we prioritise attention to parts targets that are associated with a high "Technical importance (%)". The research should again involve speaking to the owners of potentially cross-cutting activities, to identify any issues in advance. We may sometimes find ourselves constrained by pre-established process equipment or capabilities and may be encouraged (out of economic and practical necessity) to 'shoehorn' our new product into a pre-existing production system. However, if this severely hinders, or proves ineffective in terms of meeting the quality plan, including later in Phase 4, then we should clearly consider changing the pre-existing production system. Our brand new product may initially only sell in smaller quantities, which could favour the flexibility and lower start-up cost of a manual production approach. Time to market is often more important than cost optimisation, initially. The economic case for automation can sometimes follow later, once the sales quantities become more promising and can be better forecast. If this is the case then we can simply define a manual process for now. QFD Phase 3 and 4 can be revised later, for any automated process. If future process automation is foreseeable then it would be advisable that any DFM evaluation in Phase 2 takes this into consideration already now, to avoid exclusive design decisions.

SELECT – PROCESS DEVELOPMENT

In our case study we have identified 3 process options, which for selection purpose we evaluate in terms of capability – with respect to achieving the parts targets, time and cost. Here, process Option 3 has the highest estimated mean process capability (Cp) and the lowest cost.



Process option 1

#	Task	Method	Cp(est)	Time	Labour	Equip.
10	Place plastic strip in belt	Manuel	1.5	3.4s	0.47¢	0.00¢
20	Secure plastic strip	Glue	1.3	4.1s	0.57¢	0.91¢
30	Fold in belt	Mechanical	1.4	2.9s	0.40¢	0.00¢
40	Fix 8 eyes in belt	Rivet	1.4	16.2s	2.25¢	4.17¢
50	Fasten hook to belt	Glue	1.3	3.2s	0.44¢	0.71¢
			Mean = 1.38	Cost = $99.35 /'000		

Process option 2

#	Task	Method	Cp(est)	Time	Labour	Equip.
10	Place plastic strip in belt	Manuel	1.5	3.4s	0.47¢	0.00¢
20	Fold in belt and fix strip	Stitch	1.2	14.0s	1.94¢	2.97¢
30	Fix 8 eyes in belt	Rivet	1.3	16.2s	2.25¢	4.17¢
40	Fasten hook to belt	Stitch	1.3	5.7s	0.79¢	1.21¢
			Mean = 1.33	Cost = $136.11 /'000		

Process option 3

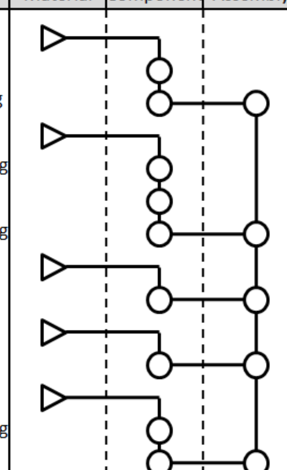
#	Task	Method	Cp(est)	Time	Labour	Equip.
10	Place plastic strip in belt	Manuel	1.5	3.4s	0.47¢	0.00¢
20	Secure plastic strip	Glue	1.3	4.1s	0.57¢	0.91¢
30	Fold in belt	Mechanical	1.4	2.9s	0.40¢	0.00¢
40	Fix 8 eyes	Rivet	1.4	16.2s	2.25¢	4.17¢
50	Fasten hook to belt	Rivet	1.5	2.2s	0.31¢	0.57¢
			Mean = 1.42	Cost = $96.50 /'000		

DETAIL – PROCESS DEVELOPMENT

We refine our process by optimising for robustness, DFM and Lean principles. For this purpose, we may want to refer back to and expand on the DFM evaluation that we opened in Phase 2.

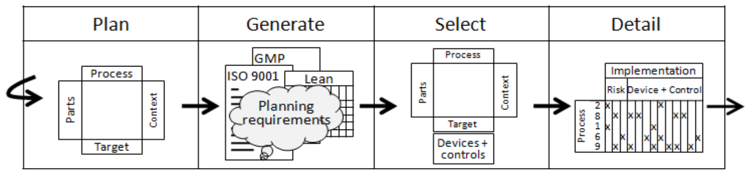
The final process consists of a flow diagram and the identification of critical characteristics for individual process elements, which we can use to validate against. It requires good operational knowledge to be able to finalise the critical process parameter values exactly. It may therefore be necessary to perform a pre-production run to learn about and verify any assumptions.

Process flow diagram				
Process step	Process element	Material	Component	Assembly
Obtain belt material	Manual handling			
Cut belt to length	Slide blade			
Sear ends	Controlled melting			
Obtain 2 plastic tapes	Manual handling			
Place on belt material	Manual positioning			
Spread glue	Gluing			
Fold in belt edges	Manual positioning			
Obtain 8 eye rivets	Manual handling			
Rivet eyes to belt	Riveting			
Obtain logo badge	Manual handling			
Rivet logo to belt	Riveting			
Obtain hook with rivet	Manual handling			
Thread belt and hook	Manual positioning			
Rivet hook to belt	Riveting			



Critical process characteristics		
Process element	Parameter	Critical value
Manual handling	Speed	<15 m/s
Manual positioning	Positioning	<1.5mm
Slide blade	Straight cut Pressure Precision	<1 mm shear 500 N/sqr.m <20 mm
Controlled melting	Temperature	80 deg.C +/-5
Gluing	Speed Cover	0.5 m/s >98% of edge
Riveting	Precision Speed	<1 mm 2 sec

PHASE 4: PRODUCTION PLANNING



PLAN – PRODUCTION PLANNING

This 'plan' activity, again, follows the HoQ (on next page) evaluation method of the previous phases. We have entered the process flow diagram into the 'hows' section. Normalising the "Technical importance" to 100% would have produced some very low values, which were difficult to compare. For purpose of better visualising the relativity between the process parameters, we have simply increased the resolution by normalising the scores to 200 points instead. The HoQ output now helps us visualise the most important process elements and their parameters target values to be controlled. We have then expanded the bottom of the HoQ matrix with an "Operational evaluation" section that uses a scoring method based on that of the FMEA RPN, to further amplify the relative importance of the individual process step. This helps identify the operational difficulty risks of the individual process parameters, for when it comes to selecting the process controls.

GENERATE – PRODUCTION PLANNING

The next activity is about creatively researching production planning space. Industry related standards for Good Manufacturing Practices (GMP), ISO 9001 and Lean principles can be sensible sources. The planning elements are defined as devices and controls required for an effectively implemented production operation. We have generated 14 relevant planning elements in this case study. An "Implementation planning requirements" matrix, which is merely an empty checkbox at this 'generate' stage, is added below the "Operational evaluation".

Luggage carry device

QFD Phase 4 plan

Parts	Characteristics	Targets	Importance	Obtain belt material: Speed	Cut belt to length: Straight cut	Cut belt to length: Pressure	Cut belt to length: Precision	Sear ends: Temperature	Obtain 2 plastic tapes: Speed	Place on belt material: Precision	Spread glue: Speed	Spread glue: Cover	Fold in belt edges: Precision	Obtain 8 rivet eyes: Speed	Rivet 8 eyes to belt: Precision	Rivet 8 eyes to belt: Speed	Obtain logo badge: Speed	Rivet logo to belt: Precision	Rivet logo to belt: Speed	Obtain hook with rivet: Speed	Thread belt and hook: Precision	Rivet hook to belt: Precision	Rivet hook to belt: Speed
Nylon belt	Length	1900mm	9	3			9			1	3	3	3		1	1							
	Width	75mm (unfolded)	13	1	3					9	3	9	9		9	3		3			3	3	1
	Thickness	<3mm	6			9		3					9			9		1	9		3	1	9
	Strength	>0.4 N/mm²	17		1	9		9					9			3		1	3			1	3
	Elasticity	L=1%,W=5%@30kg	12		3	3	1			3			9		9			3			1	3	
Poly. strip	Width	<20mm	2						1	3	3	3	3			1							
	Toughness	>30% flex at 1kg	2										1			9			3		1		3
Binding	Hook size	7.5mm	2											1						3	9	9	3
	Hook strength	30kg load	6																				
	Fastener	30kg load	7				3	9														9	3
	Hook eyes	8mm inner dia.	19											9	3	9							
Logo	Logo size	10 x 20mm	3														9	9	3				
	Logo image	Company logo	1															3					
Critical process parameter values				<15 m/s	< 1 mm shear	500 N/m²	<20 mm	80 deg.C +/-5	<15 m/s	<1.5mm	0.5 m/s	>98% of edge	<1.5mm	<15 m/s	<1 mm	16 sec	<15 m/s	<1mm	2 sec	<15 m/s	<1.5mm.	<1mm	2 sec
Score				40	92	243	114	234	2	168	72	150	467	173	291	344	27	128	120	6	89	176	151
Technical importance (200 points)				3	6	16	7	15	0	11	5	10	30	11	19	22	2	8	8	0	6	12	10
Operational evaluation 1=low 3=high	Defect likelihood			2	1	1	1	2	2	3	3	2	2	3	2	2	1	2	2	3	2	3	2
	Defect severity			1	3	2	2	3	1	1	1	3	3	1	3	1	1	2	1	1	2	2	1
	Ease of detecting			1	2	1	3	2	1	1	1	3	2	1	2	1	1	2	1	1	3	2	1
	Risk score			6	36	32	42	180	0	33	15	180	360	33	228	44	2	64	16	0	72	144	20
Implementation planning requirements	Automate, semi-automate							Y			Y	Y			Y	Y							
	Jig				Y	Y							Y		Y			Y			Y	Y	
	Mistake-proofing																	Y			Y	Y	
	Operator training							Y		Y		Y	Y										
	Ergonomics, concentration				Y	Y							Y					Y			Y	Y	
	Information, Communication																						
	Quality system documentation							Y				Y	Y					Y			Y	Y	
	Collect performance data														Y							Y	
	Review and approval (record)																						
	Waiting line control			Y					Y					Y			Y			Y			
	Maintenance schedule							Y				Y	Y		Y			Y				Y	
	Health & safety assessment							Y								Y			Y				Y
	Environmental management										Y												
	Special attention			Y					Y					Y			Y			Y			

SELECT – PRODUCTION PLANNING

The QFD project team collectively reviews the "Operational evaluation" risk scores, to select and mark the appropriate planning elements from the checkbox of 14 options under "Implementation planning requirements". Process steps with a higher "Risk score" will principally need more devices and controls selected for it, to help assure operational performance. The decision should consider carefully whether a control is really necessary, based on the risk score, or whether it will add an unnecessary work burden on to the people and system.

DETAIL – PRODUCTION PLANNING

The selected implementation plan is now ready for hand-over to the process owners, who will practically break the planning requirement down into more specific actions within their areas. It may be practical for communicating the plan, to people who were not directly involved in the QFD process, to shorthand the planning matrix for easier reading. This ends the QFD project.

Luggage carry device Production Implementation Plan					Operational evaluation 1=low 3=high				Implementation planning requirements													
Material / Component / Assemble	Process step	Parameter	Target	Importance	Defect likelihood	Defect severity	Ease of detecting	Score	Automate, semi-automate	Jig	Mistake-proofing	Operator training	Ergonomics, concentration	Information, communication	Quality system documentation	Collect performance data	Review and approval (record)	Waiting line control	Maintenance schedule	Health & safety assessment	Environmental management	Special attention
	Obtain belt material	Speed	<15 m/s	3	2	1	1	6										Y				Supply scheduling
	Cut belt to length	Straight cut	<1 mm shear	6	1	3	2	36		Y			Y									
		Pressure	500 N/mm^2	16	1	2	1	32		Y			Y									
		Precision	<20 mm	7	1	2	3	42														
	Sear ends	Temperature	80 deg.C+/-5	15	2	3	2	180	Y			Y			Y				Y	Y		
	Obtain 2 plastic tapes	Speed	<15 m/s	0	2	1	1	0										Y				Supply scheduling
	Place on belt material	Precision	<1.5 mm	11	3	1	1	33				Y										
	Spread glue	Sped	0.5 m/s	5	3	1	1	15	Y												Y	
		Cover	>98% of edge	10	2	3	3	180	Y			Y			Y				Y			
	Fold in belt edges	Precision	<1.5 mm	30	2	3	2	360		Y		Y	Y		Y				Y			
	Obtain 8 rivet eyes	Speed	<15 m/s	11	3	1	1	33										Y				Supply scheduling
	Rivet 8 eyes to belt	Precision	<1 mm	19	2	3	2	228	Y	Y						Y			Y			
		Speed	16 sec	22	2	1	1	44	Y											Y		
	Obtain logo badge	Speed	<15 m/s	2	1	1	1	2										Y				Supply scheduling
	Rivet logo to belt	Precision	<1 mm	8	2	2	2	64		Y	Y		Y		Y				Y			
		Speed	2 sec	8	2	1	1	16												Y		
	Obtain hook with rivet	Speed	<15 m/s	0	3	1	1	0										Y				Supply scheduling
	Thread belt and hook	Precision	<1.5 mm	6	2	2	3	72			Y		Y		Y							
	Rivet eyes to belt	Precision	<1 mm	12	3	2	2	144		Y	Y		Y		Y	Y			Y			
		Speed	2 sec	10	2	1	1	20												Y		

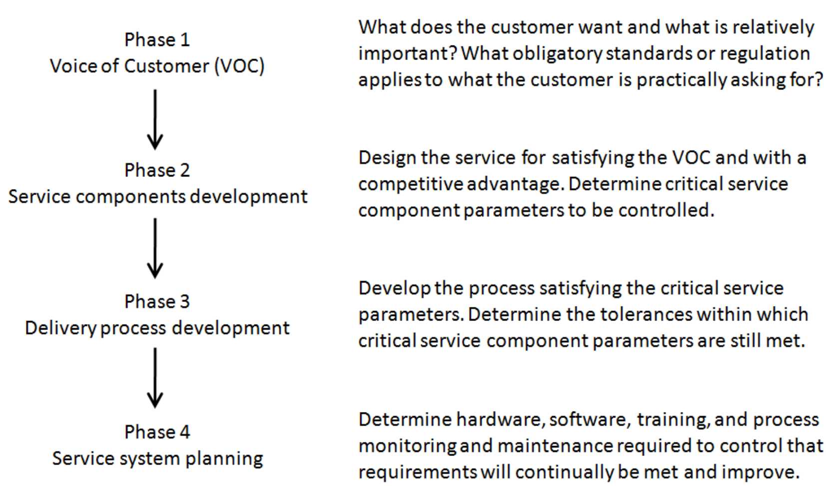
CASE STUDY 2: SERVICE QFD

The product in this case is a service process. Service differs from a manufactured article by being less tangible. It is also more difficult to distinguish between product and process. The process and the social interaction with the human operator in the delivery system are part of the customer's experience. Hence, process and operator effectively become part of the product. In practice, only some of the process exists within the product definition, while the part that is unseen by customers probably belongs in the delivery system definition. However, we will have to develop the process as a whole. In this service QFD project, therefore, we think of the process as being the product proper.

	Manufacturing	**Service**
Product	Tangible parts (components) of a physical object	Intangible components of **process**, people behaviour and ambiance
Delivery system	Production process, delivered by people and process equipment	Service system process, delivered by people and process equipment

What we typically refer to as 'service' can of course also have an intermixed element of tangible products, where the two fundamentally interrelate. For example, the buying decision for a new car is for many customers just as much about the selling and service process they experience than it is about the car itself. Also, try thinking about a restaurant. The food is effectively 'manufactured' in the kitchen and is served in the dining room through a service process. The waiter interaction, order processing, ambience and so forth are pure service elements. For a restaurant QFD, it may be advisable to treat the kitchen and the dining areas independently as two separate, though interrelated, products; where both sides are scoped together for a collective QFD team in both projects (the kitchen chef has an important opinion about how the food is served and waiters have an important opinion about the standard/appearance of the food).

There is a further difference in service QFD. Whereas the definition of quality in manufactured goods typically is about assuring consistency in conformance to specification, an element of quality in service processes is sometimes the complete opposite. Namely, about being flexibly responsive in producing exceptions and personalised customer experiences (the same is often true for manufactured products, but it is just practically impossible to think about it in this way).



Our service QFD is the same 4-phase approach. However, the output from Phase 2 is now named ‘service components’. Instead of arranging the outputs into a manufacturing bill-of-materials we will already here, in Phase 2, arrange them into the tentative process flow order – because the product is a process.

PROJECT BACKGROUND

The client is a London local municipal service for the maintenance of pay & display parking meters. These are machines from where motorists buy a time limited permit for attaching to the inside window of a parked car. The team of 4 technicians services and maintains 950 machines. London is made up of 33 municipalities. The team is contracted to further cover 2 smaller neighbouring municipalities, totalling an additional 600 machines (1550 machines in total). A further 4 people spend more than 50% of their time on machine related activities, such as accounting for money receipts and parking fine investigations. 14 other people spend up to 10% of their time on similar machine related activities. Apart for performing scheduled preventative maintenance and fault repairs, a large proportion of the 4 technicians’ time is dedicated to machine functional investigations, typically when a motorist has received a parking fine and disputes the correct working of a machine. Local municipals in the UK are under a statutory obligation to demonstrate they deliver ‘best value’ effectiveness and efficiency to their communities. QFD was identified as a tool for establishing ‘best value’, including producing the evidential link between community (customer) needs and the actual service specification. It was also predetermined that the re-developed service must meet requirements of ISO 9001, to demonstrate a commitment to quality and for accessing more new contract work in neighbouring municipalities. The service QFD here is concerned with the servicing and maintaining of parking equipment only, as opposed to the design and manufacturing of the machines themselves (which belongs in the machine supplier's domain).

PHASE 1: VOICE OF CUSTOMER

We start by scoping the customers and others who will need to interact with the project. The term 'customer' is made to include two cross-functional departments that are internal to the wider organisation, but who relies in a customer sense on the service works under review. The needs of these 'internal' customers are not given precedence over those of the 'external' customers, but we have to incorporate them nonetheless.

Project	Parking equipment maintenance			
Purpose	Re-design service functions to assure needs and expectations of customers are satisfied in an effective and cost efficienct way, and by maimising the potential of all employees.			
Scope	Project	Others	Interaction or impact (how)	Involvement
Strategy and policy		Corporate 'Best Value' review team	Demands top 25% benchmarking and 2% year on year efficiency improvement	Account for
		Commercial opportunties	Expands external contracts by 50% over 2 years	Consider
		Human Resource policies	Employee care and protection	Consider
Resourcing		Service technician team	Employee group performing the equipment maintenance service	QFD team
		Technical dept. management	Approves resource allocation	Negotiate
		Terminal maintenance	Competes for resource from same group of technicians	Negotiate
Process		Parking revenue controller	Take calls from public and investigates claims of coin loss	QFD team
		Parking fine processing department	Handles retrospective claims of machine faults. Prepare case papers for appeal adjustcation	QFD team
		Security department	Take out-of-hour calls, for redirecting	Consult
Customer		Municipal finances	Needs machines to function, in order to meet revenue budget	Consider
		Traffic management	Need machines to function, in order to achieve transport plan	Consult
		Motorists Local residents Contract clients	Quantify, organise, use and control service activites to satisfy customer needs and expectations	Survey and consult
Project time period		Start 1st May 2005. Implementation ready 20th June 2005		
Resources and aids		Contracts Manager 12 days Head of Technical Department 2 half days Senior Engineer 5 days Revenue Control Officer 3 days Parking Fine Processing Manager 2 days Other expenses £2500		
Project Manager		John Smith		

Example design solutions

For each cell ask: What are the functions, features or activity that satisfies customer requirement?

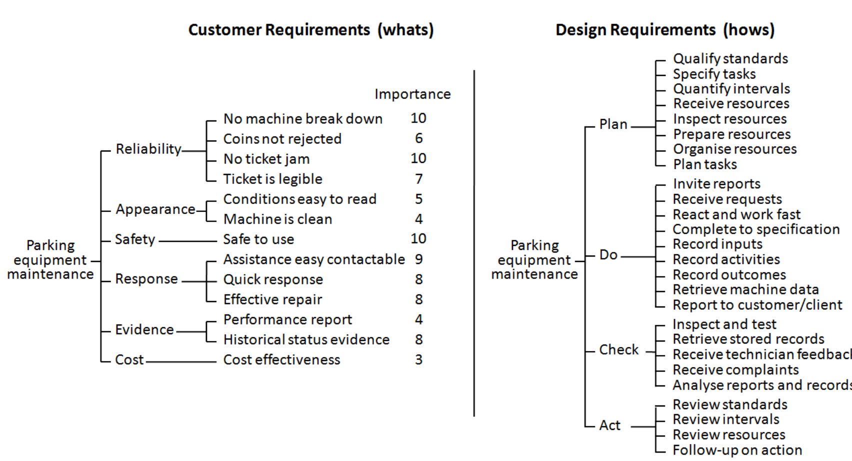
Customer Requirement	Importance	Existing own solution	Competitors' 'best' solution	Heart-lung machine maintenance	ISO 9001 requirements	Abstract analogy	**Design Requirement**
Machine does not break down	10	Plan maintenance dates Organise maintenance jobs Perform maintenance	Plan maintenance dates Organise maintenance jobs Perform maintenance Chase outstanding Technician pay incentives	Measure use Reliability analysis Evaluate maintenance needs Plan maintenance dates Organise maintenance jobs Perform maintenance Chase outstanding	Establish servicing needs Suitable equipment/parts Suitable maintenance Preventive action	Aeroplane: Trends analysis Risk analysis Forecasting Preventative maintenance Backup systems	Measure use Evaluate maintenance needs Plan maintenance dates Organise maintenance jobs Perform maintenance Chase outstanding Preventive action
Coins and not rejected	6	Receive service call, or Identify maintenance need Clean coin acceptor Test coin acceptance Record activity	Receive service call, or Identify maintenance need Clean coin acceptor Test coin acceptance Record activity	Receive service call, or Identify maintenance need Replace suspect part Test machine with new part Record activity	Acceptance criteria Corrective action Record activity	Charity collection box: Indiscriminate of all monies	Receive service call, or Identify maintenance need Clean coin acceptor Test coin acceptance Record activity Review acceptance criteria
No ticket jam, including machine running out	10	Measure machine usage Check stock levels Replenish stock Replenish machine	Specify ticket quality Evaluate supplier Receiving inspection Check stock levels	Specify high standard Audit manufacturing process Receiving inspection Receiving testing Check stock levels Preserve safety stock	Specify ticket quality Evaluate supplier Receiving inspection Check stock levels Preserve buffer stock	Waterfall: Push and pull forces Flow clears away debris/dirt Overflows if blocked	Specify ticket quality Evaluate supplier Receiving inspection Check stock level Preserve safety stock Replenish stock Replenish machine
Tickets is legible (clear print)	7	Receive service call, or Identify maintenance need Clean printer head Adjust printer head	Receive service call, or Identify maintenance need Clean printer head Adjust printer head Adjust burn time	Equipment self-diagnostics Invite user reports Alert of low consumables Replace consumables Recalibrate Test Record	Suitable equipment parts Evaluate supplier Specify purchase spec. Receiving inspection Quality records	Cat marking territory: Regular patrolling Check marking Re-mark Re-check marking	Invite reports Receive service call, or Identify maintenance need Clean printer head Adjust printer head Adjust burn time Test and record legibility
Conditions of use easy to read	5	Receive service call, or Identify maintenance need Affix new user notices Clean facia and notices	Receive request for notice Request specification Affix notice	Specify message layout Usability test of readability Specify positioning of notice	Specify process	Emergency signs: Standard text and symbols Standard placement	Specify message layout Specify positioning of notice Receive service call Affix notice to specification Clean facia and notices
Machine is clean	4	Receive service call, or Identify maintenance need Clean machine enclosure	Identify maintenance need Clean machine enclosure	Specify cleanliness standards Daily preventative cleaning Audit cleaning activity	Meet customer expectations	Surgical instruments: Cleaning standard Specify cleaning method Sterilisation control label Periodic cleanliness auditing	Specify cleanliness Invite reports Receive service call, or identify maintenance needs Clean machine enclosure Sample inspect cleanliness

Safe to use	10	Receive service call, or Identify maintenance need Remove sharps Electric safety test to BS7671 Record test result Calibrate test equipment	Receive service call, or Identify maintenance need Electric safety test to BS7671 Record test result Calibrate test equipment	Risk analysis Medical grade materials Test to medical standard Fail safe Schedule fail safe tests Record result	Invoke standards Approve equipment Inspection and testing Preventive action Corrective action Control non-conformance	<u>Life jacket:</u> Ergonomic Approved standard Highly visible	Assess safety risks Identify accepted standards Receive service call, or Identify maintenance need Remove sharps Electric safety test to BS7671 Record test result Calibrate test equipment
Assistance is contactable	9	Carry mobile telephone Organise shift rote Organise out-of-hours cover	Carry mobile telephone Carry mobile email Organise shift rota cover	Telephone no. displayed Mobile communicators Carry mobile telephone Organise shift rote cover Organise out-of-hours cover	Handle complaints effective	<u>Emergency services:</u> Easy telephone number Direct line Open 24 hours	Telephone no. displayed Direct (re-direct) telephone Carry mobile telephone Organise shift rota cover Organise out-of-hours cover Record complaints Analyse complaints
Quick response	8	Plan with flexibility Plan with contingency Organise out-of-hours cover Inform customers of plan Drive vehicle	Vehicle tracking Optimise travel times Technician pay incentive	Place resources nearby Prioritise support calls	Meet customer expectations	<u>Nail gun:</u> Stored energy Explosive Aimed at target	Motivate technician Plan with flexibility Plan with contingency Deploy technicians widely Organise out-of-hour cover Inform customer of plan Drive veicle
Effective repair	8	Train technician Issue technical bulletins Keep spare parts Test all machine functions Report to customer	Qualify technician skills Train technician Issue technical bulletin Keep spare parts Test all machine functions Technician pay incentive	Quality technician skills Competency assessment Refresher training Keep spare parts Test all machine functions Report to customer	Control customer product Invoke standards Verify process capability Qualify process Competency assessment Process control Final inspection and testing	<u>Severed earth worm myth:</u> Self-healing Re-grows broken part Genetic instinctive	Qualify technician skills Competency assessment Criteria for workmanship Motivate technician Issue technical bulletins Keep spare parts Test all machine functions Report to customer
Performance reports	4	Record events and times Receive information request Analyse performance Provide information	Record events and times Technician feedback Pro-active evaluate data Receive information request Review information Provide information	Record events and times User feedback Pro-active evaluate data Receive information request Validate information Provide information	Measure processes Control process records Record corrective action	<u>100m sprint:</u> Approved measure equipm. Calibrate equipment Agree condition parameters Scrutinise	Record events and times Technician feedback Receive customer report Pro-active evaluate data Review information Receive information request Provide information
Historical status evidence	8	Receive information request Confirm requirements Retrieve data from machine Examine records and data Collate data Prepare information Provide information	Network remote equipment Collect electronic records Receive information request Retrieve records Provide data	Receive information request Confirm requirements Retrieve data from machine Examine user records Collate data Prepare information Provide information	Measure processes Control process records Verify process capability Inspection & testing record Record corrective action	<u>National archives:</u> Protected information Validate information Index information Track movement of info.	Collect electronic records Index information Protect records (backup) Receive information request Confirm requirements Prepare information Provide information
Cost effectiveness	3	Expand business Manage efficiency Recondition parts for reuse Part exchange parts Market test suppliers	Expand business Manage efficiency Technical timesheet analysis	Cost is not important	Meet customer expectations Control process parameters	<u>Out of town superstore:</u> Bulk purchasing Reduce visits	Expand business Manage efficiency Minimise technician travel Market test suppliers

Now, try asking the average motorist or local resident if they need parking controls and permit issuing machines. Every time someone comes across an illegally parked vehicle that obstructs free movement or occupies space that is needed for one self, people will generally demand increased controls. However, as soon as the controls have removed the problem then people will perceive them as an anxiety raising menace. It is a difficult and often contentious area to balance for everybody. The project is about optimising the net value to the community overall, by kind of optimally compromising all of the individual needs. Value here is defined as 'function over time plus cost'. Many other re-designs of service systems are first and foremost motivated by a business need for cost savings or following a re-structuring (also for cost saving). Any service design aims of course to satisfy customer requirements, but it is often a case of fitting these requirements in with the necessary business cost pressures. It can sometimes feel as if the benefits to customers from such reviews are mainly economic and not necessarily about enhancing quality. For example, we do not always like being 'forced' to have to deal with our bank through what can feel like an 'impenetrable wall' at the telephone call centre. On the other hand, our bank could not possible keep its customers and survive in business if it was to pass on the cost from maintaining a personal walk-in service in many more local branch locations instead. We are frequently selfish as service customers. We recognise the business needs and agree with the minimised service-cost level being offered. That is until we are suddenly confronted with the constraints in practice. We consider our service need as a special case and we want it to be treated as such – even if it is at the expense of the provider or if fellow service receivers are being disadvantaged because of us.

Our project tapped into a recent community survey, where 3,600 respondents had helped define service priorities. Complaints records further identified current dissatisfiers. The standard translation table helped convert the customer input requirements into service design requirements, which are written as a list of some 86 service process components. Many of the design requirements in our translation table are identical statements, repeated in response to several of the customer requirements.

The Phase 1 selection and detailing stages are concerned with brining the excessive list of 86 design requirements down to a more manageable number for our next phase HoQ. We achieved this by consolidating the repeated statements into a final number of just 26 design requirements. As we will see later in the Phase 2 HoQ, this broadening of the meaning of the consolidated design requirements will have a side-effect of creating many-to-many relationships in the HoQ. However, the decrease in resolution is a justifiable and appropriate compromise to make. It makes the HoQ matrix manageable in its purpose of providing visualisation. The rationale for grouping the 26 design requirements under plan-do-check-act headings is simply that during the project scoping phase it was perceived that the client management is focused on the PDCA cycle of continuous improvement. It became a means to demonstrate that we have addressed its principles and, thereby, assuring the sponsor's on-going buy-in.



PHASE 2: SERVICE COMPONENTS DEVELOPMENT

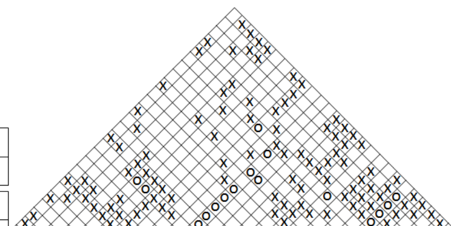
We start with an objective evaluation in the HoQ, on how design requirements relate to the customer requirements from the VOC.

Parking equipment maintenance

QFD Phase 2 plan

x = positive correlation
o = negative correlation

Ideal target direction
S=smaller T=Target L=Larger



	Customer requirements \ Design requirements	Importance	Plan: Qualify standards	Plan: Specify tasks	Plan: Quantify intervals	Plan: Receive resources	Plan: Inspect resources	Plan: Prepare resources	Plan: Organise resources	Plan: Plan tasks	Do: Invite reports	Do: Receive requests	Do: React and work fast	Do: Complete to specification	Do: Record inputs	Do: Record activities	Do: Record outcomes	Do: Retrieve machine data	Do: Report to customer	Check: Inspect and test	Check: Retrieve stored records	Check: Receive technician feedback	Check: Receive complaints	Check: Analyse reports/records	Act: Review standards	Act: Review intervals	Act: Review resources	Act: Follow-up on actions	Context weights: Own service	Context weights: Competition A	Context weights: Competition B	Context weights: Growth in demand	Context weights: Selling point	Context weights: Society importance	Weighted importance
	Ideal target direction		L	T	T	L	L	L	L	L	L	T	L	T	L	L	L	L	L	L	L	L	S	L	L	L	L	L							
Reliability	No machine break down	10	1				9	3	3	3				9											9	9		3	4	4	4	2	5	2	17
	Coins not rejected	6	3	9	9					1	9		9	9						9					3	9		3	2	3	2	2	5	1	10
	No ticket jam	10	1	3	3	9	9	1	1	1			9	9						3					3	1	9	1	3	3	3	2	5	1	15
	Ticket is legible	7	9	3	3	9	3	1	3	1	9		1	9				3		9					1	3	3	3	4	4	3	2	4	1	11
Appearance	Conditions easy to read	5	9				1	1		1				3						3		1	3		3	3			2	2	3	2	3	1	8
	Machine is clean	4	3	9	9					1	1	3		9						3					1	9	1	1	2	4	3	2	4	2	8
Safety	Safe to use	10	9	9	3		9	1	1	3	9		9	9		3	1			9		1	1		1	1			5	5	5	2	2	3	15
Response	Assistance easy contactable	9				1			9		9	9			1								9				9		1	4	4	5	5	1	23
	Quick response	8	3			3		3	9	3	9	1	9		1					1							9		4	5	3	4	5	1	16
	Effective repair	8	9	9		1	9	1	9	1			9	9					9	9		3	3		3		3	1	4	4	3	2	4	1	11
Evidence	Performance report	4	3		9								1		9	9	9			3	9	1	9	9			3		4	4	2	3	2	1	5
	Historical status evidence	8			1						1	3	3		9	9	9	9	1	3	9			9					3	5	2	3	3	1	14
Cost	Cost effectiveness	3	1	1	9	9	1		9	3										1						3	9		4	3	3	2	5	1	5
	Objective or tentative targets		Safety, workmanship, resources, cleanliness	All aspects affecting quality to customer	Inspection interval, and maintenance intervals	Technicians, spare parts, ticket stock	Test for acceptance against specification	Training, motivation, store, preserve	Technician work roster, technician carry stock	Minimise travel, flexibility, contingency	Publish contact details on machines and to security	From public, fine processing, revenue controller	<1hr fault response, <25 machine work time	100% accurate to task specification / standard	When, what, where, who	When, what, who, spare parts used	Test result, if/when revisit required	Full data upload to database on every visit	Within 24 hours, friendly manner	100% accurate to test specification	Computerised database reports	Record improvement opportunities, knowledge-base	Who, where, what, how	Monthly, inputs, activities, outcomes, complaints	Safety, work, resources, cleanliness, notices	Inspection interval, maintenance interval	Technicians, spare parts use, ticket stock level	Change methods, issue technical bulletins							
	Weighted score		559	479	389	361	568	159	609	222	769	289	661	807	210	216	186	159	113	594	171	61	324	171	319	417	620	148							
	Design importance (%)		6	5	4	4	6	2	6	2	8	3	7	8	2	2	2	2	1	6	2	1	3	2	3	4	6	2							

"Objective and tentative targets" are defined for the design requirements. The context weights are defined in consultation with client management. The "Design importance (%)" value is calculated by using the weighted importance. As mentioned under the VOC section, the many-to-many relationships have the effect of somewhat levelling the design importance values; meaning that our transfer does not reveal anything as outstandingly important or unimportant at this stage. The importance value range is still satisfactorily differentiated on a scale of 1 to 8. The QFD team is in consensus that based on its members' prior operational experiences the HoQ elements and its outputs make sense.

In renaming the design requirements into 'service components', they can now be structured into a logical process flow. The first stage is to find and develop ideas about what process options could possibly be developed, in order to deliver these service components. The diverse responses must consider the priorities derived through the "Design importance (%)" values from the HoQ matrix, which were weighed for closing the benchmarking gaps. For example, the development identified 3 optional methods for gathering, storing and analysing pay & display machine data:

a) Collect records manually (machine prints on paper) and store on paper.
b) Collect manually and transfer manually to computer database.
c) Collect and transfer electronically.

In the pre-existing system, option a), the service technicians were printing a machine audit, containing usage data, status and event log, on every occasion they attended to a machine. The paper trail was filed in date order for future reference. Whenever a historical event needed investigating, which is a common daily request, a person would manually search through and analyse the paper trail. Often the small receipt-type prints were misfiled, or forwarded to someone for review and never returned. The loss of information was considerable. On occasions, a machine is accidentally damaged or vandalised to an extent were data will inevitably be lost. However, most data loss in fact relates to process complexity and poor handling. The obvious solution is to invest in new portable data equipment for retrieving and storing the electronic data fast and securely. Such process equipment decision, however, needs evidence to support the client management in committing to the investment expenditure. The analysis, also factoring in the equipment costs, shows that the electronic solution, option 3, is significantly more cost effective and reduces data loss.

Process option 1

#	Task	Method	Time (min,s)	Cost (t,equip)	Data loss,err
10	Retrieve data (x50 events)	Manuel	29'10"	£14.58	2%
20	Record data (x50 events)	Paper	116'40"	£58.33	0.5%
30	File data	Manual	4'00"	£2.00	2%
40	Retrieve stored data	Manual	36'30"	£18.25	5%
50	Analyse data	Manual	120'00"	£60.00	2%
		Total	317'20"	£153.17	11.0%

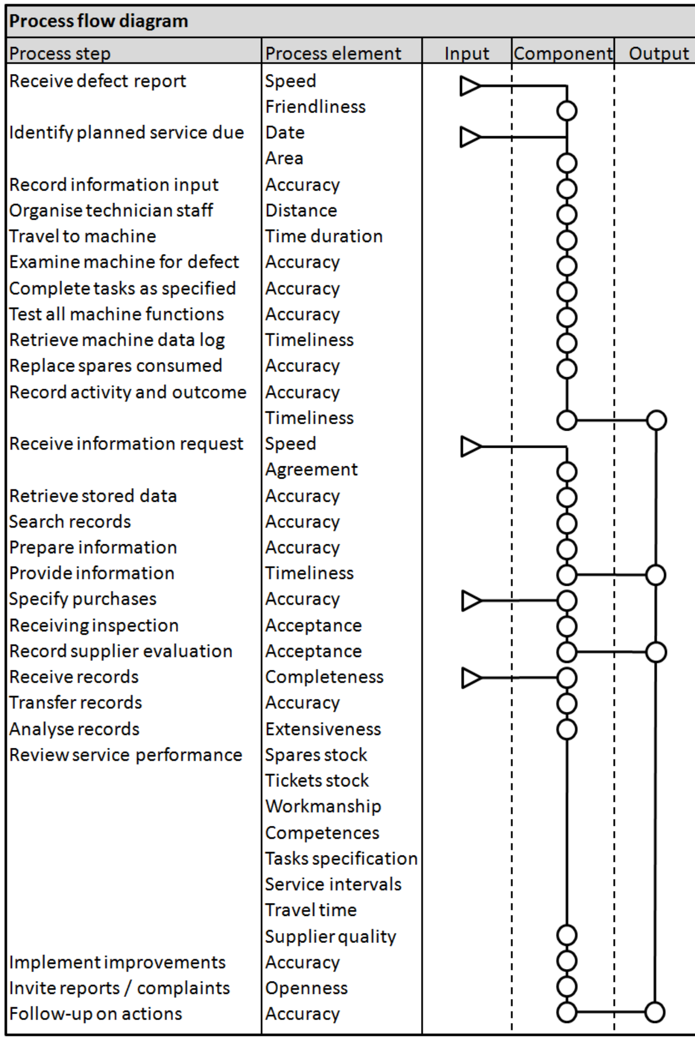
Process option 2

#	Task	Method	Time (min,s)	Cost (t,equip)	Data loss,err
10	Retrieve data (x50 events)	Manuel	29'10"	£14.58	2%
20	Record data (x50 events)	Manual	116'40"	£58.33	0.5%
30	Transfer data to database	Manual	15'00"	£7.50	2%
40	Retrieve stored data	Electronic	0'20"	£0.23	0%
50	Analyse data	Electronic	15'00"	£10.13	0%
		Total	176'10"	£90.77	4.2%

Process option 3

#	Task	Method	Time (min,s)	Cost (t,equip)	Data loss,err
10	Upload data (x50 events)	Electronic	10'00"	£6.75	1%
20	Transfer data to database	Electronic	12'40"	£8.56	0%
30	Retrieve stored data	Electronic	0'20"	£0.23	0%
40	Analyse data	Electronic	15'00"	£10.13	0%
		Total	38'00"	£25.67	1.0%

During an around-the-table group session, the QFD team now meshes together and structures the selected service process. For example, the "Process flow diagram" incorporates the selected Process option 3 for data handling.



PHASE 3: DELIVERY PROCESS DEVELOPMENT

The QFD Phase 3 HoQ (spread over the next 2 pages) derives the "Technical importance (%)" values for the various service process elements. This helps prioritising the development of appropriate resources, information systems and infrastructure required to effectively perform and support the new service process.

Parking equipment maintenance

Service QFD Phase 3 plan

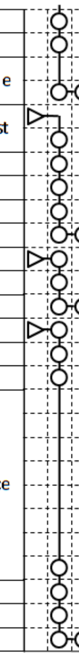
Service output / Component / Input

Service process and parameters

Design requirements (service components)

	Component	Objective or tentative targets	Importance	Receive defect report: Speed	Receive defect report: Friendliness	Identify planned service need: Date	Identify planned service need: Area	Record information input: Accuracy	Organise technician staff: Distance	Travel to machine: Time duration	Examine machine for defect: Accuracy	Complete tasks as specified: Accuracy	Test all machine functions: Accuracy
Plan	Qualify standards	Safety, workmanship, resources, cleanliness	6	9	3			1	1	3	9		9
Plan	Specify tasks	All aspects affecting quality to customer	5									9	9
Plan	Quantify intervals	Inspection interval, maintenance intervals	4			9							
Plan	Receive resources	Technicians, spare parts, ticket stock	4						9				
Plan	Inspect resources	Test for acceptance against specification	6								3		
Plan	Prepare resources	Training, motivation, store, preserve	2						9				
Plan	Organise resources	Technician work roster, technician carry stock	6						9				
Plan	Plan tasks	Minimise travel, flexibility, contingency	2			9	9	1	9	3	3	3	3
Do	Invite reports	Publish contact details on machines and to security	8	3	1						3		
Do	Receive requests	From public, fine processing, revenue controller	3										
Do	React and work fast	<1hr fault response, <25 machine work time	7	9					9	9			
Do	Complete specification	100% accurate to task specification	8								1	9	9
Do	Record inputs	When, what, where, who	2					9					
Do	Record activities	When, what, who spare pats used	2										
Do	Record outcomes	Test result, if/when revisit is required	2										
Do	Retrieve machine data	Full data upload to database on every visit	2										
Do	Report to customer	Within 24 hours, friendly manner	1	3	9								
Check	Inspect and test	100% accurate to test specification	6								9		9
Check	Retrieve stored records	Computerised database reports	2										
Check	Receive technician feedbac	Record improvement opportunities, knowledge-base	1										
Check	Receive complaints	Who, where, what, how	3	9	9								
Check	Analyse reports/record	Monthly, inputs, activities, outcomes, complaints	2					9	1				
Act	Review standards	Safety, work, resources, cleanliness, notices	3						1				1
Act	Review intervals	Inspection intervals, maintenance intervals	4			9			1				
Act	Review resources	Technicians, spare parts use, ticket stock level	6						3				
Act	Follow-up on actions	Change in methods, technical bulletins	2										
	Process capability (current Y/N)			Y	N	Y	Y	Y	Y	Y	Y	Y	Y
	Critical process parameter values			<7 rings	<0.5% complaints	to plan +/-10 days	Close proximity	When, what, where, who	Minimise travel	<10 min average	100% identified, resolved	100% to specification	100% to specification
	Weighted score			303	111	108	18	47	329	159	218	159	307
	Technical importance (%)			4	1	1	0	1	4	2	3	2	4

3	266	Full data set	N					9						9				3	9			1					3	9		Timeliness	Retrieve machine data log
3	194	100% of what consumed	Y		3													1					9	9		9		3		Accuracy	Replace spares consumed
4	333	Every spare part and test	Y	9	9	9	9	9		1					9	9						1	3		1	1		9		Accuracy	Record activity and outcome
3	245	Within 1 hour of job	Y					1							9	9			9										9	Timeliness	
3	225	<7 rings	Y										3						9	3									9	Speed	Receive information request
2	120	<5% client follow-up	Y										3				9			9		3						9		Agreement	
2	122	100% correct date, time, machine	N								9			9				1		3							9	9		Accuracy	Retrieve stored data
1	50	100% of available records	Y								1							1		3		1					1	3		Accuracy	Search records
1	41	100% correct transfer	Y																	3									3	Accuracy	Prepare information
3	213	Within 24 hours	Y										9	3					9	9									3	Timeliness	Provide information
2	167	Quantity, standard, type, grade	Y	1														1					3		1	9			9	Accuracy	Specify purchases
5	386	Ensure >95% confidence	Y		3		9					9						1						1	9	9		9	9	Acceptance	Receiving inspection
3	234	Ensure >95% confidence	Y	3	3			9											3		1				9	9		3		Acceptance	Record supplier evaluation
3	215	<1% loss	Y					9		9				9	9	9	9			3	3						1	9	1	Completeness	Receive records
2	123	99.5% correct	Y					9						9	9	9	9										3	3		Accuracy	Transfer records
4	307	>90% relevant available records	Y					9		3	9	1		1	9	9	9	1	1								9	9	9	Extensiveness	Analyse records
3	206	Min / max levels	Y	3	9					3													1	1	1	9	9			Spares stock	Review service performance
3	205	Min / max levels	Y	3	9									1									1	1	1	9	9			Ticket stock	
2	159	Satisfy legal and customer req.	Y	3			9			3								3											9	Workmanship	
2	183	Technicians fully competent	Y	3			9			3									3							3			9	Competencies	
3	212	Meet ISO 9001 requirements	Y	3			9			3								9									1	9	1	Task specification	
2	138	Set 30, 60, 90-day schedule?	Y	3		9				3				9					1				1				9			Service intervals	
3	193	Minimise	Y	3	3		1			9									9									3		Travel time	
4	305	Re-use / negotiate / find other?	Y	3	9					3									1					1	9	9			9	Supplier quality	
8	598	100% compliant to action plan	Y	9	9	9	9											3	9			9	3	3	1	9	3	9	9	Accuracy	Implement improvements
3	267	Publish tel.no / email on machine	Y	1					9	1		1	3				3				9	1							9	Openness	Invite reports/ complaints
3	238	Confirms planned actions	Y	9	1	1	1	1	1	9			1					3	3		3	3				1	3	3	3	Accuracy	Follow-up on actions
		Political		2	3	1	3	1	5	4	1	2	4	1	2	2	1	3	5	3	4	1	2	1	2	1	1	1	3	Municipal strategy context	
		Economical		1	3	3	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	3	2	4	4	1	1		
		Social		1	2	2	2	1	5	1	1	2	4	1	1	2	1	2	3	3	3	1	1	1	1	1	1	1	2		
		Technilogical		1	1	1	1	2	1	1	3	1	1	3	1	1	1	1	2	1	1	1	1	2	1	1	1	2	2		
		Weighted importance		2	10	5	4	2	6	1	2	7	2	2	2	2	2	11	14	4	12	2	7	3	7	5	5	6	9		



The “Municipal strategy context” reflects an obligatory organisational policy rule, where all its public projects must consider the wider impact through what is known as a ‘PEST’ analysis. The impact of requirements is assessed in respect of:

- Political views of the organisation.
- Economic situation and aims.
- Social needs and the influence on these.
- Technological, including impact on modernisation.

The PEST scores are not actually linked or used in calculating the output “Technical importance (%)” in this project, but are simply contained in the ‘how context’ section for visualisation and consideration. This way for integrating the particular analysis makes best sense to the project team in this particular situation. It enables the team confirming whether the phase output is also in agreement with the organisational policy adjusted requirements – i.e. judged appropriate for also satisfying the PEST weighted importance.

The next stage is concerned with a creative exercise where a number of possible optional system elements are identified, in order to increase the chance of defining a best delivery system for the process. This stage requires good understanding of the type of processes involved. Employee behaviour and attitude is a major component in the service. We have therefore included technician attributes in our evaluation. The emerging optional system elements are evaluated against the related process importance values, to enable the selection of one best initial system. The initial system is unlikely to be an optimum design yet. It will need further refining in a ‘detail’ stage.

The final detailed set of system elements, including their critical parameters and target values is shown on the next page. The elements are sufficiently developed to enable us clearly identifying what is required for delivering the service product.

	System element	Parameter	Critical value
Comms	Office telephone	Telephone number	Easy to memorise
		Permanent answer	Re-direct to technician out-of-hours
	Mobile telephones	Signal cover	Full coverage in all service areas
		Assurance of contact	Missed call indicator, Voice mail
Information Technology	Computer	Specification	Basic PC, >20Gb storage
		Networking	LAN, Internet access
	Software	Database	Relational, Office suit integrated
		Spreadsheet	Office suit integrated
		Document writer	Office suit integrated
		email	99% ISP auptime during day
	Data	Machine inventory	ID, spec, location, service interval
		Service history	Date, time, what, who, outcome
		Machine data / fault log	Full data set, store min 2 years
		Spares/tickets inventory	ID, quantity / inspection status
		Equipment/tool inventory	ID, spec, location, calibration status
		Suppliers evaluations	Date, whoe, what, action
		Technicians timesheets	Date, time, task, total daily distance
		Technicians competencies	Date, training/competency attained
		Complaints and feedback	Date, who to who, what, action
Tools	Electrical installation	Measurement functions	Earth loop, insulation leak, trends
		Calibration	BS7671
	Portable computer	Data memory capacity	1Gb
Technician transport		External size	Passenger car footprint (for town)
		Loading capacity	500kg, 1.2m height
Building	Workshop and store	Location	Central to town in travel time
		Space	Minimum 90 m^2
		Parking	4 parking bays
		Security	Full alarm, linked to security
Technician	Skills	Qualification	HND in electronics or equivalent
		Communication skill	Friendly, diplomatic, effective
		Driving licence	No dangerous driving history
	Knowledge	Town layout	<20% use of navigation tools
		Machine specification	In-depth understanding
		Tasks specification (SOP)	Able to interpret procedures (SOP)
	Experience	Equipment servicing	>12 months
		Customer contact	>6 months
	Personal qualities	Friendly	<0.1% complaints
		Methodical	0% procedural deviation
		Accurate	Make 100% correct records
		Honest (handle money)	No criminal theft history

PHASE 4: SERVICE DELIVERY PLANNING

The QFD Phase 4 HoQ (spread over the next 2 pages) derives the "Technical importance (%)" values for the service delivery system elements. This aids prioritising the development of devices and controls required for an effectively implemented operation.

Parking equipment maintenance Service QFD Phase 4 plan Service process				Comms				Information Technology														
Delivery system and parameters				Office telephone		Mobile telephones		Computer		Software				Data								
Process step	Critical parameter	Targets	Importance	Telephone number	Permanent answer	Signal cover	Assurance of contact	Specification	Networking	Database	Spreadsheet	Document writer	email	Machine inventory	Service history	Machine data / fault log	Spares/tickets inventory	Equipment/tool inventory	Supplier evaluations	Technicians timesheets	Technicians competencies	Complaints and feedback
Receive defect report	Speed	<7 rings	4		9		3		9				9									
	Friendliness	<0.5% complaints	1	1		9		1		3												9
Identify planned service need	Date	to plan +/-10 days	1					3		9				9	9							
	Area	Close proximity	0							9				9								
Record information input	Accuracy	When, what, where, who	1							9												9
Organise technician staff	Distance	Minimise travel	4							1				9						3	3	
Travel to machine	Time duration	<10 min average	2																			
Examine machine for defect	Accuracy	100% identified, resolved	3													9					1	9
Complete task as specified	Accuracy	100% to specification	2																		1	
Test all machine functions	Accuracy	100% to specification	4											9	1			1			1	
Retrieve machine data log	Timeliness	Full data set	3													1					1	
Replace spares consumed	Accuracy	100% of what consumed	3							1							9		3	9		
Record activity and outcome	Accuracy	Every spare part and test	4		3	3				1												
	Timeliness	Within 1 hour of job	3		9	9			9				9		9				9	9		9
Receive information input	Speed	<7 rings	3		9		9		9				9									
	Agreement	<5% client follow-up	2										9		3	3				3	3	9
Retrieve stored data	Accuracy	100% correct date, time, machine	2							9				3	3	3		1	1	3	3	9
Search records	Accuracy	100% of available records	1							9				9	9	9		3	3	9	3	9
Prepare information	Accuracy	100% correct transfer	1								3	9										
Provide information	Timeliness	Within 24 hours	3		9				9				9									3
Specify purchases	Accuracy	Quantity, standard, type, grade	2									9		1			9	3	9			
Receiving inspection	Acceptance	Ensure >95% confidence	5														9		9		1	
Record supplier evaluation	Acceptance	Ensure >95% confidence	3							9							3	9				9
Receive records	Completeness	<1% loss	3													3			1	9	1	9
Transfer records	Accuracy	99.5% correct	2							9				3	9	9	9	3	9	9	1	1
Analyse records	Extensiveness	>90% relevant available records	4							9	9			9	9	9	9	9	9	9	9	9
Review service performance	Spares stock	Min / max levels	3											1			1					
	Ticket stock	Min / max levels	3											1			1					
	Workmanship	Satisfy legal and customer req.	2											3	1	3						3
	Competencies	Technician fully competent	2													3					3	3
	Task specification	Meet ISO 9001 standard	3																			3
	Service intervals	Set 30, 60, 90-day schedule	2											3			1					3
	Travel time	Minimise	3																	3		
	Supplier quality	Re-use / negotiate / find other?	4												1	3	1		9			3
Implement improvements	Accuracy	100% compliant to action plan	8																			
Invite reports / complaints	Openness	Publish tel.no / email on machines	3	9	9	9	9		9				9									
Follow-up on actions	Accuracy	Confirms planned actions	3											1	1	1	1	1	3	3	1	1
Critical parameter values				Easy to memorise	Re-direct to technician out-of-hours	Full coverage in all service areas	Missed call indicator, Voice mail	Basic PC, >20Gb storage	LAN, Internet access	Relational, Office suit integrated	Office suit integrated	Office suit integrated	99% ISP auptime during day	ID, spec, location, service interval	Date, time, what, who, outcome	Full data set, store min 2 years	ID, quantity / inspection status	ID, spec, location, calibration status	Date, whoe, what, action	Date, time, task, total daily distance	Date, training/competency attained	Date, who to who, what, action
Score				28	156	75	66	4	144	140	39	27	162	161	124	141	168	87	206	186	94	260
Technical importance (%)				1	3	2	1	0	3	3	1	1	3	3	3	3	3	2	4	4	2	5
Service system planning requirements	Qualify capability				Y		Y			Y												
	Test capability					Y							Y									Y
	Preventative maintenance								Y	Y			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Protect against deterioration				Y				Y					Y	Y	Y	Y	Y	Y	Y	Y	Y
	Measure performance																		Y	Y		Y
	Records control													Y	Y	Y	Y	Y	Y	Y	Y	Y
	Training and/or re-training									Y	Y	Y	Y									
	Health & safety control																					
	Environmental mgt.control																					

Tools					Building				Technician												Operational evaluation 1=low 3=high				Service process planning requirements													
Electrical installation		Portable computer	Technician transport		Workshop and store				Skills				Knowledge		Experience		Personal qualities																					
Measurement functions	Calibration	Data memory capacity	External size	Loading capacity	Location	Space	Parking	Security	Qualification	Communication skill	Driving licence	Town layout	Machine specification	Tasks specification (SOP)	Equipment servicing	Customer contact	Friendly	Methodical	Accurate	Honest (handle money)	Defect likelihood	Defect severity	Ease of detecting	Score	Documented procedure	Quality standard, workmanship etc	Inspection and testing	Handling and storage control	Measure performance	Input to Management Review	Mistake-proofing	Recorded approval (sign-off)	Records control	Training and/or re-training	Attention to Technician motivation	Health & safety control	Environmental management control	Special attention
														9		3	1	1	3		2	1	2	16		Y	Y		Y									
										9			1	3		9		9	9		1	2	3	6					Y						Y			
													9	9	3			9			1	2	1	2	Y													
												3									2	2	1	0														
															1			9	9		1	1	1	1									Y					
			1		9		1		3		9	9		3	1			9	1		2	2	2	32		Y			Y	Y		Y						
			9		1		1				9	9						1	3		2	1	1	4		Y											Y	
1									9				9	9	9						2	2	2	24	Y	Y					Y			Y		Y		
	3								9				1	9	3					9	1	2	2	8	Y									Y				
9	9								9				9	9	3			9	1		1	1	3	12	Y	Y					Y			Y		Y		
		9												9	1						1	2	1	6	Y								Y					
				9	9	9		1						3				9	3		1	2	1	6	Y								Y					
		9												1					9	3	1	1	1	4									Y					
																		9	9		1	1	2	6		Y												
														9		3	1	1	3		2	1	2	12		Y	Y		Y									
						1				9			9		1	9	9	9	9	1	2	1	1	4					Y				Y					
	1														1			3	1		1	2	2	8	Y	Y								Y				
									3					9	3			9	9	1	1	2	2	4		Y								Y				
										9						1		1	9	1	1	2	1	2	Y							Y						
										9						9	9			1	2	1	1	6									Y					
	3									1	3			1				9	9		1	2	1	4	Y							Y	Y					
1									3				9	9	1			9	9	1	2	2	2	40	Y	Y	Y	Y	Y	Y		Y	Y	Y		Y		
										1				1				1	3	1	2	1	1	6	Y								Y					
	3	9																			1	1	2	6	Y								Y					
																		1	9		2	2	2	16	Y		Y					Y	Y	Y				
									9			9	9	9	9	3		9	9	1	2	1	1	8									Y					
									1				9		9			9	9		1	2	1	6				Y					Y					
													1		9			3	1		1	3	1	9				Y					Y					
	9								9				9	9	9	9		9	3		1	3	2	12		Y				Y			Y			Y	Y	
														9	9	9		3	1		3	2	2	24		Y							Y	Y	Y			
									9					9				3	9		1	1	2	6		Y	Y						Y					
													9		9			1	3		1	1	2	4									Y					
					1	9						9						9	1		1	2	2	12		Y							Y				Y	
									1				9		3			1	3	1	2	3	1	24		Y		Y	Y	Y			Y			Y		
									3	3				1				9	9	1	2	2	2	64			Y			Y		Y	Y	Y	Y	Y		
										3						9	3		1	9	1	1	1	3		Y												
3													1	9	1			1	9	3	2	1	1	6			Y			Y			Y					
Earth loop, insulation leak, trends	BS7671	1Gb	Passenger car footprint (for town)	500kg, 1.2m height	Central to town in travel time	Minimum 90 m²	4 parking bays	Full alarm, linked to security	HND in electronics or equivalent	Friendly, diplomatic, effective	No dangerous driving history	<20% use of navigation tools	In-depth understanding	Able to interpret procedures (SOP)	>12 months	>6 months	<0.1% complaints	0% procedural deviation	Make 100% correct records	No criminal theft history																		
53	77	90	22	27	68	56	6	3	223	101	60	117	279	401	227	151	61	522	477	97																		
1	2	2	0	1	1	1	0	0	5	2	1	2	6	8	5	3	1	11	10	2																		
Y									Y		Y	Y	Y	Y	Y	Y		Y	Y																			
	Y								Y	Y		Y		Y	Y		Y	Y	Y	Y																		
		Y																																				
													Y	Y				Y	Y																			
									Y					Y	Y			Y	Y																			
	Y	Y											Y	Y				Y	Y	Y																		
		Y							Y	Y			Y	Y	Y	Y		Y	Y																			
	Y										Y		Y	Y																								
												Y																										

The next activity is about creatively researching the planning space, for both the process and for its delivery system. Industry related operating standards, ISO 9001 and Lean principles are sensible sources. The planning elements are defined as devices and controls required for an effectively implemented service operation. We add 13 identified "Service process planning requirements" to the right of the HoQ matrix, and 9 appropriate "Service system planning requirements" below the HoQ matrix. At this 'generate' stage, the added sections are initially established as empty checkboxes. For now, it is merely about identifying them.

In collectively reviewing the "Operational evaluation" risk scores, the QFD team then selects and marks the appropriate planning elements in the 13-column checkbox for "Service process planning requirements". The decisions consider carefully whether the device or control is really necessary, based on the risk score, or whether it could add more burden than benefits.

In collectively reviewing the service elements "Technical importance (%)" the QFD team selects and marks the appropriate planning elements in the 9-row checkbox for "Service system planning requirements".

The final HoQ, expanded with the 2 planning sections, specifies the total service system plan for being put into practice. It may be practical, for communicating the plan to people who were not directly involved in the QFD process, to shorthand the planning matrices for easier reading. The process and system owners will now break down the planning requirement into more detailed actions within their respective areas. This ends the QFD project.

PROJECT OUTCOME

The organisation had the year before the QFD project performed an expert assisted self-assessment to the EFQM Business

Excellence Model (BEM). It is possible to isolate the scores for equipment servicing and its related functions. When repeating the same self-assessment 2 months following the QFD project the scores under all 9 BEM criteria are improved. The scores range on a scale from 1 to 4. Noticeably the criterion for leadership has improved significantly. It is believed this has to do with the consensus-based involvement of all of the people affected by the project. With the re-assessment being performed such a relatively short time period after the project ending, the novelty and excitement factors would inevitably still be higher. Nonetheless, the re-assessment demonstrates the ability of QFD to produce a motivational effect.

	April 2004	August 2005
1. Leadership	1.9	3.7
2. Policy and strategy	2.0	3.3
3. People management	2.5	3.1
4. Resource management	2.3	3.4
5. Process management	2.0	3.2
6. Customer satisfaction	2.5	2.9
7. People satisfaction	2.4	3.0
8. Impact of Society	3.0	3.5
9. Business results	2.2	3.5

An independent assessment of the quality management system, by the British Standard Institute, 3 months following the QFD project, concludes that the quality system and operating procedures conform to ISO 9001. There is strong traceability in the Phase 1 translation table of both direct customer requirements and specific requirements of the ISO 9001 standard being integrated up-front into the service design. The response to these requirements is also traceably evident in the final process flow diagram and implementation plan.

The project demonstrates how the service QFD approach can be low cost, fast and effective, with employees being receptive to the changes that it brings about. The QFD team consists here of a mix of technical and non-technical people. Other than the project leader, none had prior experience with QFD. It is fair to say that the HoQ matrices are probably too busy for all of the team members to follow in detail. However, people have confidence in the outputs nonetheless and they are convinced in the validity of the overall project results.

CASE STUDY 3:
1-SHEET SHORTHAND QFD

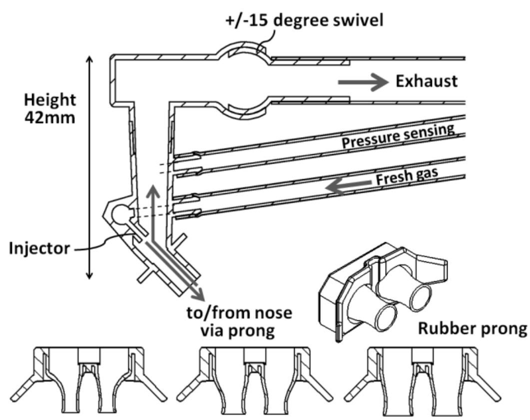
The product in this QFD case study is a nasal interface for babies receiving Continuous Positive Airway Pressure (CPAP) therapy. The project situation contrasts to the previous case studies by using a significantly shorthanded QDF approach. The choice in approach was driven by the organisational context and time constraints.

QFD lends itself well to the design of medical devices. The US Regulatory Authority (FDA), for example, specifically state for medical equipment that *"quality, safety and efficacy are designed or built into the product. Quality cannot be adequately assured merely by in-process and finished product inspection or testing"*. Medical devices require a risk-based approach to design. QFD achieves this by its seamless integration with FMEA-type tools.

PRODUCT BACKGROUND

The newborn lung is under-developed and can be lacking in surfactant (surface-tension equalising agent), which results in increased amounts of muscle work when breathing. The newborn baby can eventually tire and stop breathing all together. CPAP therapy consists of elevating the pressure in the upper airway – e.g. the nasal cavity – to about 5mbar above ambient. This significantly reduces the work-of-breathing. The weak baby can now breathe without tiring out, while it develops its lungs and becomes naturally stronger.

Hospitals use 2 types of nasal interfaces in respiratory care. The first variant, called a 'prong', is connected to a ventilator machine through 2 gas tubes, which regulates both the supply and exhaust gas flow rates. The ventilator thereby controls the gas pressure inside the nasal interface and rapidly compensates for the pressure change that occurs when the baby inflates or deflates its lungs. The second variant, called a 'flow generator', is connected to a fixed flow meter through a single gas supply tube. The flow generator incorporates a gas injector, or jet accelerator, that by a fluidic entrainment principle selectively boosts airway directed flows. This helps maintain a stable pressure when the baby breathes in and out.



Pre-existing commercial product – generator type

VOICE OF CUSTOMER

The product developer already has many years of experience from supplying 2 related products into the existing market. There is extensive knowledge and data on the application, strengths and weaknesses. The VOC in this QFD is therefore not so much concerned with collecting customer requirements, but more about clarifying them and ensuring their appropriate transfer into the design requirements.

The general technical barriers, and user anxieties, for all prior nasal interface solutions are:

a) Ineffective gas sealing, due to misalignment and poor conformance to the wide variety of nose shapes. The base of the average baby nose is about 45 degree in angle to the forehead, but this varies +/-15 degree because some noses stick up and some stick down.

b) Injury and trauma to the nose, which has been reported to occur in 20% of babies receiving nasal CPAP treatment. The cause often relates to over-tightening against the nose, due to the ineffective gas sealing.

c) Hazardously high back-pressure in excess of 140mbar in the generator fresh gas supply, compromising the internationally recognised 125mbar patient safety standard.

d) Gas jet hissing/whistling noise, as loud as 92dB at 10cm, is reported to stress the baby and hinders its natural development.

e) Condensates. The fresh gas is pre-conditioned to 37 deg.C and 100% Relative Humidity for breathing in. When the gas flows though the last 30cm of unheated tube, it cools and desaturates. The resulting water droplets can adversely enter into the patient lung and the pressure sensing tube.

f) Difficult to fit, due to the multiple floating tubes and ties effectively demanding an extra pair of hands.

g) Device dislodging or tilting on the nose. The height profile and weight distribution, with the swivel joint ‘high’ of the patient nose, are contributing factors.

1-SHEET DEPLOYMENT TABLES

Furthermore, to the already strong customer data, the organisation also has prior experience of QFD. The core QFD team members felt comfortably able in mentally approximating the translation that occurs in the HoQ, by estimating the input-output importance scores during a collective discussion session – instead of necessarily using the algorithmic matrix tool. It still remains essential to visualise the input customer requirements and their linking through the technical systems development.

The 1-sheet deployment tables provide the following benefits:

a) Clarify and maintain transparency of customer input requirements.

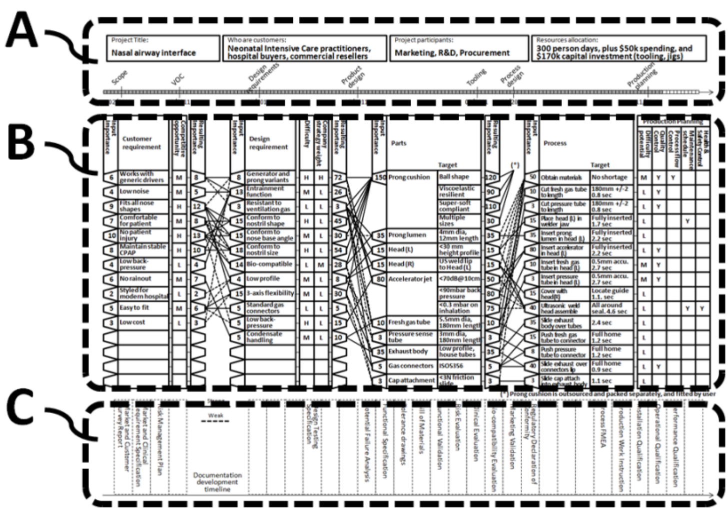
b) Transfer and maintain customer quality and innovation objectives through the stages of development.

c) Provide evidence of the requirements linking and stage verifications, as is required for regulatory third party medical device examination.

d) Provide an at-a-glance total overview on a single sheet of A3 paper. This proves easy for visualising a direct link between the original customer input requirements and any other stage in the product development – probably more so than in a more comprehensive QFD approach.

e) In relation to the product being a medical device, the 1-sheet QFD acts as a reference hub for the mandatory design dossier documentation.

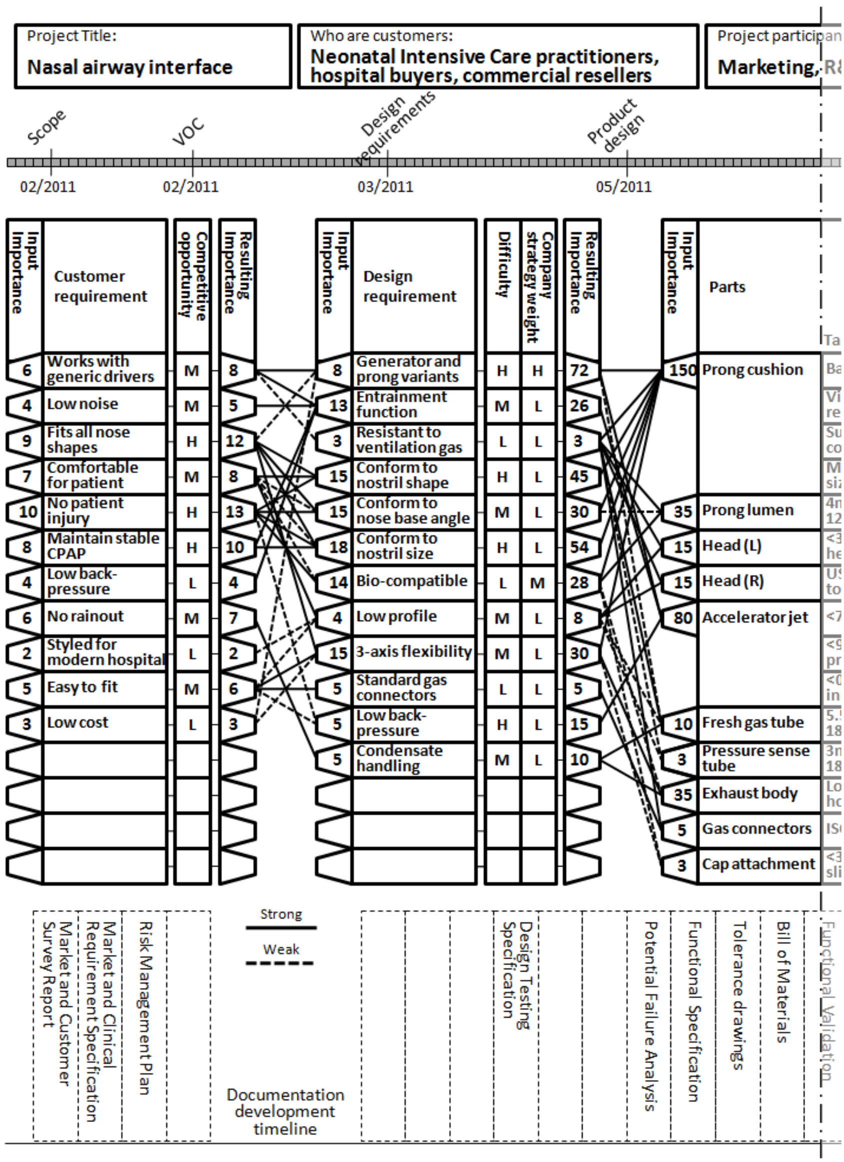
The 1-sheet QFD page has 3 sections. 'A' is a project management overview, identifying the product, customers, project participants and resources allocation. A colour-changing milestone time line indicates progress versus plan. Section ‘B’ is the deployment tables, with customer input requirements flowing in on the left-hand side and a production implementation plan flowing out on the right-hand side. Section ‘C’ is a reference to project related documents. The references are arranged on an approximate time line, which indicates the stage at which they are produced.

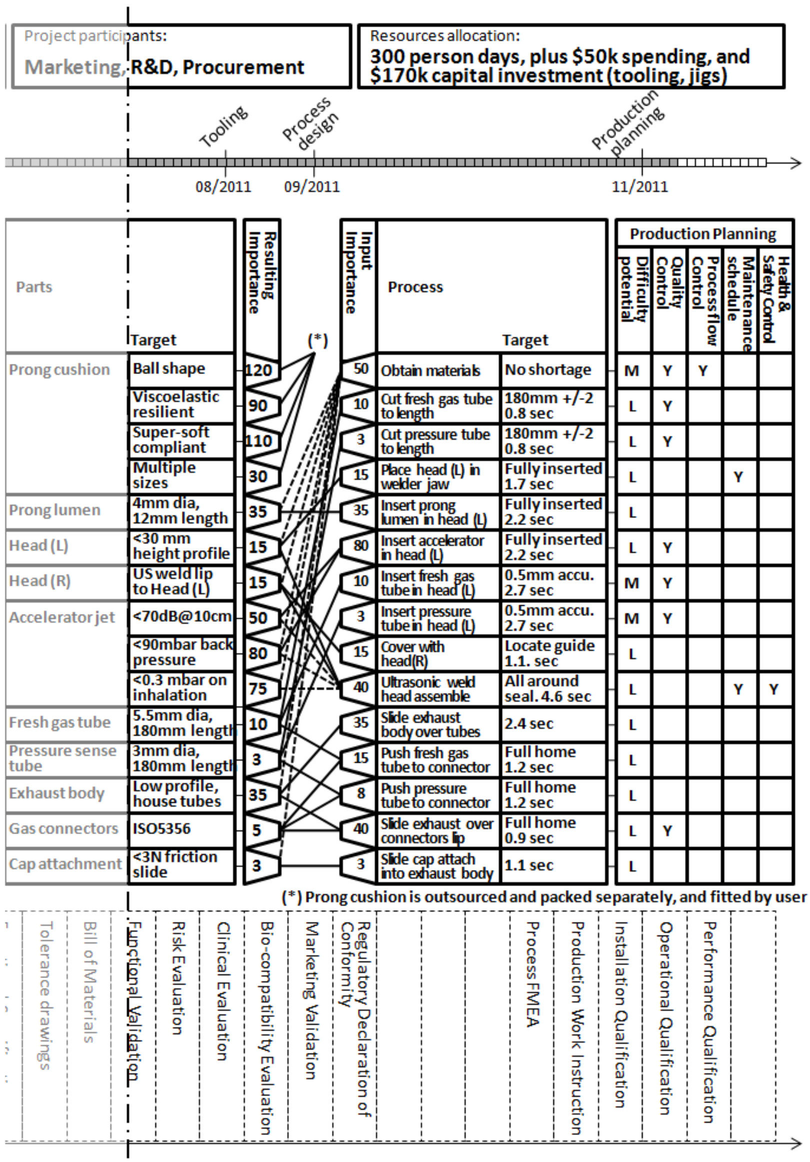


The QFD takes place in section ‘B’ (an enlarged table is shown across the next 2-page spread). Customer requirements are in the first instance weighted for their “Competitive opportunity”, where L = Low, M = Medium, H = High. The competitive opportunity is a statement on how we want our new product to perform in benchmarking against competing products, where low (L) means that we are not looking to further exploit the particular customer requirement as an opportunity – because either we are already doing well here or the particular requirement is relatively unimportant in a competition sense. This is not the same as saying that we want our product to benchmark lower than our competitors. If our existing solution is benchmarking relatively lowly then we would want to do something about it and rate the competitive opportunity higher – because of the need to improve our competitiveness. We are using a relatively modest addition here. This is to avoid excessively distorting customer requirements. The “Resulting importance”, to take forward, is produced by adding 0 to the customer “Input importance” for a low (L) score, 2 for a medium (M) score and 3 for a high (H) score.

The transfer of importance values between the stages is performed by a simple line drawing, representing ‘strong’ or ‘weak’ relationships. The input importance into the design requirements are arrived at in a consensus-based team discussion, considering the various strong and weak relationships to customer requirements. Here the team looks at how many strong and weak lines, including their root importance that comes into a design requirement. From this it judges a representative input importance score. The multiple lines can look a little busy; but the scoring is actually quick and easy when performed just after the lines are drawn, while their rationale remains fresh in the team memory. It is of course helpful when team members have prior experience with the HoQ and can mentally visualise what would have occurred in an equivalent algorithmic matrix.

In the design requirements stage we weigh the input importance by “Difficulty” and “Company strategy”. Again, we use the scores L, M or H. The resulting importance, this time, is derived by multiplying the input importance by both the difficulty and the strategy weights, where L = 1, M = 2 and H = 3. For example, the resulting score for the requirement that our design can perform as both “Generator and prong variants” becomes 8 x 3 x 3 =72. The resulting importance facilitates planning – i.e. resource and time allocation – for the product design development, which now takes place in between the second and third table (see project timeline). The designers and engineers will refer back to the original customer input importance when assessing and selecting their technical solutions.

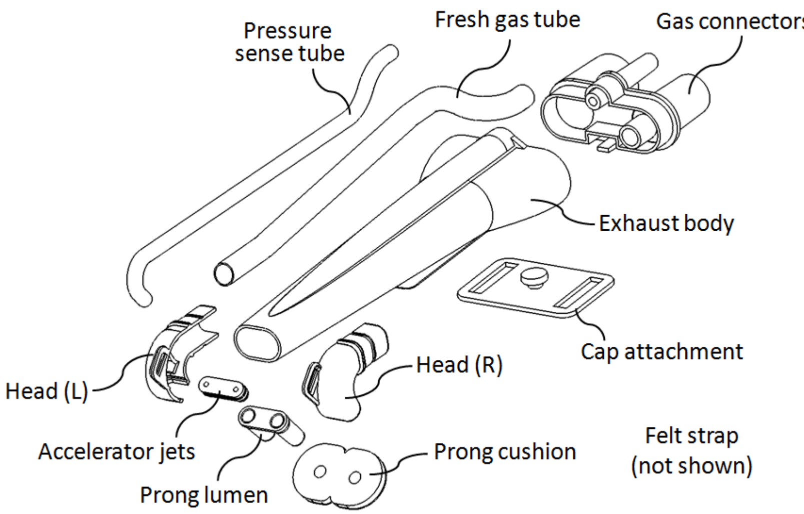

Project Title:
Nasal airway interface
Who are customers:
Neonatal Intensive Care practitioners, hospital buyers, commercial resellers
Project participan
Marketing,
Scope
VOC
Design requirements
Product design
02/2011
02/2011
03/2011
05/2011
Input Importance
Customer requirement
Competitive opportunity
Resulting Importance
Works with generic drivers
Low noise
Fits all nose shapes
Comfortable for patient
No patient injury
Maintain stable CPAP
Low back-pressure
No rainout
Styled for modern hospital
Easy to fit
Low cost
Design requirement
Difficulty
Company strategy weight
Generator and prong variants
Entrainment function
Resistant to ventilation gas
Conform to nostril shape
Conform to nose base angle
Conform to nostril size
Bio-compatible
Low profile
3-axis flexibility
Standard gas connectors
Low back-pressure
Condensate handling
Parts
Prong cushion
Prong lumen
Head (L)
Head (R)
Accelerator jet
Fresh gas tube
Pressure sense tube
Exhaust body
Gas connectors
Cap attachment
Strong
Weak
Market and Customer Survey Report
Market and Clinical Requirement Specification
Risk Management Plan
Documentation development timeline
Design Testing Specification
Potential Failure Analysis
Functional Specification
Tolerance drawings
Bill of Materials
Functional Validation



Parts	Target	Resulting Importance
Prong cushion	Ball shape	120
	Viscoelastic resilient	90
	Super-soft compliant	110
	Multiple sizes	30
Prong lumen	4mm dia, 12mm length	35
Head (L)	<30 mm height profile	15
Head (R)	US weld lip to Head (L)	15
Accelerator jet	<70dB@10cm	50
	<90mbar back pressure	80
	<0.3 mbar on inhalation	75
Fresh gas tube	5.5mm dia, 180mm length	10
Pressure sense tube	3mm dia, 180mm length	3
Exhaust body	Low profile, house tubes	35
Gas connectors	ISO5356	5
Cap attachment	<3N friction slide	3

Input Importance	Process	Target	Production Planning: Difficulty potential	Quality Control	Process flow Control	Maintenance schedule	Health & Safety Control
50	Obtain materials	No shortage	M	Y	Y		
10	Cut fresh gas tube to length	180mm +/-2 0.8 sec	L	Y			
3	Cut pressure tube to length	180mm +/-2 0.8 sec	L	Y			
15	Place head (L) in welder jaw	Fully inserted 1.7 sec	L			Y	
35	Insert prong lumen in head (L)	Fully inserted 2.2 sec	L				
80	Insert accelerator in head (L)	Fully inserted 2.2 sec	L	Y			
10	Insert fresh gas tube in head (L)	0.5mm accu. 2.7 sec	M	Y			
3	Insert pressure tube in head (L)	0.5mm accu. 2.7 sec	M	Y			
15	Cover with head(R)	Locate guide 1.1. sec	L				
40	Ultrasonic weld head assemble	All around seal. 4.6 sec	L			Y	Y
35	Slide exhaust body over tubes	2.4 sec	L				
15	Push fresh gas tube to connector	Full home 1.2 sec	L				
8	Push pressure tube to connector	Full home 1.2 sec	L				
40	Slide exhaust over connectors lip	Full home 0.9 sec	L	Y			
3	Slide cap attach into exhaust body	1.1 sec	L				

(*) Prong cushion is outsourced and packed separately, and fitted by user



Once we have completed our product design work the product parts and their target values are entered into the third table. Again, we drawn lines to indicate relationships and transfer the importance values. Individual parts may have multiple target parameters. We try best possible to judge how much of the part input importance value relates to each the individual targets. For example, "Prong cushion" has an importance value of 150. The "ball shape" parameter relates to about 120 of the 150. The "Viscoelastic resilient" relates to about 90 of the 150. The resulting importance facilitates planning – i.e. resource and time allocation – for the process design, which now takes place in between the third and fourth table. One particularity concerning this project is that the prong cushion foam moulding process is outsources to a specialist sub-manufacturer. Although we do now not produce this part internally, its quality characteristics and importance values form basis for the negotiations, specification and process validation that we put in place with the sub-manufacturer.

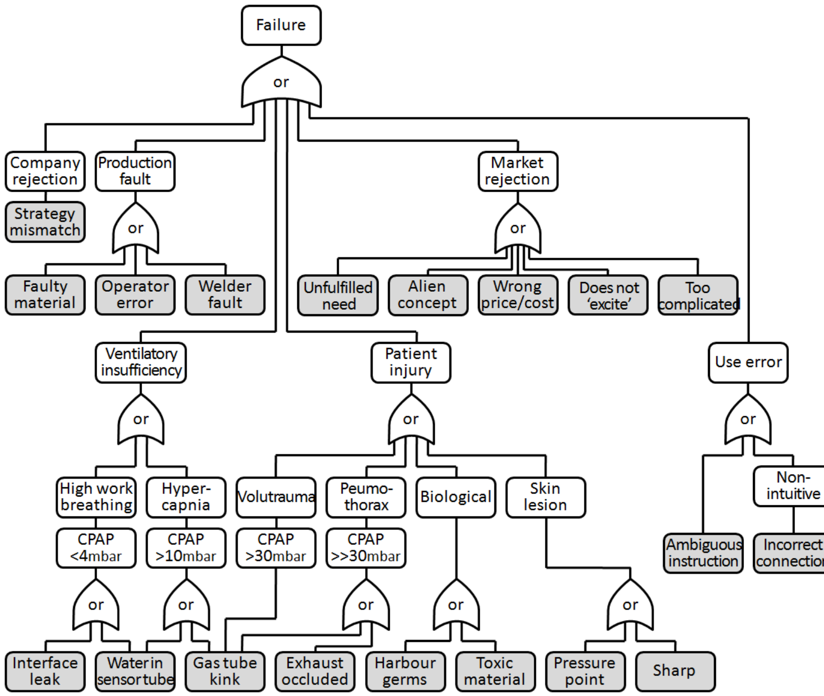
Once we have developed our process its steps and their targets are entered into the fourth table. The relationships and input importance is derived by line-drawing, as previously. In the final "production planning" stage we first assess the "Difficulty potential" in achieving the target for each individual process step. The assessment, combined with consideration to the input importance value, facilitates planning of the production implementation. The planning elements here are selected as being important to this particular case study; but they could be modified for other cases:

- "Quality control" indicates that the company's quality management function will have to implement controls to assure the process step target value is maintained.
- "Production flow control" indicates potential for scheduling and waiting line difficulties, where the production management function will have to implement devices, such as kanban, multi-skilling or monitoring, to assure the continued production efficiency.
- "Maintenance schedule" refers to assuring the tolerances and reliability of important process equipment.
- "Health & Safety control" indicates a potential for harm being caused to people and where the production management function will have to implement safety controls, to manage the risk of any such harm being realised.

POTENTIAL FAILURE ASSESSMENT TOOL

The 1-sheet QFD approach makes extensive use of an FMEA-variant assessment tool, titled Potential Failure Assessment (PFA). The tool is started early and is maintained as an on-going working document throughout the QFD project, where the PFA is revisited at every design review opportunity. Remember, the Kano model tells that a strategy aimed solely at preventing failure is not a recipe for creating true satisfaction (see pages 89, 90). Achieving what Kano terms “excitement attributes” require that we think about failure as something that goes beyond the mere technical needs. When defining failure in our PFA we have to set the bar wider and higher than simply ‘quality assuring’ the technical system. For some of the high importance requirements we also have to set the bar higher than current customer demand, to enable us creating new customer excitement and innovation. Whereas the conventional FMEA tends to be aimed at making a technical system failure-free, we use the PFA tool here to manage a wider range of objectives. In thinking of failure as a *“shortfall in meeting standard or expectation”* and further thinking of success as being the opposite, namely *“no shortfall in meeting standard and expectation”*, it enables us to manage both dissatisfiers and satisfiers within the one tool. The PFA does not only ask the FMEA question: *“What could potentially go wrong”?* It further addresses: *“What will it take to do it right”?* For example, we have included an assessment of the potential failure of “Market rejection”, which is simply the reciprocal of market acceptance. The “Does not excite” root cause is integrated into the single design document together with the more conventional technical ‘quality assurance’ root cause types, such as “Interface leak” and “Gas tube kink”. This gives us a single focal point for managing and designing out all types of failures. If we look at the PFA in another way it can be said to be a kind of inventory for value creation.

The PFA tool has two elements: 1) a fault tree visualising the failure modes and their root causes – the latter being highlighted in the grey text boxes here; and 2) an evaluation table. The two elements, together, make up an FMEA. By dividing the FMEA in this way we reduce the size and complexity of our frequently revisited assessment table. The assessment table lists and considers solely the root causes (the greyed boxes in the fault tree), which makes the approach overall more manageable.



Potential Failure Assessment

Product	Nasal prong interface	Prj.Mgr	John Smith	Date	01/07/2013

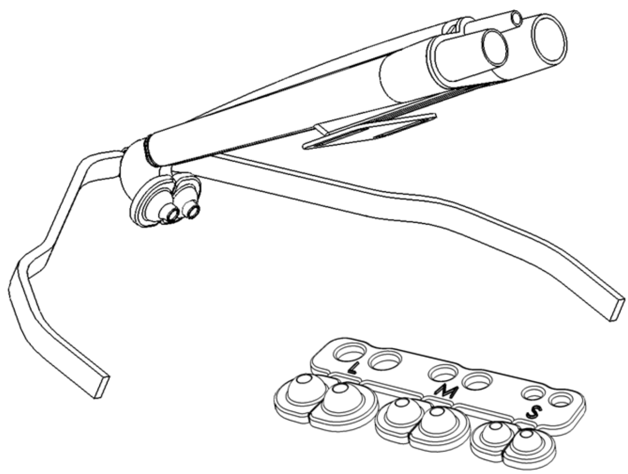
Failure root cause		Sev.	Occ.	Score	Countermeasure	Sev.	Occ.	Result
M1	Unfulfilled need	8	2	16	Systematic product development from VOC. Perform (non-clinical) market testing of prototype, before committing to final design.	8	1	8
M2	Alien concept	6	3	18	Usability testing of prototype. Flow-pressure generator principle does not deviate in function of performance from market established principle proven in clinical papers.	6	1	6
U1	Incorrect Connection	5	6	30	Connectors conform to ISO5356. Male connector for supply gas and female connector for exhaust gas prevents incorrect matching. Graphical user instruction illustrates clearly.	5	1	5
P1	Faulty material	5	3	15	Receiving quality control in implementation plan. Inspection criteria defines. Suppliers subjected to on-going evaluation and continual improvement.	5	1	5
D7	Skin pressure point	7	8	56	Viscoelastic super-soft foam member exceeds current state-of art for distributing pressure loads and, thereby, being gentle on skin. Low profile reduces tendency to tilt.	3	3	9
D4	Exhaust occluded	10	5	50	Large area overlap between resilient elastic exhaust body and stiff connector body leaks at 40mbar +/-5mbar pressure @ 8 l/min flow rate. Acts as safety relief valve.	2	5	10
D6	Toxic material	8	2	8	Specified materials have known low toxicity profile and prior commercial use. Biocompatibility evaluation to ISO10993. Clean room injectio	8	1	8

The PFA scores severity and likelihood of occurrence on a scale of 0 to 10. The aim is to make the resulting risk score as low as practically possible. Anything with a score above 10 is generally intolerable, where the product cannot be released until the underlying cause is resolved or controlled. By "generally" we refer to the fact that in some instances for medical devices the market regulators, in society's best interest, tolerate higher risk devices in a trade-off for their potentially positive medical benefits. However, this is not the situation for the type of device in this case study and we therefore aim to have all of the risks scores reduced to 10 or below. The PFA focuses the design activity to some extend on creating countermeasures, to eliminate or reduce the potential failures. The PFA proves a highly valuable tool, forcing the designers to evaluate and re-evaluate the strength of their design decisions and to balance them across the domains, such as engineering, production and marketing. For example, when making an engineering cost reduction decision we can simultaneously assess its impact on market acceptance. Once we have adequately countered the potential for all root causes then we have in effect the successfully filled the inventory of value creation. The design work is complete.

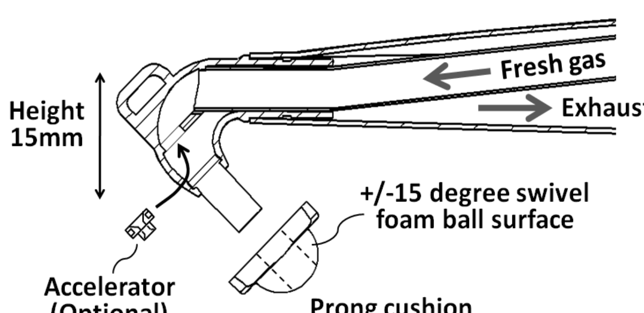
The PFA tool is highly appropriate in medical device design, where the principle design aim is overall "safety and efficacy". The medical device design dossier must, by a mandatory regulatory requirement, contain a formal documented design risk assessment and also a usability evaluation. The formal documents format must be suitable for third party examination. Basically, had we not used the PFA tool here then we would have had to produce something very similar anyway. We have labelled each failure root cause in the table, with a suffix that enables us sorting and extracting those specific to the design (D), process (P), use related (U) and marketing (M). This enables us easy extracting domain specific assessments, such as for the mandatory design risk assessment and for the usability assessment.

PROJECT OUTCOMES

This section describes some of the design decisions made in our case study, for purpose of demonstrating how they are enabled by the 1-sheet QFD and PFA tool.



Final nasal interface design



The second table in our 1-sheet QFD highlights *"generator and prong variants"* and the 3 *"conform to ...."* design requirements as being most important to customer quality and our strategic innovation objectives. This importance is subsequently reflected in the principal aspects of the designed product listed in the third table – namely by emphasis and novelty in the *"accelerator jet"* and the *"prong cushion"* parts. The 1-sheet QFD approach has thereby realised the required quality and innovation potential. We are referring to a 'potential' when looking at the table 3 stage, because quality is only really assured once we have also correctly worked the remaining table 4, which we have.

The third table in our 1-sheet QFD sets us some ambitious but realistic performance targets for CPAP noise, back-pressure and stability. This ambition is essential to maximising the identified commercial opportunity. The realism is based on estimates on needless inefficiencies observed in existing commercial products.

One solution considered is to depart from a round tubular jet (injector) nozzle, and instead shape the nozzle into a flat rectangular slit near the internal wall leading into the patient's nose. By making better use of the fluidic surface attachment (Coanda effect), this could make the jet travel further before breaking up, thereby improving its entrainment stability effect. Technically, the concept idea looks promising, but the PFA immediately identifies an unacceptable risk for "Alien concept". This is because the principle has no prior evidence of efficacy – i.e. no clinical research paper has ever referred to any such nozzle shape. It would therefore potentially be difficult to market, without first establishing evidence through costly and time-delaying clinical trails. Fast time to market is an important project aim. The PFA tactical countermeasure is therefore to copy and improve the existing recognisable conventional jet (injector) principle instead. Experimenting identifies that a 10% larger jet orifice, but with a 0.33 x diameter radius on the inlet edge and

0.14 x diameter radius on the outlet achieves a significantly better laminar gas flow profile, compared to existing commercial products. However, now the PFA identifies a potential production operator error risk of inserting the accelerator back to front. The countermeasure response is a slight design compromise in setting the radius to 0.14 x diameter at both the inlet and outlet, thereby making the part insensitive to the assembly orientation, but still decisively out-performing the competition. Further back-pressure reduction is achieved by up-rating the fresh gas tube inner diameter from 2.6mm to 5.1mm, and by making the gas flow turn in towards the nose through a single smooth bend. The specifying of pressure and fresh gas tubes in different sizes agrees well with the process PFA, by simultaneously mistake-proofing their accidental reversal during assembly. The final design matches existing commercial devices in airway pressure stability performance; while successfully achieving our more ambitious targets for low noise and low back-pressure operating point.

It was discovered during the creative thinking stage that the 'generator' version of the product can be converted into a 'prong' version, simply by leaving the accelerator element out during the assembly process. The accelerator is therefore designed as an optional part. The same production line can then produce both product variants, using the same components and processes. This solution has cost and user training benefits. On a negative, it does increase the risk of an end-user connecting the similarly looking devices to the wrong kind of ventilator. The PFA evaluation identifies that this user error risk can be adequately countered by making the accelerator clearly visible through the translucent device material and by clear colour-coded labelling.

One market leading device uses a ball-and-socket swivel in its plastic body, with a resulting parts complexity and weight penalty. By mentally visualising the standard translation table, we ask its questions during a brainstorming session: *"How does our* *existing product achieve this"? "How does our best competitor do it"? "What would a state-of-the-art provider do"? "What analogue systems are there"? "Do we have any precedent design rule"?* Discussion at one stage moved on to the swivel analogy of artificial knee and hip joints, which gave rise to the novel idea of making use of the nostril's own 'anatomical socket'. The nostril rim in effect already provides one half of the ball-and-socket joint. The prong contact surface can be made dome-shaped to provide the matching ball element. This eliminates the weight, height and complexity penalty from having the swivel component designed into the interface plastic head. Thinking of a low cost foam ear-plug solution, which conforms to variable ear canal shapes, it is decided to make the prong cushion in viscoelastic foam, also referred to as memory-foam, for improved and gentler sealing to a wider variety of nose shapes.

In discussion, again asking the questions of the standard translation table, it is considered how 'air-tight' dwellings use a heat-exchanger to manage human breath and sweat condensates during cold winters. By threading the supply fresh gas tube through the inside of the exhaust tube, the patient's own exhaled breath can now keep the fresh gas warm to prevent condensates. Overall, the solution enables the interface being significantly lower in profile, reducing its height and weight by some two thirds, for better patient comfort. The consolidation of tubes and the method for attachment now also make it possible for a single person to fit the device to a patient.

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