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Developing a risk-assessment methodology in the U.K. defence industry

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As a leading defence equipment company, the Dynamics Division of British Aerospace Defence Company (BAeDef(DD)) has experienced the worst effects of post-Coldwar defence cuts, a global recession, and a determination by the U.K. Government to achieve greater value for money in defence procurement. The major tenet of this new approach to defence procurement was 'eyes on, hands off', promoting a shift of the management of project risks from the Ministry of Defence (MoD) to industry. Initial industry reaction was sceptical but became increasingly compliant as tendering requirements included visibility of contractors' risk assessment. This paper describes the risk-assessment methodology created by BAeDef(DD) to meet these changed conditions.

The human and organizational aspects of these developments on risk have helped create a pro-active risk-management culture at BAeDef(DD). Continuous assessment of project risks provides the impetus for wider thinking beyond risk-taking or risk-aversion preferences, leading to greater realism in planning. Decisions to implement risk resolution measures require competence in cost–benefit analysis. The conditions to foster this new behaviour are better-informed senior management, with the rejection of bad news eliminated at all levels, and the laying of a path to becoming a learning company.

1. Introduction

Origins of the project

The managing director of the Dynamics Division of British Aerospace Defence Ltd (BAeDef(DD)) had attended an annual symposium in August 1990 convened by the MoD Master General of the Ordnance (MGO). The symposium was attended by senior MoD military and non-military staffs and by senior industry representatives. At this symposium, a paper entitled 'Risk: its assessment and management' was presented by the director general of guided-weapon and electronic systems (DGGWES). A clear signal was being given by the DGGWES to industry to adopt the principles of risk assessment in order to be able to compete in the future for defence work. This provided the necessary interest for BAeDef(DD) to develop a risk-assessment methodology.

Background of the industry and the company

The U.K. defence industry is defined by the Ministry of Defence (MoD) in its defence budget document published in the autumn of each year. In 1988–9, the MoD planned to spend £8241 million on equipment for the armed forces, representing 43% of the

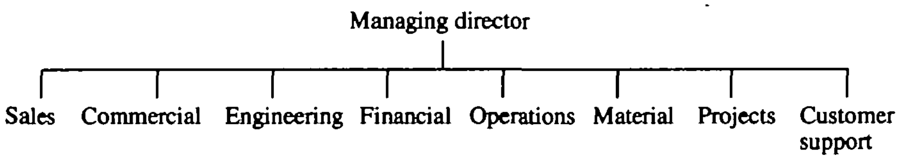

FIG. 1. Organization of the Dynamics division.

total defence budget (Ref. 1). Some 9000 U.K. firms produce defence equipment for the MoD and export customers. The U.K. was consistently among the top four arms exporters during the 1980s with £2.4 billion of sales in 1989 (Ref. 2).

British Aerospace (BAe) plc is a company that owes its origins to the nationalized company of the same name (except plc) which comprised two of the leading UK aerospace and defence companies at the time of nationalization in 1975, namely British Aircraft Corporation and Hawker Siddeley Ltd. The British Aerospace Defence Company Ltd operating under the BAe plc comprises four major divisions (the previous defence companies): Military Aircraft, Royal Ordnance, Systems and Services, and Dynamics. Each division is operated as a profit centre and has a managing director accountable to the chairman of the defence company. The Defence company designs and manufactures military aircraft (Hawker Harrier, Tornado, European Fighter Aircraft (EFA), missiles (ALARM, Seawolf, Sea Skua, Sea Eagle, Sea Dart), complete weapon systems, including missiles (Rapier, TRIGAT), rocket motors, ammunition and integrated defence systems (Al Yamamah).

The Dynamics division is organized into company functions as shown in Fig. 1. Each function is headed by a director accountable to the managing director. A wide range of management, engineering-design, and production disciplines are employed to achieve a portfolio of technologically complex products. To illustrate the range of engineering skills in the Dynamics division, Fig. 2 shows the engineering organization.

A major initiative commenced in October 1989 in the Dynamics division with an engineering competitiveness programme. The programme was designed to streamline the engineering process in the design of the products, from inception to certifiable design completion. The three main achievements were (a) reorganization of the engineering directorate along purely functional lines as depicted in Fig. 2 (there was a mixture previously of product and functional departments), (b) implementing a consistent approach to the management of projects by a process known as project

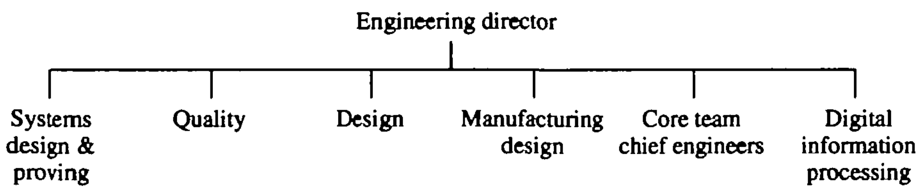

FIG. 2. Engineering organization of the Dynamics division.

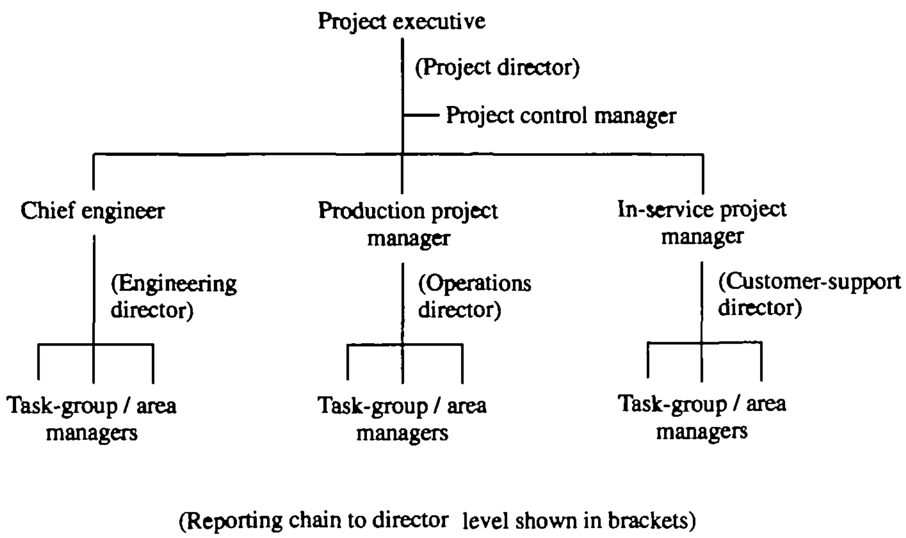

FIG. 3. Generic project core team.

control, and (c) the establishment of a bid centre to provide a centre of excellence in the way the Division handled bids for new work. The project control process resulted in the establishment of a project core team for each project; a generic core team is shown in Fig. 3. The purpose of the core team was to provide an accountable nucleus of senior managers headed by a project executive who reported to the project director.

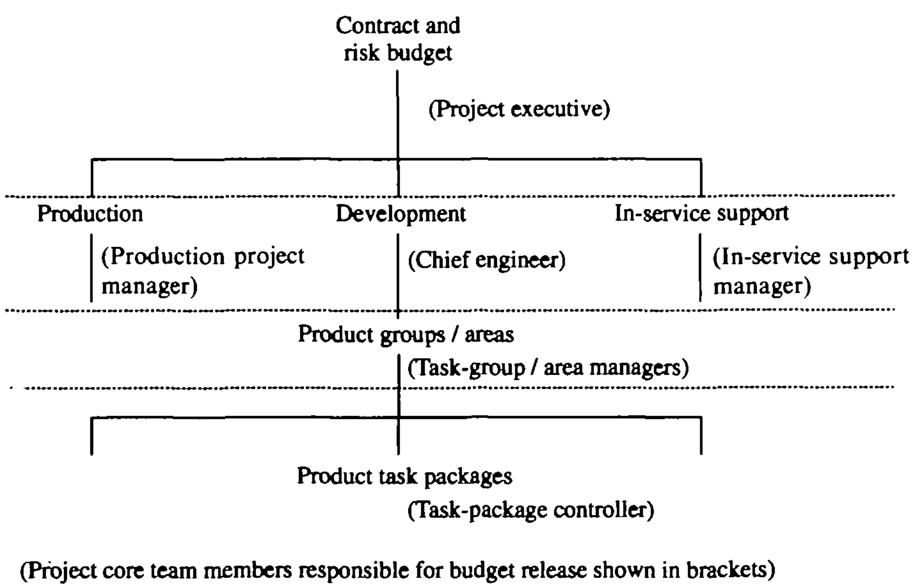

FIG. 4. Generic work breakdown structure.

Supporting the project executive directly was a project control manager and from other directorates was (a) the project chief engineer and his/her team of task-group/area managers, (b) the production project manager and his/her team of task-group/area managers, and (c) the in-service project manager and his/her team of task group/area managers. Work to be undertaken on a project is further sub-divided under the task-group/area managers to the level of accountability namely the product task package under control of a task-package controller. This delineation of work is called the work breakdown structure, a generic form of which is shown in Fig. 4.

The current report

For the purposes of this report, *risk* is defined as the probability of occurrence of an adverse event coupled with the impact that event will have. Also, risk assessment is the process of identifying events, analysing the impact an event will have, and prioritizing the elimination of risk (at best) or reducing the probability of occurrence, according to economic criteria. The objectives of this report are (a) to describe the background to the need for risk assessment, (b) to record the development in BAeDef(DD) of the risk-assessment methodology, and (c) to explore the implications on the Division's human resources and organization.

In this report, Section 2 provides a background to the problems facing the defence industry and an historical perspective for the need by industry to adopt techniques for project risk assessment; the development of the risk-assessment methodology in the division is described in Section 3. The implication on the Division's human resources and organization are covered in Section 4. Section 5 contains conclusions of the developed risk-assessment methodology.

2. Background

The purpose of this section is to provide evidence that supports the need for the U.K. defence industry to adopt formalized risk-asesessment techniques.

Initial literature search

An entry under 'risk assessment' was found in a library database on the proceedings of a one-day seminar held on 8 March 1989 at the Royal Aeronautical Society, London, entitled 'Project risk analysis in the aerospace industry' (Ref. 3). The opening address (Ref. 4) by the assistant chief scientific adviser (projects and research) of the MoD noted the developing concern in MoD about cost and timescale overruns. These characteristics were tending to become the standard on projects that were pushing the limits of state-of-the-art technology, particularly in software, sensors, signal processing, or—increasingly—some combination of all three. Reference was made in the opening address to a report 'Learning from experience' (Ref. 5) known as the 'Jordan/Lee/Cawsey report' which had investigated hardware-based MoD-funded projects and found similar problems.

The theme of cost and timescale overruns was continued in a paper (Ref. 6) by a member of staff of the principal directorate of technical costs, procurement executive, MoD, on the use of risk-analysis techniques in proposal assessment. Reference was made to a report by the House of Commons defence committee (Ref. 7). This report found that the causes of cost escalation and, in some cases, programme overruns were due to an insufficiently critical approach to technological risk assessment. One of the major problem areas identified was management. On this topic, of key importance to this report, and included in it, is part IV of the House of Commons report on project management (Ref. 8).

A major equipment programme is managed through the procurement process by a project manager who is assisted by technical, financial, and contractual staff. The examination highlighted four aspects of project management in MoD that were fundamentally weak. They are

- lack of risk assessment
- lack of commitment to sound management practice
- lack of software management expertise
- lack of support.

The first of these aspects, lack of risk assessment, is the necessary evidence that supports the need for formalized risk-assessment techniques to be adopted, not just by MoD but by industry. To the roots of cost escalation that lie in the lack of technological risk assessment must be added the unjustified optimism in the ability of contractors to develop solutions dependent upon unproven technology, within the time constraints of a project development programme.

Addressing the lack of risk assessment

Studies of MoD procurement practice were commissioned of which resulted in a paper 'Learning from experience' by co-authors Jordan, Lee, & Cawsey (Ref. 9)—sharing its name with the collective report edited by them—which concluded that further safeguards could be introduced at the selection stage of competitors through the use of risk-assessment principles. However, priority would be put on existing contracts that depended heavily on software development, since these were identified as the projects most susceptible to cost and programme overruns. The purpose of this focus of attention was to understand the degree to which MoD were still exposed to technical risk, and to see how management attention could be mobilized to limit further slips to programme. The activity would also serve as a proving ground for subsequent training. Problems were also being encountered on hardware-based projects and these would be assessed for risk next.

In the medium term, MoD personnel engaged in the selection of competing contractors would be trained in risk-assessment principles, with the long-term aim of shifting the emphasis to the contractors.

Shift of burden of responsibility of risk

The long-term shift of the burden of responsibility for risk would be achieved by a policy known as 'eyes on, hands off'. The policy was to be applied by a strategy conducted on two fronts. The first was the emergence of cardinal-point specifications in which the performance requirement would be broadly defined with the emphasis on the contractor to demonstrate compliance. The second front was that of requiring contractors to submit with their response to bids

- the results of their own risk assessment of the work to be undertaken
- what measures would be introduced to contain the effects of risk materializing
- what fallback options would be invoked to recover the programme.

Also to be included in bids would be a risk-management plan detailing how risk would be managed during the project (or phase of a project). These measures, to be included in taut contracts, would progressively shift the emphasis for risk assessment and management from MoD to Industry.

Evidence obtained of MoD's intention was found in the opening address of the seminar in 1989 entitled 'Project Risk Analysis in the Aerospace Industry' (Ref. 10). The relevant quotation from this address is: 'In future, a requirement for proposals for risk assessment and risk management in the next phase will be expected to form part of the statement of work on contractors carrying out the feasibility study and project definition phase of a project'. The message to industry was reinforced in the Master General of the Ordnance, August 1990 Symposium to senior MoD staff and leading industry representatives, managing directors, and chief executives.

BAeDef(DD) received its first MoD invitation to tender (ITT) with specific requirements for risk assessment and management on 30 January 1991. The format and content used is now standard for all MoD ITTs. Additionally, standardization of responses is manifested in the risk questionnaire. The first of these was received by BAeDef(DD) in September 1991 as an appendix to an ITT. The messages delivered and the measures taken underline the determination shown by MoD to reduce its risk exposure in the procurement of defence equipment.

3. Risk-assessment methodology

Definition of terms

Risk management in the context of this report is used to mean the application of disciplines to manage the specific risks of a project, as distinguished from the assessment and control of corporate risks involving insurance, contract provisions, and currency hedging for example. The elements of risk management are shown in Fig. 5, adapted from Boehm (Ref. 11). *Risk assessment* is the process using a set of disciplines to identify, analyse, and prioritize risks. *Risk control* is the resolution, monitoring, and reporting of measures to overcome identified risks.

Foundation

The original objective was to develop a risk-assessment methodology which would quantify the company's exposure to risk, and provide evidence to support a risk

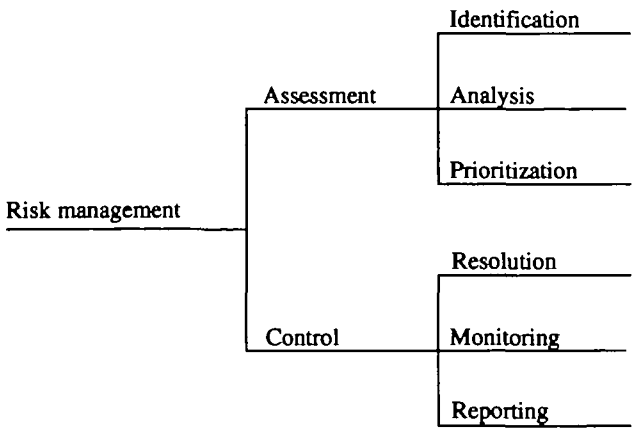

FIG. 5. Elements of risk management.

budget at the bidding phase of a project. The aim was to produce a solution which would prove to be practical, and which would provide useful, credible, and meaningful results.

Risk identification

Risk identification is the first and most important element of the risk-assessment process. It is fundamental to the attainment of meaningful results during the risk-analysis stage, i.e. the analytical techniques will only yield worthwhile results if the data derived during the identification phase are of value; emphasis is placed on realism in this stage. The derivation of meaningful results during the bidding phase is not easy. The very fact that these assessments are made at an early stage, sometimes before the project definition is complete, means that the assessor's depth of knowledge of the project can be relatively limited. If an assessor feels insufficiently equipped to identify the risks (e.g. due to inadequate project definition, or high technological advance on a sub-contract item), then he/she should inform the project executive and indicate the problem on the company's risk identification form in the space provided for notes and assumptions.

Risk identification is typically carried out for each task package on the work breakdown structure, and also at overall 'system' level. Risk is assessed for development, production, and subcontractors. Risk identification has two phases at task-package level: (a) descriptive and (b) quantitative. Then an overall assessment is made at (c) system level, as outlined below.

Descriptive phase. The descriptive phase requires the assessor to record the risk drivers intrinsic to the nature of the task package. These typically include technology, human resource capabilities, complexities in dealing with interfaces to the task package (whether in-house or subcontractors), and interpretation of requirements. Certain assumptions are given to assist the assessor with the identification: for example, that inputs and outputs to and from the task package are on time and risk-free and that required resources are available as needed. Overriding exclusions are also given such as natural disasters, industrial action, and company reorganizations. Risks likely to impinge on other task packages are required to be noted so that an assessment may be made at a system level.

Quantitative phase. This is the numerical definition of the risk associated with a task package. For a simple situation, a risk could be quantified by stating a single probability of occurrence, and a single resulting cost impact. However, risk is generally not a black-and-white situation. There are usually different levels of impact that could result if a given risky event materialized. These levels of impact are usually associated with a variety of probabilities. It is for this reason that an approach based on statistical probability distributions has been chosen to analyse risk.

Because most of the people assessing risk within the company had little or no statistical background, it was clearly impossible to ask them to define the required distribution and its required parameters. Therefore a pragmatic approach was taken, whereby the risk assessors quantified the risk by defining minimum, most-likely, and maximum values for each risk (see Table 1 for definitions). In general, a triangular probability distribution was applied to each 'three-point estimate' (see Fig. 6); but, where this was considered inappropriate, another distribution such as beta, normal, or uniform was used. The product of the risk-identification phase would be a complete set of minimum, most-likely, and maximum values for each task package on the work breakdown structure, with their supportive descriptive statements.

System-level risk. In addition to the risk identification at task-package level, it is also necessary to consider any system-level risk. This is risk which has not already been identified at task-package level, but may occur as a result of interfacing sub-systems or task packages. The assessment of system-level risk should be carried out by people with a broad knowledge of the project, e.g. chief engineer, production project manager, etc. Often a brainstorming session is used, bringing together people from across the complete spectrum of the project.

Modelling

On receipt of all of the three-point estimates, they are examined by a risk analysis

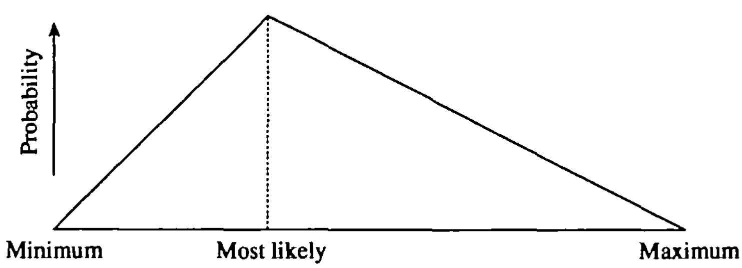

FIG. 6. Triangular distribution based on a three-point estimate.

TABLE 1

Definitions of minimum, most likely, and maximum estimates

	Minimum	Most likely	Maximum
General definition	the lowest estimate (optimistic) assuming that none of the identified risks materialize, and excluding unknown break-throughs in new technology—statistically, the highest estimate such that there is no probability of achieving a lower value	the most probable estimate assuming that likely risks materialize—statistically, the highest frequency of occurrence, i.e. the mode (not the mean i.e. the average, or median, i.e. the 50% point, unless the distribution of estimates is symmetrical about the most likely value)	the highest estimate (pessimistic) assuming that all identified risks materialize, excluding cata-strophic failures—statistically, the lowest estimate such that there is no probabillty of exceeding it
Development assumptions	experienced staff are available, with above average effectiveness; down times of facilities do not delay programme, and the tech-nology is fully understood	staff have typical skills and effectiveness; down time has minor effect; some learning of technology is required; etc.	staff have below average skill, experience, and effectiveness; down time has major impact; staff are unfamiliar with the technology; etc.
Production assumptions	improvement in manufacturing practices is greater than expected under normal cost improvement; the design solution achieves minimum-cost hardware, e.g. 3 printed-circuit boards	current performance with predicted level of improvement continues; the most probable hardware cost arises, e.g. 4 printed-circuit boards	little or no improvement, or even worsening of performance occurs; for hardware cost, the worst-case arises, e.g. 6 printed-circuit boards
Material assumptions	No changes occur to subsystem specifications on subcontractors	a typical level of subsystem specification changes occurs	a high level of subsystem specification changes occurs

TABLE 2
An example of 3-point estimate data

Total inputs excluding system risk:		23,971,608	31,168,403	44,817,736	23.09%	43.79%	33,319,249
Total inputs including system risk:		28,083,776	37,449,644	57,151,300			40,894,907

Activity description	Risk excess†	£ Minimum estimate	£ Modal estimate	£ Maximum estimate	Deviations Min % (−VE)	Max % (+VE)	Mean risk‡
Core team	166,667	5,000,000	5,500,000	6,500,000	9.09	18.18	5,666,667
Motor	24,155	470,000	633,768	870,000	25.84	37.27	657,923
Airframe	29,970	37,686	43,983	140,190	14.32	218.74	73,953
Command break-up units	673,422	897,773	1,439,339	4,001,171	37.63	177.99	2,112,761
Epack	50,320	3,936,304	4,693,876	5,602,408	16.14	19.36	4,744,196
Seeker	842,214	4,611,306	5,999,448	9,914,231	23.14	65.25	6,841,662
Gyro	32,042	3,242,196	4,295,923	5,445,776	24.53	26.77	4,327,965
Trials	187,746	1,830,000	2,133,381	3,000,000	14.22	40.62	2,321,127
Modelling	0	3,000,000	5,000,000	7,000,000	40.00	40.00	5,000,000
System specifications	144,311	946,343	1,428,685	2,343,960	33.76	64.06	1,572,996
Programme overrun	429,144	287,431	1,000,000	3,000,000	71.26	200.00	1,429,144
Motor requalification	23,059	213,431	281,793	419,333	24.26	48.81	304,852
Seeker redesign	842,214	3,611,306	4,999,448	8,914,231	27.77	78.30	5,841,662

† The excess of the mean risk estimate over the modal risk estimate, in £.
‡ In £; this value is not used for modelling.

TABLE 3
Monte Carlo simulation results for the total project

	Percentage cumulative probability of achievement	Total project cost (£)	Percentage risk allowance from the most likely
	0	34,299,960	10.05
	10	38,152,400	22.41
	20	39,032,260	25.23
	30	39,706,840	27.39
	40	40,246,320	29.13
	50	40,799,780	30.90
	60	41,378,850	32.76
	70	42,002,800	34.76
	80	42,794,050	37.30
	90	43,759,080	40.40
	95	44,633,500	43.20
	100	48,392,210	55.26
Mean value	52	40,894,910	31.21
Most likely	0	31,168,403	0.00

Best possible underspend from the mean (expected) value is	£6,594,950 (16.13% of mean)
Worst possible overspend from the mean) (expected) value is	£7,497,300 (18.33% of mean)

to find the major-cost risk drivers. The indicator for these is the excess of the expected ('average') risk over the modal (most-likely) risk, listed under the heading 'risk excess' in the example shown in Table 2. The drivers in this case are the seeker, seeker redesign, command break-up units, and programme overrun. Once the three-point estimates have been checked for anomalies, a proprietary software tool is used to carry out a Monte Carlo (Ref. 12) simulation, of the costs at project level. In general, 5000 iterations are carried out. When the simulation is complete, a table of results is produced as in Table 3. (The software package used also presents the results in the form of a histogram and a graph of the cumulative distribution.)

The baseline for the bid is the most-likely value. In the case of a non-competitive bid for a Government contract, the most-likely cost is thoroughly investigated by MoD's pricing and quality services team, and the bid is pitched at the mean value. Table 3 shows that, for our example project in Table 2, the mean value is £40.89M. This is 31% higher than the most-likely value of £31.17M, and has 51% confidence of achievement. The worst possible case for the company should be an overspend of £8M from the contracted value.

Improvements to risk-assessment methods

Risk analysis is still developing within BAeDef(DD), and we are continually seeking to improve our methods until we are satisfied with them. The difficulties of achieving an accurate assessment of risk include the following.

- The technical specification is often not fully defined at the time the risk assessment is made.
- The customer's requirement may change during the assessment phase.
- There is seldom enough time for the assessors of the risk to consider all the possible sources of risk.
- Our projects use many leading-edge technologies, and the risk assessor may not have an in-depth understanding of whatever it is that he/she is assessing the risk of—this may particularly be the case where the item is being subcontracted.
- Approximately 80% of our work is subcontracted, and this presents a significant challenge at the bidding stage to predict the exposure to BAeDef(DD) of subcontractor problems; contract terms alone will not safeguard programme-dependent activities.
- Some risk assessors are naturally optimistic and tend to underestimate the number of risks.
- Other risk assessors are naturally pessimistic and tend to overestimate the number of risks.
- There is a lack of well documented historic data.
- Often it is difficult to see the full scope of the task, at an early stage, and activities may be omitted.
- Our projects teams are often very large ($\approx$500 people), and good communication is a constant challenge.

By addressing the above difficulties, it will be possible to improve the risk-assessment data. The final results of the analysis can at best be as meaningful as the initial data from which they were derived.

4. Implications for human resources and company organizations

A number of key themes emerge from the foregoing description of the risk-assessment methodology that relate to the validity of the results of risk analysis. They are personal skills, organization, and best practice.

Personal skills

These are the skills required by those undertaking risk assessment in order to provide justified inputs that will result in valid outputs. Among the list of skills required, those below are considered the most important for the reasons given.

- Technical knowledge is vital for understanding the innate technical risk and complexity of tasks.
- Knowledge of risk factors is necessary to enable correlation between resources, facilities, technology, and subcontractors.

- Personnel selection is key to achieving the optimum team membership by drawing on experience and mix of discipline from the available workforce.
- Realism in cost and timescale estimation, because it is important to balance out the natural optimism.
- Knowledge of the system is required to enable an overview of the risks within and between tasks.
- A degree of caution and scepticism in assessment is required during the collation of individuals' risk estimates.

Organization

Company organizations may be stable or change frequently. However, the business processes conducted by a company will usually be constant. The following procedures help a company to organize its processes for risk assessment methodology.

- The compilation of data recording work day by day. These may be reflected upon, together with case studies drawn from the company's records.
- The recuction of data to enable the identification of trends and development of tools to assist with risk assessment. Examples are checklists, synthetics, standard work schemes or task breakdown structures to ensure that nothing is missed, and risk registers used as living documents from the bid stage through to task completion.

Best practice

The purpose of risk assessment is not only to identify those risks that may have an adverse impact on company performance, but also to foster an environment that addresses risk early. Best practice is the potent combination of personal skills working with the organization to spawn the following characteristics:

- a commitment to being a learning organization through pan-project learning events, open access to historic data, benchmarking, and strong policies for the development of human resources;
- pro-activity in identifying and averting risk, founded on cost–benefit analysis;
- better-informed senior management;
- lateral thinking and problem solving as routine responses to new risks;
- freedom from the fear of and rejection of bad news at all levels.

The key schemes can be mapped to provide a continuous-improvement model as shown in Fig. 7. The implications of the continuous-improvement model are: (a) developing personal skills through training, multi-skilling, coaching, and self-assessment, (b) organizing company systems to capture and analyse data, and (c) best practice through learning.

5. Conclusions

This report set out to describe the development of a risk-assessment methodology in the UK defence industry. The conclusions may be summarized as follows.

- Identification of risks is the most important challenge of all the elements of risk, since it provides the base data for the other elements. Emphasis is placed on realism

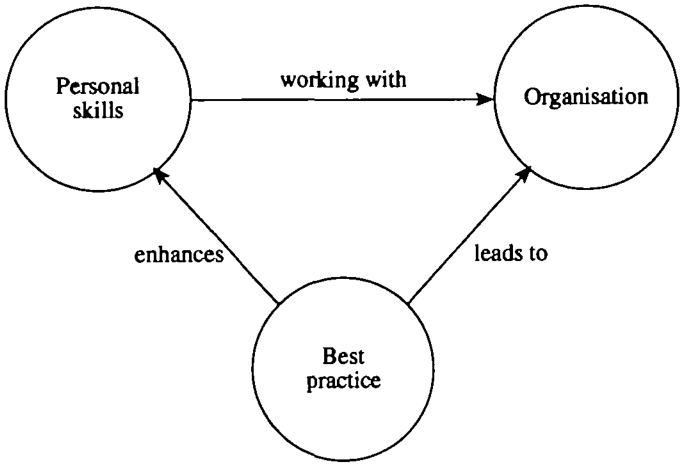

FIG. 7. A model for continuous improvement.

in the identification stage; otherwise the results can indicate overoptimism or undue pessimism.

- Interpretation of results needs to be conducted by suitably skilled staff who also need to be able to challenge the inputs to the process.
- Events in project history, together with the cost and programme impacts, should be recorded and shared in order that case-study material is captured and used in tutoring of staff enaged in risk identification.
- For risk identification to be successful, the key personnel need to learn of project risk factors through training and case studies and then be given the latitude to apply the learning to their own applications.

A model for continuous improvement presented in the paper suggests an integrated approach to support the task of risk identification and analysis of results.

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