Optimal Timing for Replacing Aging or Obsolete Assets

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Abstract
Aging physical assets and infrastructure are headaches shared by many industries in many countries around the world. Hundreds of billions of dollars of re-investment are going to be needed over the coming years, at a time when financial pressures make such investments particularly hard to justify. The SALVO project is addressing such problems with a fresh look – how to make the right decisions about what to do and when, even with limited data and uncertain assumptions. This paper summaries the objectives, scope and progress of the SALVO Project, and illustrates the processes with the first of the field trial cases that have been explored.

1 Introduction
The management of aging assets is one of the most critical issues facing many industries. Over £25 Billion of infrastructure re-investment is deemed to be required in the UK, and over $200 Billion each across Europe and USA, during the next 5-15 years. Furthermore, evidence shows that up to 30% of the total cost of ownership can be avoided by better decision-making on what to do, and when. So it is clear that aging assets present some of the most challenging and critical issues facing asset managers in the coming years. Yet, despite the criticality and urgency of the situation, current decision-making practices are often subjective, inconsistent and based on technical arguments rather than robust “business case” justifications. For example, it is usually much easier to get funding to meet a new operational demand or to upgrade technology than it is to justify the timely like-for-like replacement of an existing, deteriorating asset. Technology change rates are also much higher nowadays, yet the decision-making about obsolescence or upgrade timing is similarly fraught with uncertainty and the inadequate evaluation or transparency of the total cost/risk and life cycle implications.

The SALVO project is a cross-industry consortium, comprising The National Grid, London Underground, Scottish Water, SASOL, Scottish Power Energy Networks, The Woodhouse Partnership, Cambridge University, Decision Support Tools, Centrica, Forbo and Halcrow. It is pooling experiences and identifying best practices in addressing aging asset problems – and it is doing so at several levels, ranging from the identification and selection of candidates in the first place, and discrete individual decisions about justification and optimal timing of interventions, to the best combined approach to multiple activities across portfolios of assets. Many of these elements already have well-developed ‘niche’ solutions and there are good examples around – SALVO is “joining up the jigsaw puzzle”, and also developing some of the vital links and new capabilities (such as the selection and correct usage of mixed hard data and quantified expert/tacit knowledge). So, with some very experienced industrial practitioners and leading-edge R&D resources, the SALVO team is aiming to distil best practice guidance, templates, case studies and tools, applicable to any asset class and business environment.

SALVO is also the natural ‘next stage’ to the R&D groundwork performed by the European Eureka MACRO Project (EU1488)\(^1\). MACRO covered many instances of asset management decision-making, particularly when hard data is limited or unavailable. It produced a combination of short training courses and free-standing analytical software.

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\(^1\) See [www.MACROproject.org](http://www.MACROproject.org).

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1 IET Asset Management Conference, London
tools (APT) that have been very successfully applied, but only in a relatively small number of large organisations. The underlying concepts, for example, for how to capture and quantify ‘tacit knowledge’, plus the mathematical algorithms needed to calculate net cost and reliability implications when there are multiple risks interacting with each other, are clearly very applicable to the SALVO objectives. So they have been acquired, suitably adapted and extended for the specific decisions encountered in the aging assets environment (see figure 1).

One of the first priorities, therefore, is clarification of what options exist to prevent, slow down, recover or mitigate the effects of aging (see Figure 2). SALVO is creating a checklist of things that might be worth considering – to force some ‘lateral thinking’ and make sure that we do not always just leap towards the ‘obvious’ solution. Perhaps, for example, a partial or temporary solution is worthwhile, buying us time to address the underlying problems more cost-effectively. In other cases, the intervention that we feel to be right (e.g. asset replacement) is difficult to justify, but we must also demonstrate that the ‘do nothing’ and alternative solutions are worse (i.e. more expensive, higher risk or less beneficial). SALVO has already identified over 50 possible intervention options that might be applicable, ranging from the technical (e.g. asset modification, refurbishment, renewal) to the commercial (e.g. outsourced functionality, insurance policies) and people or process changes (up-skilling, operating, monitoring or maintenance strategies).

Only a few of these options will be viable in any particular case, of course, but there will nearly always be more than one way forward, and the necessary evaluation methods do vary considerably between proactive, risk-based interventions and reactive, consequence mitigation options. The next step, therefore, in SALVO guidance is to ensure that, whatever options are deemed possible, they are evaluated on a ‘level playing field’. Only in this way can the best value solution (or combination of solutions) be identified and business-case justified.
1.2 Evaluating options & demonstrating value-for-money

Risk-based and whole life costed decisions are increasingly recognised as the necessary basis for demonstrating and delivering sustainable value-for-money. Regulators, shareholders, customers and other stakeholders also increasingly demanding much greater transparency in how expenditure decisions are made. In simple terms, we need to demonstrate and explain not just what is worth doing, but also the when and the why.

Furthermore, the BSI PAS 55:2008 standard for optimized management of physical assets (which is also the basis for the forthcoming ISO 55001 standard for asset management) requires organisations to actively and evidently optimize their asset management plans. These requirements (see Figure 3) exist at three levels of ‘granularity’:

a) Individual activities on individual assets (Is this job worth doing, and if so, when?) - this is where the MACRO project deliverables already help significantly but SALVO is ensuring greater integration with business data & processes and more simplified, ‘wizard’ guidance to help their adoption and usage by a wider range of personnel.

b) Integrated optimisation of an asset’s life cycle (What is the best combination of capital investment, utilization, maintenance and life expectancy?). This is where various simulation modelling tools exist but the SALVO project is also breaking some new ground to assist in whole life cost optimization, including multiple risks and determination of the optimal life/replacement timings.

c) Total activity programme delivery and coordination of multiple activities across multiple assets (How do we optimally programme the conflicting urgencies of different activities to exploit ‘bundling’ opportunities and/or to smooth resource requirements/performace effects?). Here there are some existing approaches, usually based on portfolio simulations, using asset-type generic assumptions, weighted factors and global ‘what if?’ parameters. SALVO will be refining these capabilities with better component contributions from the ‘bottom up’ influences of individually timing-optimised tasks. This will enable much greater transparency and demonstration of why the optimal programme is indeed optimal, and quantify the net business/financial impact of any changes to this plan.

Figure 3. PAS 55:2008 requirements for decision optimization
2 The SALVO processes

2.1 Generic principles applied
There are some process steps and best practices that are always needed, irrespective of the option being evaluated. SALVO guidance is capturing a lot of common sense here, and aims to ensure that such principles are followed in all cases:

- Wherever possible, a quantitative, risk-based approach will be taken – this must include the handling of uncertainty in assumptions and available information (e.g. by sensitivity testing).
- A criticality-proportionate approach will be applied – the rigour and sophistication of method must be appropriate to the criticality and complexity of the decision being addressed (see figure 4). The simple approach is always to be preferred, with increased sophistication only applied when it is worth the additional effort and need for precision or audit rigour.
- Just having identified the technically correct solution or decision is not enough – the outcomes must be explainable and understandable to those who will need to accept, endorse and/or implement the decisions. This involves language, presentation and communication skills plus business process integration, over and above the analytical steps needed to make and optimise the decisions in the first place.

![Figure 4 Analytical methods proportionate to decision criticality & complexity](image)

2.2 Step-wise, disciplined consideration
The biggest challenge for optimising decisions about mature assets is the objectivity and integration of:

- Detecting which assets, in which functional locations, have the greatest urgency of attention.
- Determining the nature of the aging problem (risk, performance, economics, obsolescence etc.)
- Determining what options exist for addressing the problems (enhanced maintenance, refurbishment/life extension, replacement, upgrade, modification, disposal etc.).
• **Evaluating the options** for cost/benefit/risk impact and identifying their optimal timings.
• Identifying and **combining the best mix** of options for the specific case.
• Optimising the **multiple interventions** and activities needed across multiple assets and their different problems (portfolio-level)
• Deriving the required total expenditure profile, residual performance and risk impact, resourcing implications etc.

The SALVO project has grouped these requirements into a generic 5-step ‘top-down’ investigation of problems, and ‘bottom-up’ assembly of solutions (see figure 5).

![Figure 5 SALVO steps: Top-down targeting & Bottom-up justification of efforts](image-url)
3 Progress to date
The project has been run with a number of workstreams, coordinated by an overarching ‘process mapping’ activity. Each major step has been recorded in progress guidance, flowcharts and case study illustrations. The R&D elements have been particularly important in steps 3 & 4 (evaluation and optimisation of discrete solutions and the integration of these into optimal combined programmes). This guidance, the case studies, and the resulting toolkit will be published progressively during the remaining 12 months of the project. In the meantime, and in summary, the following findings have been significant.

3.1 Targeting the right problems in the first place
Step 1 of SALVO identifies candidates for investigation - the assets are grouped into different ‘urgencies of attention’. Competing apparent sources of concern need to be sorted out for real business significance (e.g. safety concerns, economic ones, reliability issues, performance improvement opportunities, compliance obligations and technology upgrade opportunities). A wide range of asset health (condition and/or performance) indicators, criticality studies and other ranking methods are currently used (sometimes inconsistently) for this purpose, but we have found that, whatever the available data, there are two dimensions that must be considered to correctly group the assets and their aging problems into a logical prioritization of analysis:

a) Decision criticality (how big is the cliff we are facing if we do nothing?)

b) Decision urgency (how close to the cliff edge are we today?)

Some of the common indicators for this systematic targeting are self-evident, and can be used to pre-group the assets into candidate groups quite simply (e.g. by asset type). The SALVO team have identified 14 of these ‘filters’, which can be used to bundle the primary areas of concern very rapidly. Drill-down into these bundles involves using other attributes, of which three classes and 45 discrete influences have been identified. Drawing upon available hard evidence and tacit knowledge, these enable the combination of decision criticality and decision urgency to be assigned. So an organisation can identify (and demonstrate) which asset headaches need the greatest priority attention and why.

3.2 Identifying possible intervention options
In considering available ‘medicines’ to address a specific and urgent problem, the SALVO team has explored a very wide range of possible options. A particular feature was the recognition that a technical or engineering solution is not always required. In total, 53 potential interventions were identified and these were classified into 13 ‘intervention types’. They range from planned replacement (like-for-like or including a design change/upgrade) to the management of customer expectations, insurance policies, changed maintenance regimes, contingency plans, sparing policies and decommissioning/abandonment.
The team is developing illustrations and guidance to identify which such options are likely to be worth considering in which individual circumstances. It is already clear, however, that there are at least 5 different techniques required for their correct cost/benefit appraisal in order to arrive at comparable, value-for-money conclusions. For example, a design modification to an existing asset requires a cashflow evaluation of the 1-off expenditure in relation to the ‘step change’ in levels of risk, performance etc. An asset replacement, on the other hand, will often require a ‘rate of change of risk’ (deterioration pattern) quantification and integral calculus mathematics in determining if and when the renewal is justified.

3.3 Evaluating discrete interventions

3.3.1 MACRO project contributions

The original MACRO project addressed over 40 different types of discrete decisions, including the capital investment, project appraisals, asset renewals and refurbishments. Significant pre-consideration of these topics is therefore already available and the resulting decision support tools (see figure 7) have been developed and successfully used in various industries. These tools do, however, need to be better integrated and extended in some of the areas that SALVO has identified for the better management of aging assets.

- APT-PROJECT: Cost/Benefit/Risk Evaluation of Projects & Changes
- APT-MAINTENANCE: Risk/Performance/ Cost Optimisation of PM tasks
- APT-INSPECTION: Inspection, Condition Monitoring & Safety Testing
- APT-LIFESPAN: Life Cycle Costing, Renewal & Upgrade timing
- APT-SPARES Evaluation & Optimisation of Spares decisions
- APT-SCHEDULE: Shutdown Work Content & Timing, Work Bundles

![Guided capture of tacit knowledge (quantification of deterioration, performance, risk patterns etc)](image)

![Uncertainty in costs & failure consequences](image)

![Utilities to look up hard data, standard default rates, operational impact etc](image)

![Audit trail for assumptions](image)

**Figure 7 APT-LIFESPAN method for justification & optimal timing of asset replacement**
3.3.2 SALVO project innovations

As well as the integration of existing good practices and common sense, a number of innovations are being made in the project. These mostly lie in the safe, robust handling of complex risk and reliability interactions – most existing risk modelling methods (e.g. FMEA, RCM, RBI, simulation tools) treat each degradation, failure mode or risk as independent threats, whereas the reality, recognised at the common sense level, is that they often interact: one risk or degradation mechanism can exacerbate, dilute or even introduce another risk. The SALVO team have developed tools to convert such complexities into simple, total cost and risk implications - in ‘real time’, so assumptions and “what if?” questions can be explored instantly.

Another important emerging feature of this stage is the adoption of a consistent unit of cost/benefit (so that widely different options can be compared on a common value-for-money basis). Historically, the cash flow and cost/benefit evaluation of interventions has been heavily dependent on Net Present Value (NPV) and other financial measures (Internal Rate of Return, Profitability Index, Return on Investment etc.). Unfortunately these are only suited to the evaluation of a limited range of the decision options. The problem lies in their requirement for a pre-selected, fixed ‘horizon’ – whereas many of the asset life extension, or replacement, or decommissioning options involve comparisons of different horizons (where NPV values, for example, would not provide valid comparison). Fortunately there is a financial method, ‘Equivalent Annual Cost’ (an annualised version of NPV, like a pension ‘annuity’), that provides such comparability and so is incorporated within the SALVO toolbox.

Other innovations have been made in the optimization of inspection and condition-monitoring strategies, including iterative updating of the next optimal time to inspect, based on the last condition/performance found. Similarly, some new capabilities have been developed in the evaluation of life extension work such as refurbishments (including determination of the optimal amount of deferment for asset replacement) and in the systematic evaluation of multiple, dissimilar minor projects (with competing priorities for safety, reputational, performance, risk, financial impacts).

3.3.3 Field trials and case studies

Case studies for these discrete strategy optimisations and intervention justifications are being assembled into a structured ‘library’ to show how different problem types, for different asset types, in different industries can be handled. The first wave of such cases as included:

- Pole mounted **transformers** – optimal replacement timing
- **Water filter** elements – optimal replacement intervals and design option selection
- **Process control systems** – obsolescence, evaluation of options and timings
- Electric **motors** – optimal replacement timing & justification
- **Escalators** – condition monitoring, maintenance and component life cycle optimisation

Every case examined so far has shown scope for more than £700,000 per year improvement compared to existing plans or strategies.

These cases (and the on-going further studies) are being written up for inclusion and publication in a SALVO case study library, providing illustrations of the process for different decision types on different asset types in different industries.
3.3.4 Work bundling and blending

The next SALVO step combines individual tasks on individual assets or asset groups to deliver best overall life cycle value-for-money. Two core subprocesses are involved, drawing on very different methods to tackle different manifestations of this complex requirement.

**Blending** refers to finding the right combination of inspections, maintenance, 1-off interventions and renewal strategies for a specific asset or asset group. It has to cope with the fact that changes to one strategy may change the underlying degradation or risk patterns that in turn affect the urgency or value of other interventions (e.g. cleaning cycle for a boiler, to recover operational performance, has secondary effects upon the longer term degradation and ultimate replacement timings for tube bundles). SALVO models these inter-dependencies to identify the best blend, including both short term effects and downstream/total life cycle consequences.

**Bundling**, in contrast, aims to optimise the alignments and groupings of multiple activities to share some alignment advantage such as system downtime, shared overheads or remote site visit logistics. It explores the ‘bundling’ advantages versus the cost, risk or performance impacts of the individual tasks needing to occur at sub-optimal timings to enable such alignment. The APT-SCHEDULE module from the MACRO project (see Figure 8) is currently the leading edge solution for this, employing advanced ‘genetic algorithm’ modelling to find the best combinations of work and timings. It has been used very successfully for evaluating and optimising shutdown strategies (work content and shutdown intervals) in petrochemical processes, manufacturing plants and electrical utility networks, typically reducing planned downtime by 28-50% and total cost/risks by 15-25%. SALVO is incorporating this methodology and will be extending it further.

![Figure 8. APT-SCHEDULE auto-searching for best bundling of activities.](image)

3.4 Total investment plan aggregation

The final step, constructing a full picture, with budget forecasting and residual risks and performance implications, is addressed in some organisations by a direct, total workload and asset population modelling. This may incorporate degradation, risk and cost assumptions (with block-assignment of rules or weightings for their impact and consequences). Various service providers and commercial simulation tools are also available in this area. This approach can be excellent for ‘macro’ decision-making.
on system configuration options, total budget trends, major investment programme appraisals etc. (the oil & gas sector has been doing this routinely for major projects since the 1980’s, and transport and utility networks have developed similar solutions more recently), but the approach has a number of weaknesses, such as the difficulty of ‘proving’ the output, and the set-up time/cost of each ‘what if?’ scenario. So SALVO is trying to increase the transparency and instant ‘drill down’ auditability of individual contributions within the overall plan. ‘What if?’ questions can then be answered instantly at any level, from an individual intervention for a specific asset, to the global effects of changes to common factors (like resource costs or the impact of downtime).

4 Conclusions

The SALVO project represents an important development in decision making in Asset Management; in particular pressing concerns in management of aging assets. It takes existing knowledge and tools, and develops, extends and integrates them to provide a systematic and robust way of determining what is worth doing, and when for any asset type in any industry. In particular, it equips technical and asset management staff with the facilities and processes to make a clear business case, in terms that financial controllers and other stakeholders will understand.

Much work is still ahead, but the findings so far are confirming that great improvements are possible, and that they are widely applicable and real-life practical. They comprise a necessary combination of structured thinking (including education in some areas), process templates and analytical tools, which are used to navigate the complexities and to support decisions with clear, business-impact hard numbers. The project deliverables of published guidance, case studies and decision-support tools will emerge during 2012. In the meantime, bulletins and updates will be made available via the project website www.SALVOproject.org

John Woodhouse 25th October 2011