Surviving Failures: Lessons from Field Study

By A. Jaafari,[1] Member, ASCE, and A. Schub[2]

Abstract: This paper presents the results of a field study of a sample of 15 projects and an equal number of organizations in the Federal Republic of Germany. The study objectives are firstly to elucidate typical approaches currently taken to technical and technological risks in engineering projects; and secondly to see if the existing concepts and techniques can be improved further. The work indicates that there is a need to radically revise the attitude and approach to identification, assessment of the impacts, and "engineering out" or mitigation of these risks. A major finding not widely recognized concerns the relationship between risk reduction and business profitability. A case is made for the introduction of a proactive management policy to technical and technological risk control involving the entire organization. Case material shows that the acceptance of risks by construction contractors in depressed market conditions is a deadly gamble, as it will inevitably lead to severe cost penalties. An alternative approach based on a higher level of risk assessment and work organization is presented in this paper. For this to be successful, adoption of a different management philosophy is required.

Definition

The word *risk*, as used in this study, is taken to mean the presence of potential or actual constraints that could stand in the way of project performance, causing partial or complete failure either during construction and commissioning or at the time of utilization (Jaafari 1987). Technical risks are those that relate to the fundamental properties, processes, and concepts such as failure of an earth dam embankment in operation due to the overestimation of the shear strength of its structure. Technological risks are related to plant and equiment, manufacturing and construction processes, state of hardware, and the like. Failure of a construction method to achieve its expected production level is an example of technological failure, as is a situation of frequent plant breakdown during the utilization phase of a project. Technical and technological (T and T) failures can be of a minor nature, e.g., a modest cost overrun, or they may produce catastrophic results, involving loss of human life.

Introduction

Traditionally, engineers and managers have been wary of potential T and T failures in planned processes, facilities, and the like due to the adverse publicity associated with such failures. The legislature has tended to step in after the onset of a tragedy, enacting statutes and introducing regulations to ensure public safety. These measures have been aimed at reducing incidences of death and personal injuries in projects. Beyond the concern for public safety, the economic consequences of T and T failures in projects

[1]Sr. Lect., School of Civ. and Mining Engrg., Univ. of Sydney, NSW 2006, Australia.

[2]Prof. of Constr. Mgmt., Tech. Univ., Munich, West Germany.

Note. Discussion open until August 1, 1990. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 7, 1989. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 116, No. 1, March, 1990. ©ASCE, ISSN 0733-9364/90/0001-0068/$1.00 + $.15 per page. Paper No. 24424.

seem to have received little attention by the practitioners, despite all the attendant disturbances suffered in practice.

In fact, many consider such disturbances to be a natural part of project planning and implementation in engineering fields, and quite a few go on to pride themselves in having been able to fight, and partially contain, the effects of disturbances due to T and T risks. Few professionals have questioned whether enough is being done at the early stages to eliminate or reduce T and T risks in the first place, and whether such measures have any impact on the viability of the project itself, positive or negative, or the profitability of the organizations undertaking it, or the national economy as a whole. These questions influenced the writers to undertake the study reported in this paper.

Objectives

More specifically, the initial objectives were as follows:

1. Study of the actual approaches typically adopted by a selected sample of organizations to identify T and T risks, assess the impacts, and eliminate or cover the same in project undertakings, particularly in innovative projects.
2. A fundamental inquiry to identify the main factors presently affecting organization T and T risk control, and suggestions of ways and means of improving the approach and mechanics of controlling these factors in practice.

Study Methodology

Limitation of space does not permit a full coverage of the research methodology deployed; this has been fully explained in the main report of this study (Jaafari and Schub 1988). Briefly, because of the nature of the subject, it was decided to base the study on structured interviews with senior head-office managers or directors of both owners and contractors. A questionnaire was designed and used as a "vehicle" for the work (Jaafari and Schub 1988). Owing to the idiosyncracies in projects and the need for the writers to adequately understand the technical nature of T and T failures, a considerable amount of additional facts and information was also obtained and recorded for each case study.

The actual field study was conducted in the summer months of 1988. This posed a limitation on the number of cases that could be covered. In all, 15 organizations and an equal number of cases were researched; these were either situated in, or originated from, the Federal Republic of Germany (FRG). Table 1 shows characteristics of the studies.

The study was designed to shed light on a number of hypotheses:

1. The necessity of a proactive management policy towards T and T risk control.
2. The necessity to subject the project to an independent T and T risk review by qualified professionals of high status and authority, before implementation.
3. Risky projects require additional measures to control T and T risks, e.g., review of critical issues by experts, group brainstorming, extensive testing, and pilot plant operation.
4. The industry culture or traditional project implementation practices will have

TABLE 1. Characteristics of Case Studies and Their Respective Organizations

Case number (1)	Project type size (dollars in millions) (2)	Organization type, size (total employment) (3)	Purpose (4)	Sponsor (5)	State of technology (6)	National or transnational (7)	Implementation period (8)	Actual or potential loss (dollars in millions) (LL = no)[a] (9)
1	Subway tunnel (33)	Contractor (1,300)	Public transport	Public agency	Established (new application)	National	1978–84	Significant (6.6)
2	Large open pit 50 × 70 m	Ground engineering contractor	Large commercial	Private	Established	National	1986–87	Significant (exact figure not available)
3	Subway tunnel (15)	Owner (300)	Public transport	Public agency	Partly new for the owner	National	1978–82	Major (10.5)
4	Canal (water transport) (33)	Owner (1,050)	Water transport	Public agency	Established	National	1967–79	Catastrophic (6.6) (LL = 1)
5	Bridge	Owner (6,300)	Public transport	Public agency	Established	National	1974–76	Catastrophic (for contractor)
6	Environmental improvement (10)	Owner (2,000)	Public health	Public agency	Established (new application)	National	1988–?	Expected overrun = 20% (Negotiation for contract)
7	International airport (2,000), subproject (26)	Owner (1,600)	Air transport	Public agency	Established	National	1987–91	Minor. (None suffered by owner)
8	Building (7)	Contractor (23,450)	Housing	Public agency	Established	Transnational	1984–86	Major (10)
9	Subway tunnel (40)	Contractor (23,450)	Public transport	Public agency	Established	National	1984–89	Significant (12)
10	Sewage treatment plant (40)	Contractor (2,885)	Public health	Public agency	Established (new application)	National	1984–87	Critical (14)
11	Suburban railway (40)	Contractor (22,130)	Public transport	Public agency	Established (new application)	National	1985–88	Minor (2.8)
12	Nuclear Power Station (2,360)	Contractor (>40,000)	Power	FRG Government State Government and utilities (all public)	Established (extended)	Transnational	1971–88	Major (1,967)
13	Satellite (50)	Contractor (2,500)	Scientific exploration	European Space Agency	New (for a familiar function)	Transnational	1983–84	Significant (subcontractor 2.5)
14	Nuclear fuel reprocessing (2,200)	Owner (250)	Reprocessing spent fuel	Utilities (public agencies)	Established	National	1982–?	None (redesign for improved performance)
15	Direct reduction sponge iron plant (200)	Contractor (4,000)	Sponge iron production	Overseas government	New (for a familiar process)	Transnational	1982–86	Significant (10)

[a]Refers to the number of lives lost.

a bearing on the approaches to T and T risk control, with newer, and more technically complex industries being better placed to control T and T risks compared to more established ones.

In addition, a clear distinction was made between T and T risk control on the one hand and safety engineering and/or quality assurance on the other hand. T and T risk control extends beyond the objectives of safety and quality assurance, as it affects the inherent processes in project construction or operation and thereby affects the potential return on the funds invested in the project by all participants.

The writers decided to measure the magnitude of disturbance in each case project relative to its initial budget. The scale suggested ranged from minor (e.g., up to 10% overrun) to significant (10–30%), critical (30–70%), major (>70%), and catastrophic (involving loss of life).

As seen in Table 1, the study includes 4 cases outside the construction industry. These were included for the purpose of cross comparison and to enable investigation of the hypothesis No. 4, which concerns the influence of the type of industry on T and T risk control practices.

General Organization Attitudes

Out of necessity, only a brief discussion of the responses received and other information assembled is presented in this paper. [See Jaafari and Schub (1988) for a more detailed coverage.]

Tables 1 and 2 show key information items of the organizations that took part in the study, as well as their current orientation to T and T risk control. Generally speaking, there is no set pattern for each organizational type. For example, there is no significant difference between the responses in the construction sample versus the rest (Table 2). However, the owners, as a whole, appear to be better organized to control T and T risks on their projects compared with contractors.

The spectrum of information gathered through field interviews also confirms a perceptible recent trend in both owner and contractor organizations towards a more effective T and T risk control (see case studies).

There is an apparent mismatch between the responses included in Table 2. Eighty percent of the organizations (12 out of 15) stated that they had a proactive policy to T and T risk control. However, in reality, many did not have an organization unit to carry out these policies. Only four organizations had a set procedure for T and T risk control. Moreover, as will be seen from the case studies, their behavior in many cases can be classified as "reactive" rather than "proactive." Also, despite a thorough briefing by the writers, two organizations (of which one is only included in the sample) considered their quality (or product) assurance departments to be responsible for T and T risk control, and one contractor considered that construction managers, who are technically qualified, are fully responsible for T and T risks on their projects.

On projects involving considerations of structural stability, such as bridges, the owners relied heavily on the experience and skills of proof engineers to insure against T and T risks. This is a statutory requirement in the FRG. Also, in the water resources sector, the provision of public health engineering acts influenced the owner to carry out independent reviews of the

J. Constr. Eng. Manage., 1990, 116(1): 68-86

TABLE 2. Summary of Responses Received on Policy/Strategy/Organizational Setup

Case number (1)	(2.1) Declared policy (2)	(2.2) Person/ department consultant (3)	(2.3) How it came to be set up (4)	(2.4) Project control (5)	(2.5) Controlled by whom (6)	(2.6) Status (7)	(2.7) Qualification and experience (8)	(2.8) Independence (9)	(2.9) Effectiveness (10)	(2.11) Set procedure (11)
(*a*) Construction Industry Branch										
1	Y	N	—	Y	NF	—	—	—	—	N
2	Y	N	—	Y	NF	—	—	—	—	N
3	Y	Y (1980)	PFF (1980)	—	—	Y	Y	Y	Y	Y (construction)
4	Y	Y (1979)	PFF (1980)	—	—	Y	Y	Y	Y	Y (design)
5	Y	Y	RG	—	—	Y (PE)	Y (PE)	Y (PE)	Y (PE)	Y (DIN's)
6	Y	Y	RG	—	—	Y	Y	Y	Y (partially)	Y (EIL)
7	Y	Y (CM and PE)	T	—	—	Y	Y	Y	Y	Y (Project handbook)
8	Y (1985)	Y	Reduce risks	—	—	Y	Y	Y	Y (optional)	In progress
9	Y (1985)	Y	Reduce risks	—	—	Y	Y	Y	Y (optional)	In progress
10	N	N	—	Y	NF	—	—	—	—	N
11	Y	Y	To reduce T and T risks	—	—	Y	Y	Y	Y	Y
(*b*) Other Industry Branches										
12	Y	Y (QA)	RG	—	—	Y (QA)	Y (QA)	Y (QA)	Y (QA)	Y (QA)
13	N	Y (product assurance)	PA	Y	NF	Y (PA)	Y (PA)	Y (PA)	Y (PA)	Y (PA)
14	Y	Y (+committee)	T	—	—	Y	Y	Y	Y	Y
15	*N*	N	—	Y	*NF*	—	—	—	—	N

Note: Columns 2.1–2.11 correspond with the questions of the same numbers in the questionnaire. Y = yes; N = no; CM = construction manager; PE = proof engineer; PA = product assurance; QA = quality assurance; PFF = prevent further failures; RG = regulatory requirement; T = traditional practice; NF = normal function; DIN's = the German codes of practice; and EIL = environmental impacts control laws.

pertinent projects before implementation (case No. 6).

The motivation in the case of two large contractors (cases No. 8 and 11), to set up T and T risk control units in 1985 and 1982 respectively, is purely commercial. The contractor in case No. 11 stated that various company branches were making the same technical mistakes, and that their bids were not being prepared using a consistent format. The new practice instituted by this contractor involves formation of a "bidding project group" for each project at the branch level, with one or two participant experts from the head office to oversee the preparation and submission of the bid. Once a bid is successful, the project manager, who has been a member of the same bidding group, will take over the job. However, this particular group meets twice or more annually, during the execution phase to monitor the adequacy of its prebid planning, and receive feedback from the project manager.

This company is in the process of implementing a company-wide scheme to record and share experiences of its professionals throughout all its branches.

General Pattern of Failures

Table 3 shows a summary of the responses received on case studies. A brief discussion is given below [consult Jaafari and Schub (1988) for an expanded discussion].

Generally speaking, Table 3 shows that disturbances occurred at critical times; during construction, commissioning, or operation. Failures were often due to the malfunction of the completed facility or serious shortcomings of the construction methods. The rank is as follows: wrong methods (five cases), latent ground conditions (four cases) and omissions/errors on the part of the designers (four cases). However, of the latter, two cases were related to the inadequacy of site investigation (soil) reports. Thus, the commonly held view that design omisions and errors are the primary cause of disturbances in projects is challenged.

The magnitude of disturbances ranged from minor (3 cases) to significant (five cases), critical (three cases), major (two cases), and catastrophic (two cases). In the latter two cases, nine people lost their lives. The financial impact of these losses on the respective organizations (Tables 1 and 3) varied, being positive in case No. 14 (in the sense that a redesign took place to reduce T and T risks, and thereby improve project's safety and maintenance operations), through to minor (six cases), significant (three cases), major (four cases), and ruinous (one case). One of the contractors of the joint venture in case No. 1 (not included in the sample) also went into liquidation, though not solely due to this case.

Although the financial impacts in relation to the size of many organizations were not significant in many cases, the same is not true of the branches or divisions of these organizations who were hit very badly. These branches often operate as subsidiaries or as profit centers.

The majority of cases (11 out of 15) deployed established technologies; of these over half (six cases) considered new applications and/or new environments. There were cases where new technologies were either used or the existing technology was taken one step further. However, there is no evidence to suggest that the respective cases suffered more disturbances due to the use of new technology. This finding is a variance somewhat with the view put forward by Morris and Hough (1987), who see technical com-

J. Constr. Eng. Manage., 1990, 116(1): 68-86

TABLE 3. Summary of Responses Received on Case Studies/Disturbances/Strategies Adopted/Actions Taken and Consequences

Case number (1)	(3.1) Project contract type (2)	(3.2) Size of disturbances (% cost) (3)	(3.3) Stage of project discovered (4)	(3.4) Timeliness (5)	(3.5) Who discovered (6)	(3.8) Financial impact (7)	(3.9) Effectiveness in this case (8)	(3.10) Cause (9)	(3.11) Influence of luck (10)	(3.12) Adequacy of approach (11)	(3.13) Maintaining T and T risk unit (12)	(3.14) Means of T and T risk control (13)	Remarks (14)
(a) Construction Industry Branch													
1	TK	S(20)	Construction	NT	Contractor	MA	—	CWM, LGC	UL	N	—	IRC, GBS	Joint venture with two contractors
2	T	S	Construction	NT	Res. Eng. Owner	MI	LE	CWM	UL	N	—	GBS	Transfer risk to owner
3	T	MA(70)	Construction	NT	Contractor	S	—	LGC	UL	N	Y	IRC, GBS, CNT	T and T unit after project
4	T	CA(200) LL = 1	Operation	NT	Method failure	MA	—	OD, LGC others	UL	N	Y	GBS, CNT, LST	Risk control after project
5	T	CA(200) LL = 8	Construction	NT	Method failure	NIL(0) R(PC)	NAA	CWM, PE	PL(0) UL(PC) UL(PB)	Y(0)	Y	IRC, GBS, CNT, LST	No effect on the owner
6	In the process	S	Design	ACS	Project manager	MI	LE	—	NRC	Y(0)	Y	IRC	Project not yet fully designed
7	T	MI	Construction	ACS	Fellow designer	MI	AT(0)	OD	PL	Y(0)	Y	GBS, LST	Good managerial practice and coordination

8	TK	MA(100)	Procurement construction	NT	Owner	MI	Set up later	FSW	UL	N	Y	GBS, LST	Subcontractors default
9	T	S(30)	Construction	NT	MF due to ground	MI	Not audited	OS (soil report 2 was diff.)	UL	Y	Y	GBS, LST, PP	Soil condition varied. Change const. method
10	T	S(35)	Construction	NT	Contractor	MA	—	Complex job	UL	N	—	None	Market conditions are tough
11	T/TK	MI(7)	Construction	NT	Contractor	MI	SE	OD, CWM	UL	N	Y	IRC, GBS LST	Unusual problems
(*b*) Other Industry Branches													
12	TK → CR	MA(500)	Construction	NT	RG, MF	MA	NAA	OD, OS,	UL	N	Y	IRC, GBS,	Overrun mainly due to EIL & safety regulations
13	TK	NIL(PC) CT(35) SC	Commission (testing)	NT	Contractor	S	—	CWM	(SC)	Y(PC) Y(SC)	Y(PA)	GBS, IRC, CNT	PC did not lose money due to compensatory events
14		MI	Design	Redesign (concept)	PM, Owner	Positive	AT	N.A.	P	Y	Y	IRC, GBS	Change of concept design to improve M and R
15	TK	CT	Commissioning	NT	Contractor	S	N.A.	OS Coal variations	UL	N	—	GBS, LST, PP	T and T control acts against creativity

Note: Columns 3.1 to 3.14 correspond with the questions of the same number in the questionnaire. See also notes in Table 2. TK = turnkey; CR = cost reimbursement; S = significant; MA = major; CA = catastrophic; MI = minor; CT = critical; NT = not timely; ACS = avoiding cost/schedule overrun; LE = to a large extent; NAA = not at all; AT = almost totally; SE = significant extent; CWM = contractor's wrong method; LGC = latent ground conditions; OS = owner's change of scope; FSW = fabricator's wrong information; UL = unlucky; PL = plain lucky; NRC = no room for chance; IRC = independent risk consultants; GBS = group brainstorming; CNT = conservative use of new technology; LST = laboratory/scaled testing; PP = pilot plant.

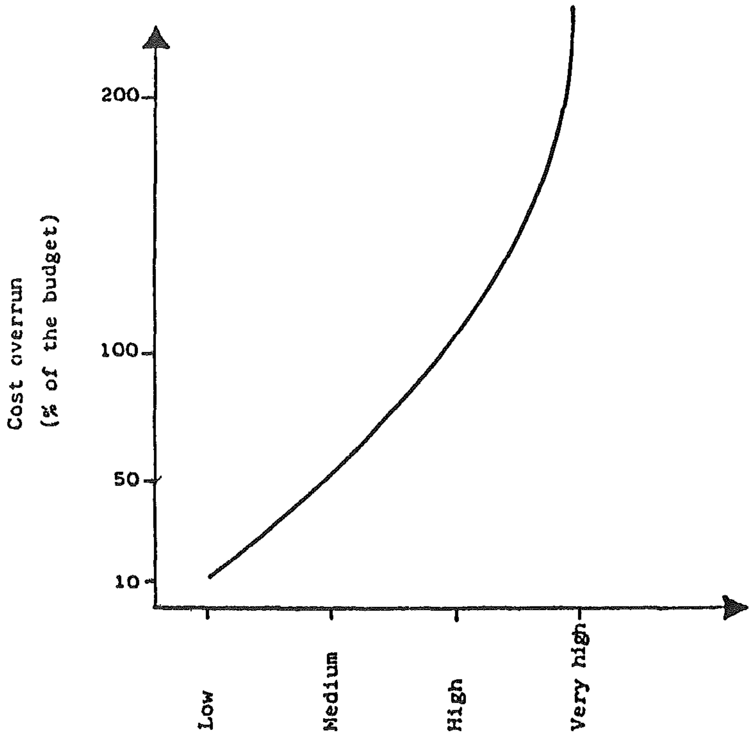

FIG. 1. Schematic Relationship between Residual T and T Risks and Potential Cost Overrun

plexity or innovation causing cost overrun and taxing management's capability.

Technical complexity in a project is not necessarily a failure by itself, as in a seemingly simple project using established technology, there is always a possibility of experiencing significant disturbances if T and T risks and other constraints are not adequately addressed beforehand. The evidence in many cases, as summarized in Table 3, supports this point. These will be discussed further on in this paper. Suffice to state that it is the presence of residual (or dormant) risks that can cause failure, unless there are compensatory events or processes that can save the project.

Table 3 clearly shows that luck did not play a role in the vast majority of failed cases. Only in case No. 13 (satellite project) did it save the private contractor, i.e., this contractor did not suffer financial loss when a subsystem supplied by a subcontractor failed to perform satisfactorily in ground testing prior to the launch. This was mainly due to the delay in the preparation of the launcher (not part of the same contract), which provided the prime contractor with ample time to get things right.

The general picture of the cases in this study shows (see Tables 1 and 3), that the higher the residual or dormant T and T risks in a project the greater the extent of expected disturbances. A linear increase in T and T risks can

J. Constr. Eng. Manage., 1990, 116(1): 68-86

cause an exponential increase in the project cost overrun (see Fig. 1). The relationship in Fig. 1, which is derived from the data gathered from the project cases, clearly shows how unmitigated T and T risks can influence the project outcome commercially. For example, case material shows that the unresolved T and T risks in cases No. 1 and 9 were around the medium mark on the horizontal axis. The cost overruns suffered in these projects by the contractors were of the order of 20 and 30% of the budgets respectively.

It is interesting to note that this relationship is in general agreement with that suggested in Jaafari (1987). The latter was derived from entirely different case material.

Altogether, nine organizations stated their dissatisfaction with their approaches to T and T risk control in their respective projects; whereas six stated their satisfaction. The follow-up information confirmed that in the dissatisfied groups, serious moves aimed at changing the organizational approaches and setup had basically followed the unhappy outcomes experienced in two cases (No. 3 and No. 4).

A general agreement could be observed that in the light of their experiences many organizations were convinced of the worth of T and T risk control units and attendent policies, even though there was some disagreement on their effectiveness in the cases under consideration (see Table 3).

Although many considered group brainstorming and pilot plant operation as effective means of T and T risk control in risky projects, one contractor considered that in heavy construction projects exploratory work should form an integral part of the bid and be allowed for in the contract by the owners. The reason is that in the time slot typically allocated by owners for tender preparation, there is often insufficient time to undertake the required exploration, and in any case, the costs are too high to be set against the bid preparation account.

Validity of Hypotheses

As stated previously, the study was formulated to shed light on four main hypotheses concerning policy, organizational set up, extra measures for handling risky projects, and the influence of hereditary environment. The idea was to challenge the recorded information to see whether there is evidence of association between a particular organizational approach and the corresponding outcomes experienced commercially. The writers did not use statistical tests to test the validity of the aforementioned hypotheses for three main reasons;

1. The idiosyncratic nature of projects in the sample, ranging from small to highly complex projects.
2. Nature of study methodology, which, out of necessity, has a "negative" tendency as it concentrates on "failed" cases to distil significant lessons from them.
3. Nonrepresentitiveness of the sample, and the fact that organizations selected for research were not evenly spread geographically. (The practicalities of time and travel had to be taken into consideration when one writer tried to shortlist organizations and cases for inclusion in the study.)

After much deliberation, the writers decided to summarize the information in a tabulated form, showing the position of a given organization at the time

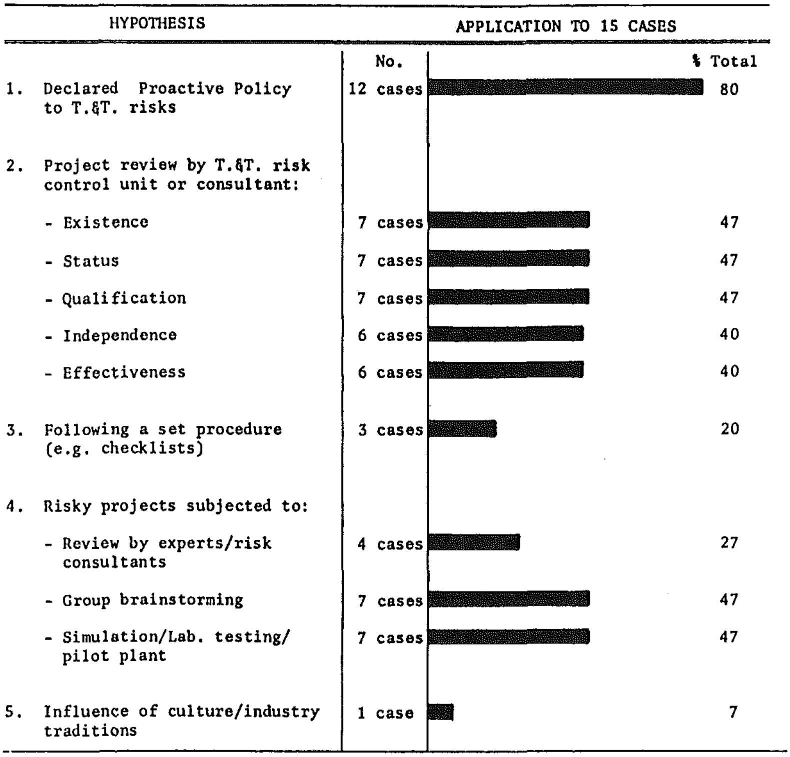

FIG. 2. Application of Hypotheses to Case Studies

of undertaking its project against the corresponding consequences suffered. Owing to the shortage of space, the result is shown in Table 1 of the main report of this work (Jaafari and Schub 1988). Fig. 2 provides a pictorial representation of the application of the hypotheses in a combined format. It is drawn from the aforementioned Table. The advantage of this methodology is not only confined to the ability to get a fuller picture by examining the collective entries. It also provides a means for performing a comparative study of the individual cases in terms of the hypothesis under consideration. Moreover, summarized entries can be augmented by reference to the field data recorded for each case when needed.

Influence of Policy and Organizational Setup

As was stated previously, the management claimed in at least 13 cases that it had instituted a proactive policy to T and T risk control; these included 11 fully or partially failed cases. Thus, on the surface, one might conclude that hypotheses No. 1 and 2 are not valid.

A glimpse over Fig. 2 (compare the length of the relevant bars) indicates that the management claims may only be partially true. In fact, it shows the apparent mismatch between the declared policies on the one hand, and the means of execution of these policies on the other hand, as was referred to previously.

Setting aside the management's claims to control T and T risks actively, the body of evidence available shows clearly that where a diligent attempt has been made to control T and T risks, especially through an independent organizational unit of adequate authority, the result has been successful (cases No. 7 and 14). Even in case No. 5, despite the tragic failure, the owner, who had followed up this practice, did not suffer liability for consequences.

The most significant case is the nuclear fuel reprocessing project (case No. 14). Despite a fairly complex technology and many potential T and T risks, the project has progressed well so far. In this project, the expenses of T and T risk control were accepted as a sound commercial investment from the outset, and appropriate strategies were incorporated into the design and implementation plans of the scheme. In fact, not one but many systematic reviews by top experts have contributed to the project's overall configuration. The final layout and the associated software (including operating procedures) were designed for not just a bare minimum compliance with the statutory nuclear regulations. The aim has been much higher. The owner decided to develop and construct a reliable plant with adequate back-up systems and safe operational characteristics. Thus, the expenditure on the systematic T and T risk mitigation is considered a sound commercial investment by the owner.

This theme is repeated in the design and construction management of the international airport project [case No. 7, discussed in Jaafari and Schub (1988)].

Contrast these cases with the tunneling projects (cases No. 1 and 9), which suffered cost overruns due to inappropriate construction methods. For example, in case No. 1, the contract called for two parallel tubes with only a small separation, to be excavated for subway railways. The joint venture of contractors proposed to use a tunnel boring machine (TBM), working in compressed air, to excavate the tunnel.

Several difficulties arose that forced the removal of the TBM and the change of the construction method to the New Austrain Tunnelling Method (NATM). The web between the two parallel tunnels was too thin to absorb the considerable side thrust exerted by TBM. When excavating the second tunnel the web deformed and failed. Other problems included excessive loss of compressed air due to ground porosity, and ground collapse in sandy unstable areas.

Cases No. 1 and 9 were not reviewed by independent experts. The explanation given to the researchers apparently points to an error on the part of those who proposed their respective construction methods. However, it is overly simplistic to accept such an explanation. The researchers speculate that in both cases the joint venturers knew the T and T risks. Their submission of "ungeared" tenders could be attributed to two possible reasons, viz: (1) An attempt to secure the work first and seek to make the money later, utilizing contract variations; and (2) an attempt to win work in a badly-depressed market, even if it involves accepting some risks.

The losses in cases 1 and 9 amounted to $6,600,000 and $12,000,000 respectively. These were mainly due to the necessity to change the construction methods. A conclusion is that it is not easy in heavy construction to have "fall-back" plans, ready to put in place should the original method fail.

J. Constr. Eng. Manage., 1990, 116(1): 68-86

The only viable approach is to get it right first time, or to "engineer out" or cover T and T risks, not just simply accepting them, even in a depressed market.

Influence of Advanced Technology

By way of examples, cases No. 7, 12, 13, 14, and 15 embodied advanced technologies. Although cases No. 7 and 14 may be considered successful projects, cases No. 12 and 15 must be viewed differently. Let us consider case No. 15 first.

This project involved construction of a direct reduction plant to produce 700,000 tons of sponge iron annually in an overseas location, employing a unique process technology, which utilizes the local coal as the source of fuel.

When the plant was commissioned, it performed well from the technical point of view. However, the output that had been guaranteed was significantly short of the contracted output, apparently due to the fact that the grade of coal in practice had turned out to be lower than that of the sample supplied by the owner. As the contractor had not specified a consistent procedure for the owner to supply the original sample, he had to accept the responsibility for plant modifications, amounting to at least $10,000,000. This is a classical example that even when the contactor has a mastery of the technology there is a risk of failure commercially if T and T risks are not analyzed and mitigated systematically.

This case and cases No. 7 and 14 point to an important observation, i.e., advanced technologies do not necessarily induce T and T failures by themselves. It is the failure to systematically assess and mitigate their impacts on projects that can potentially cause failure. This observation is reinforced when case No. 12 is also considered. What caused the massive cost and schedule overruns in this project was not the newness of technology [see Jaafari and Schub (1988) for details]. It was, in major part, a failure to proceed cautiously, and to get a clean bill as far as the residual T and T risks were concerned during the concept design and project formulation.

A conclusion is that on technically complex projects, it is prudent to sign the contract when it is seen with reasonable certainty that adequate assessment has been made of dormant T and T risks, and that there are provisions to cover any residual risks beforehand (see also Morris and Hough 1987). In fact, this procedure is well exemplified in case No. 14, which is a nuclear fuel reprocessing project briefly described previously. Another good example is the international airport project (case No. 7, Tables 1–3).

Case of Risky Projects

One aspect uncovered by this study is the fallacy of the common perception of heavy construction projects by many professionals and the public at large. Although these projects do not make sensational media headlines, they are often complex and risky undertakings, according to the definition of risks in this study. Many familiar projects are, nowadays, required to be executed under numerous constraints, including environmental and economic pressures.

The tunnelling projects described previously illustrate this point amply.

To survive and prosper in such an industry it is thus necessary to adopt a very thorough approach to prebid planning and assessment of T and T risks, a practice not well appreciated traditionally in the construction industry, but one that will have to be adopted in future as is exemplified by the perceptible recent moves by the majority of the contractors in the sample (see cases No. 1, 2, 8, 9, and 11 included in Tables 1–3).

It is submitted by the writers that under tight market conditions currently prevailing, both nationally and internationally (Navaare and Schaan 1987), it is no longer viable to leave the planning of construction to supervisors and site managers closer to, or at the time of construction. To show the necessity for a different approach and to illustrate the fact that many seemingly routine projects may turn out to be risky projects, one needs only to review the outcomes experienced in cases No. 2 and 10.

Case No. 2 was a contract for the excavation of a large pit (50 × 70 m × variable depth) in a soft clay, for a large building project. The contractor left the preparation of the construction plan and the actual execution of the work to the engineer in charge, who was not sufficiently experienced. Steel sheet piles were driven around the proposed pit, and excavation proceeded inside the area. The clay was too soft, however, and began to flow into the pit from under the toe of the piles containing the pit area. This was discovered too late, when it had already induced significant ground depression in the adjoining area, which in turn had led to the settlement and major cracking of the buildings in the neighborhood. The excavation had to be halted, and a new construction method devised. Not only did the project suffer substantial cost overrun and delays, but it also fell victim to complex legal proceedings.

Case No. 10 illustrates a different aspect of risky and complex projects. In this project, the joint venture of contractors lost a total sum of $14,000,000 on a $40,000,000 contract for the cónstruction of a sewage treatment plant. According to an expert analysis, 45% of the losses were due to underestimation of the costs (or inadequate analysis of the job's T and T requirements); 45% due to the acceleration of the schedule in the later part of the contract; and the remaining 10% due to poor management of the joint venture, poor organization of the site, general site overheads for the winter months, and problems related to the subcontractors.

Of the six lots of contracts consolidated into a single joint venture contract, five were technically interdependent, thus requiring extra efforts to coordinate the work of the contractors. Also, the original tenders were based on smaller sites, limited site transportation and material handling expenses. In a consolidated contract the expenses of transportation and material handling within a larger area increased significantly.

These points confirm the fact that there is a transition point regarding the size of the project, beyond which a linear increase in size may necessitate an exponential increase in managerial efforts to plan and coordinate the project; a situation the writers call "negative economies of scale."

Obviously, it is not possible to eliminate T and T failures altogether no matter how sophisticated the analytical and experimental methods become. However, it is submitted that the adoption of innovative approaches to T and T risk mitigation will still pay dividends, as in aggregate, the magnitude and frequencies of T and T failures will be down. Thus, it will result on a profitable operation in a tight market. In other words, if a thorough planning is undertaken, T and T risks are assessed and mitigated beforehand, and other things are equal, then at least 80–85% of the operations are expected to be profitable, resulting in an overall acceptable profit margin.

From the owner's perspective, the management of a risky project becomes even more critical because he is the one who stands to lose most if T and T failures occur.

In summary, the case evidence clearly suggests that complex projects should be: subjected to group brainstorming, covering underlying design philosophies, assumptions, nature of process/methods, proposed sequence of operation, variations in raw materials/soils, susceptibility to environmental factors, etc. The aim should be to identify all possible combination of factors/processes, environments, and associated T and T risks including suggestions for engineering out or mitigation of these risks; and complex projects should also be subjected to rigorous testing and pilot plant operation or trials. This is especially important at a time when computers are being used increasingly to carry out the relevant engineering calculations, and even design the plant using, for example, computer-aided design and drafting packages.

Influence of Hereditary Factors

One of the hypothesis in this study, mentioned previously, concerned the influence of hereditary factors within a particular branch of industry. The supposition was that newer industries, such as aerospace, were better organized to handle T and T risks compared to the traditional industries such as construction.

This hypothesis may be considered from several aspects such as the nature of projects typically undertaken, the structure of the industry, the business procurement practices, the influence of the regulatory bodies, and the single corporation versus the total industry in which it operates. These aspects are considered herein. However, based on statistical rates of failure alone, the writers believe that the hypothesis just mentioned cannot be proved valid. The least that can be stated is that the evidence is inconclusive, as there are costly failures in aerospace industries and in construction (see Jaafari and Schub 1988). The following point comparison may thus be more informative than the comparison of the T and T failures statistics in each branch of the industry.

Nature of Projects

The evidence in cases No. 13 and 14 show that the nature of a given project can influence its management philosophy. Nonetheless, it is wrong to assume that heavy construction and even complex building projects are taken lightly. In fact, engineering sciences and technologies have just progressed in these fields. For example, the writers can cite the international airport project (case No. 7), in which a myriad of complex technologies related to numerous fields had to be designed and integrated. The approach taken by the owner team was, no doubt, influenced partly by the nature of this project. In case No. 6 too, the owner displayed a high degree of sensitivity partly due to the nature of the project.

Thus, the degree to which the nature of the project undertakings may influence the managerial approaches typically adopted within distinct industry branches cannot be ascertained. All that can be said is that in the construc-

J. Constr. Eng. Manage., 1990, 116(1): 68-86

tion industry there is probably a wider spread of appreciation of the task at hand compared to the newer, more centralized industries, such as aerospace.

Structure of Industry

Construction contributes a significant proportion of the national economy in most countries. However, its structure is dispersed. No single company, however major, has a commanding share of the market. Contrast this with the often oligopolistic or monopolistic structure of other industries. Does this affect assessment and mitigation of T and T risks in projects?

In response, the writers believe that the following will probably apply:

1. In the centralized industries, due to the concentration of projects and manufacturing processes, any T and T failure can have substantial consequences. Thus, although T and T failures are more systematically controlled in these industries, there are still occasional failures with substantial financial impacts, and even loss of life (e.g., the Challenger disaster). On the other hand, in the construction industry, T and T failures are more frequent but of less damaging effects. One reason for development of this situation is the diffusion of responsibilities in the construction industry (i.e., separation of design from fabrication or construction), coupled with its fragmented structure. These forced the legislature to enact statutes to ensure the public safety. Much of the design is, in fact, based on conservative codes.
2. The process of T and T innovation in the construction industry is slow and incremental. In contrast, the centralized industries are dependent on a continuous stream of T and T innovations to ensure market competitiveness and profitability. These industries are subject to both revolutionary and evolutionary processes of innovation. Thus, on this score alone, the possibility of T and T failure is greater in these industries.
3. The likelihood of past mistakes and T and T failures repeating themselves in centralized industries is relatively small due to a stricter control of the design and development process. On the other hand, it is not uncommon to observe repetition of a mistake in the construction industry, not only among different companies, but also within different branches of the same company. Prevalence of mistakes often leads to unreported economic losses, which are in turn responsible for the relatively high rate of bankruptcies observed in the construction industry.

To recapitulate this point, it is evident that the dispersed structure of the construction industry is probably responsible for a greater number of T and T failures, but with the distinction that construction-related failures have generally less severe consequences compared to those in the centralized industries.

Business Procurement Practices

Considering that in a competitive bid on a turnkey contract, the contractor typically accepts all the T and T risks, one would expect that the incidences of T and T failures would be less common in these approaches compared to the traditional measurement-type contracts. The case evidence collected (Tables 1–3) does not support this theory. As was discussed previously, on

J. Constr. Eng. Manage., 1990, 116(1): 68-86

some projects researched, some incredible T and T risks were accepted by the contractors, which ultimately entailed substantial losses. Why should this be the case? One probable reason is the keen state of competition in the market place and the multiplicity of the building and civil engineering contractors with an infinitely varying range of overhead expenses. The rate of entry and exit in the construction industry is so high that it may resemble that of new crowds of people constantly entering and leaving a casino; some rich, others mostly penniless.

The situation in centralized and oligopolistic industries is not as desperate, since major companies often control a commanding share of the market, and can influence the price structure. Thus, compared to construction contractors, they have a much better chance to control T and T risks on their projects, and pass on the expenes to their customers.

In short, the method of procurement in the construction industry has an adverse effect on the assessment and mitigation of T and T risks by contractors. In tight market conditions, a prospective contractor has to have a very low T and T risk, as a change of construction method half way through construction, or reworks and other changes, or even extra supervision efforts necessary to inspect and verify the work in progress, are all cost burdens that he cannot afford.

Influence of Regulatory Bodies

Looking across the cases and the body of evidence gathered, it is not possible to differentiate between the relevant branches of industry as far as the influence of the regulatory bodies on T and T risk control is concerned. In the construction industry, the provision of safety and public health regulations does not necessarily eliminate or mitigate all T and T risks as one can imagine a perfectly safe site but with a costly or impractical construction method, or with inferior quality materials or frequent performance failures of the completed facility, and so on. During the operational phase, incidences such as substandard product, excessive energy input, and frequent equipment failures also constitute T and T failures that are not necessarily directly related to the safety regulations.

One would expect that the fear of financial losses and other consequences should be sufficient to motivate owners and contractors alike to assess and mitigate T and T risks systematically on their projects. However, the evidence from the case material suggests that this is not necessarily always the case. In other words, safety violations and/or loss of life due to a catastrophic failure (such as a structural collapse), tend to figure highly in the minds of designers and managers, especially when it is connected to adverse publicity and loss of license. In contrast, there is a general lack of appreciation of the relationship between successful T and T risk control and business profitability. As was stated in the introductory remarks, many even consider that the disturbances suffered due to T and T failures are a natural part of project engineering and construction management processes, a most undesirable perception.

The writers, throughout this study, have, in fact, attempted to highlight that T and T risk control has a positive return, and can improve commercial profitability of the respective organizations (cases No. 7 and 14). It is not a cost burden on the organization under consideration.

J. Constr. Eng. Manage., 1990, 116(1): 68-86

In short, reliance on the regulations alone does not ensure a smooth and profitable project outcome. There is a need to assess and mitigate T and T (and other) risks systematically throughout project stages.

Single Corporation versus Total Industry

Should there be management plans specifically designed to suit individual organizations, considering managerial styles, organizational characteristics, and the individual capacities to undergo the desired organizational changes within a designated period of time?

The evidence from case studies and the writers' observations indicate that technological organizations have different structures and styles of management. Some have evolved, others designed to suit their size and operations, and a combination of these factors may also apply. Further, as was observed, different organizations tackle T and T risk control differently; some seek to incorporate the required measures into their overall scheme, much similar to the quality assurance schemes (cases No. 3 and 4), while others see it as an integral component of the scheme (cases No. 7, 9, 13, and 14).

In other words, the industry association should raise the awareness of the membership in general, and provide guidelines, as well as convincing case histories. Each individual organization should then devise and implement its own unique scheme to suit its needs and aspirations.

Conclusions

The work presented in this paper shows that T and T risk control lies at the heart of successful project planning and implementation. The writers submit that a radical change of perception of the field of project engineering and management is necessary. The aim should be to identify all risks and constraints in projects beforehand and not to proceed on a less-than-thorough plan. One must not accept as "natural" the costly disturbances typically suffered during project implementation.

Acknowledgments

To all those distinguished managers and directors who spared so much of their valuable time to receive the writers, and cared to contribute their views to this work. We are also grateful for the suport of Deutscher Akademischer Austauschdienst, without whose sponsorship of Dr. A. Jaafari this work would not have been possible.

The writers gratefully acknowledge the support of their respective institutions, especially Technical University's Institut fur Bauingenieurwesen IV, Munich. Thanks are also due to Ester Cabrera, who typed the manuscript of this paper.

Appendix. References

Jaafari, A. (1987). "Genesis of management confidence technique." *J. Mgmt. in Engrg.*, ASCE, 3(1), 60–80.

Jaafari, A., and Schub, A. (1988). *A study of technical and technological risk assessment and mitigation strategies in major engineering projects.* Institut fur

Bauingenieurwesen IV, Tech. Univ., Munich, FRG.
Morris, P. W. G., and Hough, G. H. (1987). *The anatomy of major projects*. John Wiley and Sons, Chichester, United Kingdom, 216–220.
Navaare, C., and Schaan, J.-L. (1987). "International engineering project management: Key success factors in a changing industry." *Int. J. of Project Mgmt.*, 5(4), 238–245.

J. Constr. Eng. Manage., 1990, 116(1): 68-86