Facilitated decision making for investment in process innovation

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Introduction

Why is it that the introduction of innovative process technologies appears to be so slow in the process industries? The benefits of implementing flow chemistry at smaller commercial scales (for instance) have been discussed for over a decade, and yet the reality is that new products continue to be realised through batch processes. Economies of scale and the two-thirds rule dominate the approach to large-volume, commodity chemicals, leading to highly centralised production, reliance on long-established process routes, and incremental improvements.

The process industries seem to display conservatism and risk aversion when it comes to investment in new technology.[1] This behaviour may be rational to some extent if it is a response to previous bad experiences, but to what extent were those bad experiences self-inflicted? In 1998, McNulty[2] gathered 41 case histories in the mineral processing sector. He charted the rate at which each project achieved nameplate capacity and divided his sample into four types of project, of which we now briefly review the two extreme cases. Type I achieved nameplate within 12 months of commencing commissioning but were copies of existing processes; they were, in other words, non-innovative. Type IV projects, which involved substantial innovation, failed to achieve 60% of design capacity within 36 months of start-up. McNulty notes that of the seven Type IV case studies he identified, three closed within the three-year period. The paper goes on to highlight four causes of failure (Table 1), with each case study exhibiting more than one of these. The first two of these derive directly from management actions and the other two relate to lack of process understanding. Bad experiences with process innovation are evidently largely self-induced!

- If any pilot-scale testing was conducted, it was for generating product, not for confirming process parameters.
- Equipment was downsized or design criteria were made less conservative in response to projected cost overruns.
- Process flowsheets were unusually complex with prototype equipment in two or more critical unit operations.
- Process chemistry was misunderstood.

Table 1: Key Problems with Type IV Projects (after McNulty 1998[2])

McNulty's work is twenty years old, but we see few signs that much has changed since he reached his conclusions or that they can't be generalised across the process industries. It is proposed that the reasons for failures of innovative projects are systemic and common across many organisations in the process industries (including the EU Sustainable Process Industries (SPIRE) PPP sectors of cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel and water).

[1] Process Management and Technological Innovation: A Longitudinal Study of the Photography and Paint Industries, Benner, MJ, Tushman, M, Administrative Science Quarterly, Volume: 47:4, page(s), 676-707, 2002, https://doi.org/10.2307/3094913
[2] Developing innovative technology, McNulty, TP, Mining Engineering, October 1998, 50-55

The Business / R&D Disconnect

One problem that contributes to unhelpful management decisions is a disconnect between business/commercial functions and an organisation's research and development community. This is typified by statements such as, "Commercial will never attend, they are too busy", a common response heard by Britest facilitators trying to establish the business case during initial screening analysis of a development project under study. Yet such projects are usually seen as critical for business sustainability and/or growth! The disconnect can also be detected in substantial R&D hours being expended on an interesting problem that has little relevance to business needs. An example (which we have encountered but which was in practice averted by discussion) might be, lab work to improve the utilisation of an expensive raw material for which previous similar efforts have not been implemented because the product economics did not justify the improved efficiency.

Communication between the business and R&D communities is further hindered by a lack of understanding of business drivers and economics in one direction and requirements to achieve the technical targets expected in the other direction. Unrealistic timelines and resource constraints are major contributors to the problem of insufficient process understanding.

Handling Uncertainty and Mitigating Risk

Uncertainty within the data upon which a complex decision is based is a serious problem for decision-makers. This is particularly a concern at the very early stages of a project where the decision is about whether or not to commit resources to developing one or more options. Uncertainties in estimating the market opportunity, the project costs and the technical risk involved will be at their maximum at this point in the project life-cycle. With the current culture towards making major decisions with perhaps only a few minutes discussion time and on the basis of a single page summary, a tendency for conservatism to dominate over innovation is not very surprising. The other impact of this high-pressure approach to decision-making is that the basis of the decision may be instinctive rather than evidential and is typically incompletely recorded and irreproducible. In this situation a business cannot learn lessons from failure or equally learn how to further propagate success.

One consequence of (inevitable) uncertainty, is the need to establish a strategy for mitigating risk. In this context, all types of risk should be considered, not just those associated with safety and environmental protection (extending to patient safety within the pharmaceutical sector). The organisation's in-house use of language can be a strong barrier to taking an all-risks approach. One particular risk mitigation strategy that is frequently absent, is having a clear understanding of when to either kill or proceed with (and continue investing in) a project.

Towards a Methodology for Early-Stage Decision Making

What is required is a structured approach to making early stage decisions on whether or not to invest in developing innovative processes and technologies. The issues described above, provide a guide towards specifying the features that such a methodology needs to incorporate. It should provide:

- Independence and objectivity – ensuring that the decision-making process is data/evidence driven and dispassionate
- Traceability – recording and clearly presenting a recommendation for decision outcome in an auditable and reproducible way
- Adaptability – whilst being aimed particularly at early stage decisions from initial idea to engineering feasibility, the methodology should be useful for project stage gate decisions later in the cycle as the project moves to implementation

- Compatibility - seamless integration with usual project management practices
- Complementarity – the risk mitigation strategy should be complementary to, rather than a replacement for, existing, well established and more detailed risk assessment techniques (such as HAZOP, FMEA)
- A unified approach - Combined commercial and technical criteria (including safety and environmental factors) in a single analysis
- The ability to capture and assess uncertainty in the available data
- The means to enable communication and understanding between business and R&D communities of each other's respective needs and delivery
- Targets - setting specific development targets that are aligned with requirements for commercial success
- A systematic probe of whole process knowledge and understanding

In one approach, a facilitator leads the complex decision-making process with a team of project stakeholders. The facilitator's role is to guide the team in defining the project itself, the alternatives to be considered, the selection criteria to employ, and the scoring of the alternatives against the criteria in order to reach a decision. A skilled technical facilitator, external to the project team provides the vital element of independence to the process and enables communication and understanding between the different groups represented in the team. These will ideally cover (at least) R&D, manufacturing, and business functions. If all functions are not party to the discussion, then part of the facilitator's role is to try to ensure that the wider picture is considered by those who are. It is assumed in the following discussion that the study is taking place at the outset, with the project consisting of little more than an idea for development., however, the principles and techniques outlined could in fact, be applied at any stage in the project life cycle.

Britest Decision Making Methodology

The methodology we now summarise is the result of nearly twenty years practical experience in the field of technical facilitation for whole process understanding. This has been gained in the context of a specialist not for profit SME service provider to a diverse client base ranging from multinational pharmaceutical and fine chemical manufacturers through to contract manufacturers and biotechnology start-ups. It is therefore primarily empirical – over time, we have retained what works and modified or removed what didn't, however much of that experience and evolution of the tools employed has been furthered by collaborative innovation with knowledge base partners specialising in the more fundamental aspects of decision research.[3,4,5]

Initial Screening Analysis

The study should begin with a review of the project as presently proposed. This Initial Screening Analysis (ISA) needs to cover six areas:

[3] Practical Assessment Methodology for Converting Fine Chemicals Processes from Batch to Continuous, Teoh, S,K Rathic C, Sharratt, P, Org. Process Res. Dev. 20, 2, 414-431

[4] Analytical hierarchy processes (AHP) for the selection of solvents in early stages of pharmaceutical process development, Perez-Vega, S, Salmeron-Ochoa, I, Nieva-de la Hidalga, A, Sharratt, PN, Process Safety and Environmental Protection, Vol 89, Iss4, pp 261-67, 2011

[5] Everyday Industry—Pragmatic approaches for integrating sustainability into industry decision making, Peace, A, Ramirez, A, Broeren, MLM, Coleman, N, Chaput, I, Rydberg, T, Sauvion, G, Sustainable Production and Consumption 13 (2018) 93 – 101

Project Definition

The general context and key goals of the project should be captured, and consensus obtained on current status and the desired final state. The potential and desired benefits sought once the new process enters operation, and/or the new product reaches commercial launch, should be identified and documented.

Objectives for the study

The decision team needs to be clear on exactly what needs to be decided at this decision point and how the results will be used and/or disseminated. In the simplest case this may be simply a decision to proceed with or discontinue further development. In many cases the decision may be to select from a number of alternatives which options to develop further before making another selection based on the increased information gathered in the interval between decision points.

Constraints

Identify and note any constraints or restrictions that may influence the decision made. These may include regulatory, business or technical practicalities.

Product definition

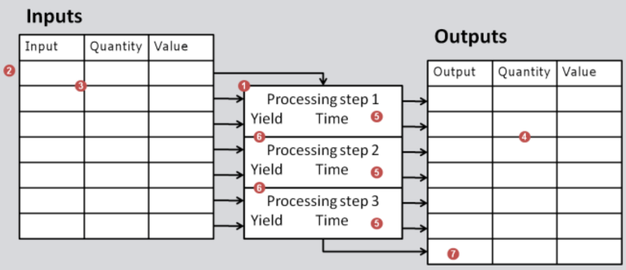
What are the specific features required of the product to achieve customer acceptability? These may lead to identification of further constraints. Discussion should cover the whole supply chain to the end user in case this turns up new delivery opportunities that ought to be brought within consideration. It may be useful to use a tool such as Strategyzer's® Value Proposition Canvas[6] to help ideas to flow.

Process definition

Process definition is perhaps the most important of the ISA stages. The boundaries of the process scope are important here. The team should consider the whole supply chain from suppliers to customers even if subsequently parts of the chain are deemed less important when choosing the areas of focus in the sixth step below.

This step is particularly important for two reasons. The first is that it provides an opportunity to gauge the present state of process understanding and hence technical risk. The second is that this is the point to start collecting the data on which the decision will be based. A tool such as Britest Limited's Process Information Summary Map (PrISM)[7] can be useful for this. PrISM (see right) captures a simple, semi-quantitative model of the proposed process and is easily extended in both directions along the supply chain. It can be a useful tool for checking whether the options actually align with the desired business benefits and as a starting potential for simple financial modelling. The facilitator's role is essential to

PrISM captures key stages within a process, along with the key inputs and outputs for each stage. This tool helps the team to focus their activities on the most appropriate parts of the process by providing an overview of the most critical material, time and energy dependencies.



1. List the key process stages.
2. Record information about the principal feedstocks.
3. Record information on reagents added at each stage to the left.
4. Record information on wastes removed from each stage to the right.
5. Record information about each stage inside the box.
6. Draw a horizontal line between each stage once all information about each stage is recorded.
7. Record information about the desired product exiting the bottom of the box.

Figure 1: Britest's PrISM tool[7]

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[6] https://strategyzer.com/platform

[7] McLachlan et al., J Bioprocess Biotech 2017, 7:2DOI: 10.4172/2155-9821.1000305

ensure that the level of detail is kept appropriate to the development status of the project. PrISM can also reveal gaps in data and understanding, highlighting areas of uncertainty. This step is also the starting point to identification of the gaps in whole process understanding. Process knowledge and understanding can be explored fully using tools such as Process Definition Diagrams (PDD), a form of State Task Network.[8] This is a separate task to the decision study, but the results should feed back into further iterations of the decision.

Critical aspects to focus on

Identify and note the key features of the project that potentially enable differentiation between options and hence provide a basis for a decision. In the context of deciding upon a reaction scale-up strategy for example the chemical synthesis step(s) of a process may be important, but is also vital to consider product isolation and any solids handling steps as these may in practice be where the greatest scale-up risks lie.

Simple Financial Modelling

At this point it is useful to construct a simple, financial model of each of the alternatives. The aim should be to generate a graph of the Net Present Value (NPV) over time. This appears to happen rarely in the very early stages of project development, possibly because the business/commercial functions have not been engaged and the technical personnel involved often lack familiarity with simple, financial modelling. In practice, remarkably few parameters need to be estimated to construct a NPV curve, enabling the team to visualise the financial differences between alternatives. It is useful to do this even if “accurate” information is not available, because the existence of a model, even if it is “wrong”, will promote discussion – of *why* it is “wrong” and where and how better data can be sourced, all leading to better understanding and refinement of the business drivers for the project. This discussion should encompass the uncertainty in the input data, and different scenarios can be run to see how this affects the NPV.

Evaluation of Alternatives

By this stage, sufficient data should have been gathered to enable the decision alternatives to be evaluated. The evaluation needs to be carried out in a manner that is reproducible and auditable. A number of decision making algorithms have been proposed in the literature and are in practical use in a number of applications. One algorithm in particular, Hodgett’s Multi-Attribute Range Evaluations (MARE)[9], is well suited to selecting between options for chemical process routes because (unlike other available options) it has been designed to accept and process uncertainty ranges in the input scores. Britest Limited has implemented MARE under licence through a simple software tool, ChemDecide, which enables a facilitator to lead the decision team through the process of defining and scoring selected criteria across the alternatives under consideration. The decision process is quite simple, and the majority of the problem definition and data collection work will have already been done if an initial Screening analysis has been completed.

The first step in a ChemDecide session is to identify the alternatives from which to make a selection. It is worth taking some time to carefully describe each option rather than simply listing them by name. This improved understanding of the alternatives will help when it comes to scoring. In most cases one of the alternatives that needs to be considered is what happens if the decision is not to invest. The team language used to describe this situation is informative. It may be described as, “Business as usual”, “Do nothing”, or “Zero capital”. It is important to explore and challenge the underlying assumptions and connotations (either positive or negative) behind these statements. Such options are for example, rarely zero cost in reality: an existing plant will always require some continuing capital investment in order to sustain extended operations

[8] Plant-independent Process Representation, Wall, K, Sharratt, PN, Sadr-Kazemi, N, Borland, JN, 1999
[9] Comparison of multi-criteria decision-making methods for equipment selection, Hodgett, RE, Int J Adv Manuf Technol, October 2015

and, if (say) the business benefits rely on market growth, then where will the necessary additional production come from under a "Do nothing" scenario?

The next step is to brainstorm the possible selection criteria to be used to differentiate between the alternatives under consideration. An ISA as described above, can expedite this stage. The team will then need to pick a set of criteria that will be used to score the alternatives. Suitable criteria are likely to be those that test the ability of each option to deliver the desired business benefits of the project. Each of these criteria should be fully defined to understand the basis on which they will be scored. The number of criteria selected for scoring should ideally be kept in a range of four to ten to avoid over-simplification on the one hand and an onerous and confusing scoring process on the other.

The team should allocate a score to each alternative with respect to each of the selected criteria. Scoring may be quantitative if a specific value can be assigned (*e.g.* time to beneficial production) or qualitative (*e.g.* overall technical risk on a scale from extremely low to extremely high). Qualitative and quantitative criteria can be mixed, and in subsequent iterations, a qualitative criterion may become quantitative as better information becomes available. With each score, uncertainty can be represented as a range between maximum and minimum, with the most likely score lying somewhere in between. For some criteria there may be no uncertainty in scoring, in which case no range should be supplied.

Once the scoring is complete, the algorithm calculates the overall rating for each alternative, effectively ranking them in order of attractiveness. Visually presenting the results in a chart, indicating the uncertainty ranges for each alternative as well as the most likely outcome, is usually the best way to communicate the overall result (Figure 2). The team should always check that the result is explicable in terms of the input data.

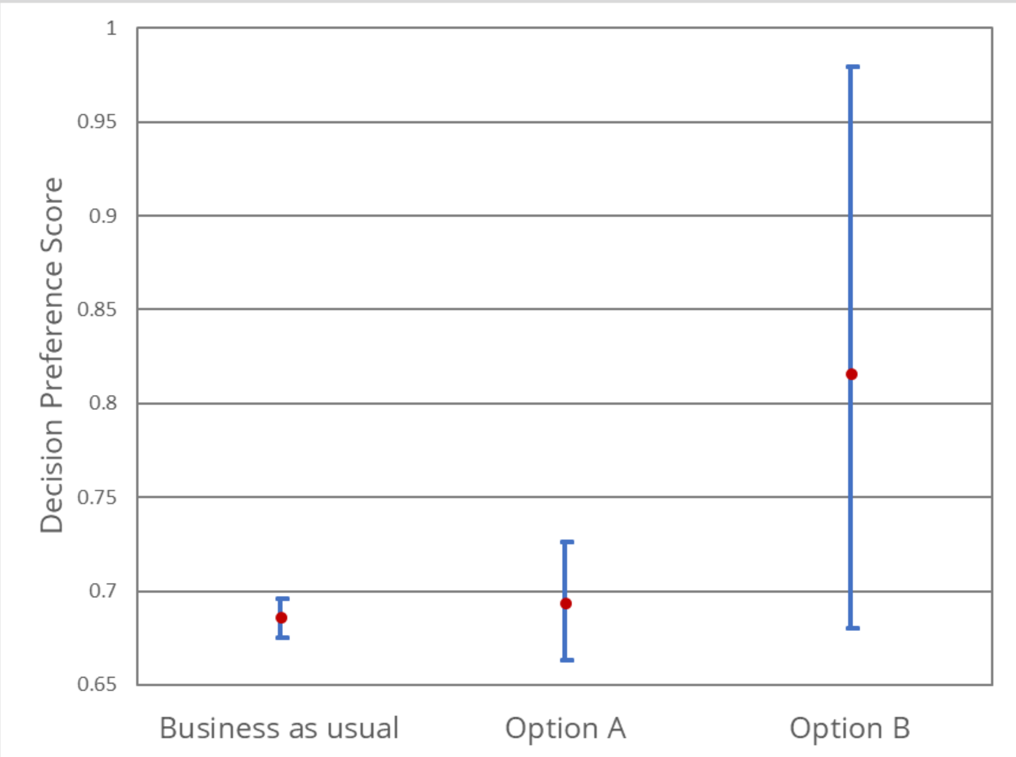

Figure 2: Idealised output for a MARE decision – Option B appears to offer the prospect of substantial benefits overall compared with Business as usual or Option A, however a high degree of uncertainty is indicated by the error bar. Further data refinement will be needed for a conclusive decision to be made.

It is only at this stage that we would recommend considering whether weightings should be applied to the various criteria. It is generally better to complete the scoring and obtain preliminary results with equally weighted criteria before deciding whether to give one criterion more weight than others.   Generally speaking, we have found the overall result to be relatively insensitive to weightings, (especially when there are more than 5 criteria employed) and so a major difference in outcome would require a single criterion to be extremely heavily weighted. Weighting the criteria may therefore not be a useful additional step. However, if it *is* desired to weight the criteria, then a semi-quantitative (*e.g*. low, medium, high) approach will usually be sufficient, rather than spend a lot of time trying to refine quantified weighting values for each individual criterion. The algorithm should then be re-run with the agreed weighting.

This is the end-point for a single iteration of the decision-making process. In practice, it is likely that the cycle or parts of it will be repeated as further information is obtained. The decision is therefore refined as the project progresses, and so the methodology is well adapted to support stage gate based approaches to project management. In particular, financial information is likely to firm-up from initial qualitative (non-numerical) or very approximate values to more detailed numbers.   Uncertainty in these quantities can usefully be explored with a Monte Carlo simulation, and the results directly input in the decision-making algorithm if MARE is used for this purpose.

Conclusions

In our experience, the process described above provides a structured approach to making complex decisions on selecting investment and development options for innovative products and processes in the process engineering sector. A structured approach of this type will benefit businesses considering innovative proposals in several ways.

- Efficient capture of the salient points of the basis for making a decision is enabled, together with the uncertainty in those points in a clear, concise, and visually supported discussion paper for consideration by executives or boards.
- A process led by an independent facilitator allows any significant risks, gaps in process understanding, and gaps and uncertainty in available technical and commercial information to be identified. This provides the basis for an ongoing project development plan targeted at mitigating the identified risks. The facilitated process also promotes clear and mutual understanding of project goals and benefits between business, R&D and manufacturing functions.
- Clear, structured documentation and consistency of approach makes the reasoning behind the selection of alternatives clear and reproducible. It also enables the process to be audited making it possible to review and capture learning from both successful and unsuccessful projects with a view to improving future success rates.
- The approach will test the alignment between desired business benefits and technical alternatives proposed, and aid the iterative establishment of clear, technical specifications that need to be achieved in order to realise the intended business benefits. In other words, the team establishes unequivocal “kill” or “proceed” conditions for project stage gates from the outset.

Helping organisations gain value from process understanding

ABOUT THE AUTHOR

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