

Technological Disasters: Policy Imperatives in High-Technology Settings

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Abstract

In this paper, a cognitive analysis is presented of alternative paths available to an organization to slide into a technologically-induced crisis state from more routine modes of operation. Cognitive mapping of plausible crisis decision-paths results in a multi-path scheme that enables one to comprehend, even assess, the erratic development of political and socio-technological events. Contrasting the cognitive opportunities in crisis situations with the cognitive failures implicit in pre-crisis settings, the multi-path simulation technique enables a more sophisticated understanding of the dynamics of crisis development.

Introduction

It is now more than 25 years since the 'accident' at Three Mile Island (TMI) (Sills, Wolf and Shelanski, 1982; Lebew, 1987; Sagan, 1993). Since the mid-1980s, such accidents have become more notable. The Shuttle exploded over the coast of Florida (Jarman and Kouzmin, 1990). And so the dates diminish: Chernobyl, Exxon Valdez and others which would also include the environmental discoveries of massive pollution in the former communist states-both west (the Elbe River) and east (the Valdivostock submarine fleet base). The list of 'human-caused' disasters is not diminishing.

Lest the optimism within us takes over too readily, one is sobered by the recent observation of Erikson (1994:142):

Technological disasters have clearly grown in number as we humans test the outer limits of our competence, but more to the point, they have also grown in scale..... (Concerning Three Mile Island).... there is a sense it did "just happen". This is not because the fates are full of mischief sometimes but because accidents are simply bound to happen sooner or later as human systems become more and more elaborate.

In part, this paper is concerned with the implicit meaning of Erikson's term 'elaborate'. For many other authors such a term might imply, as synonym, the word 'large-scale'. Others might mean 'complex' - a term whose usage deserves careful explication following La Porte, (1975; 1996) and others (Hall, 1980; Morone and Woodhouse, 1986; Lagadec, 1990).

Conceptual formulation of this issue concerns the last interpretation of the word 'elaborate'. As we shall see the idea behind this interpretation is that in the context of technological disasters, 'simple' systems can become 'complex' very, very quickly: a topic to be discussed below. In three examples (Chernobyl, Aeroplane Crashes and Software Systems' Failures), what might be one minute a working science/technology marvel can become the next 'living hell'. The Concorde failure confirms this assertion. Again from Erikson (1994:142).

It is also true in the sense that the news of it (the accident at TMI) broadcast so quickly and so widely that it becomes a moment in everyone's history....a part of our collective consciousness.

Technological disasters: Conceptualizing the contingent

In presenting this paper, it could be argued that the joint authors are being a little self-indulgent. After all, it is nearly 15 years since this putative contingency schema was first presented to a European audience in 1987 (Kouzmin and Jarman, 1989). Figure 1 (Appendix A) shows the graphical schema whereby the three independent variables are: environmental *states*; decision *processes* and technological *states*.

It should be noted, however, that in the 1989 model, the authors chose to concentrate their conceptual ideas on the inter-relationships of the first two variables; that is environment and the decision process. A second accusation could be that the authors have likewise been tardy. Perhaps, but for a good reason: the heuristic value of the original 1989 schema has been so rich in applications' potential that it is time to 'push the conceptual envelope' further and explore the second half of the original schema - the environment/technology connection. This is done with a sense of obligation to many others.

Lying behind this initial sense of general obligation is a profound sense of acknowledgment to the Berkeley/Yale contributors to this discussion. While many others have informed our ideas concerning these topics, the analytical work begun with La Porte's (1975) volume concerning 'organized social complexity' to Erikson's (1994) recent 'new species of trouble' deserve our appreciation.

Having said this, all of these gentlemen may not agree wholly with our reformulation of some of their central concepts, especially Perrow (1967, 1984, 1994) and Brewer and De Leon (1983). A detailed reference to Figure 1 will show immediately that we have altered Perrow's (1967) well-known 'technology' typology. In the case of Brewer and De Leon, (1983) our proposed 'meta-policy' progression does not conform exactly to their 'policy science' schematic (Brewer and De Leon, 1983: 150-154). Finally, are the authors being dogmatic? This accusation is possible regarding most contingency theorists: it is *their*, possibly unique, typology after all. If so, the authors are in numerous and perhaps famous company. Colleagues from around the globe have either invited us to their homes (literally) and/or visited us in Australia to discuss these conceptual ideas and their practical application (Kouzmin and Jarman, 1989; Kouzmin, Jarman, Korac-Boisvert and Saleeba, 1992; Kouzmin, Sainsbury and Jarman, 1994, 1995). More recently, Australian disaster experience (NSW bush fires of 2000) have informed our case-data base.

At a more technical level of discussion, it is necessary to see what lies inside 'the envelope'. Its basic components are familiar to contingency theorists in general, but a formalization of the variables deserves some explication. Specifically, the schema might be summarized as follows:

Decision-Making
Rules

| | | | |
|-----------------|-----|---------------|---------------|
| Concerning | (F) | Environmental | Technological |
| Technological = | | X | State |
| Disasters | | Type | |

The dependent variable (decision-making rules) relates to the interaction between Perrow's (1967) reformulated *Technologies* and Emery and Trist's (1965) *Environmental States*. In this formula, it is assumed that the rules for technological planning exist (as with an algorithm) and that such rules require a 'congruent' form of environmental state. In the context of our three disaster case studies, for example, with regard to Chernobyl, it was not wise to use an old nuclear reactor for the purposes of performing 'sensitivity' simulations. In similar vein, the US Shuttle, as a more stochastically-sensitive system, could not withstand the risk of a frosty morning launch, while in many weapon systems, flawed systems' design meant that pattern-recognition scenarios were not comprehensively programmed.

Figure 1 and Table 1 (Appendix A) present a brief picture of where the authors want to take the new analysis. The main interest concerns reformulating the environment/technology relationship so that the three cases can be described and 'explained'. Before this can be done, however, a fuller state of the contingency relationship deserves at least tabular explanations (see Table 1).

Determinism

As the first of the four derived types of technological context, a few general comments are needed before discussing each type in order. Initially, it should be understood that the environmental/technical 'interface' might be bi-directional; that is, the original cause of the disaster could be from within the machine itself or, alternatively, begun in the system's environment. Secondly, as one progresses from Determinism toward physical disaster, the social aspects of risk can begin to dominate the nature of the policy making discussion (Wildavsky, 1988). Thirdly, this paper will not consider the significant issue of compensation for the victims of such disasters. We believe others have analyzed and written about these topics more comprehensively (Bovens, 1990).

The main task is to consider the basic decision rules which can be applied to certain, and increasingly inherently, 'risky' situations. The analytical concern lies more with the constraining parameters of the 'design' issues which engineers, in particular, might acknowledge as they seek to bring some mechanical concept into operational reality. As such, one should recognize the strengths of many such designs but also the weaknesses which can exist as the technological *and* environmental factors begin to interact over time. Chernobyl and the Concorde are, in this context, 'cases in point'.

Determinism, as the first of the four types, should of course be the most familiar type of decision context for physicists and engineers (Sutherland, 1977: 12; Stacy, 1996). Whilst they are all educated to understand the impossibility of the 'perfect machine', they also spend much of their design time seeking to calculate the 'factors of safety' which their specific operational system might require so as to perform to its intended function. Friction and gravity underline all such calculations.

Therefore, such engineering 'science' is more likely to be concerned with the effective rather than the efficient. In this context, effectiveness does not mean the perfect machine, but it should compel the designer to seek the 'reliably' - working machine. Such machines probably never will be wholly 'cost-effective'.

A nuclear reactor should qualify as a suitable example. Although such machines may differ in terms of basic design factors, for example, heavy water versus ordinary, they all need to be cooled and controlled so that core 'meltdown' does not occur. Even the movie *The China Syndrome* was probably a caricature of what really happened inside the control rooms of Windscale (1957), Three Mile Island (1979) and Chernobyl (1988),

when the prospect of such meltdown became either statistically probable, or worse, imminent. The causes of the demise of these three reactors are well known today.

Imagine the scene at Chernobyl a decade ago: Technicians wanted to find out if sufficient power could be maintained while standby diesel generators were brought into emergency use, in contravention of written rules, the team put the reactor into low power and switched off some important safety systems. All these moves made the reactor more unstable (Czada, 1990).

We know much of the rest of the story which immediately had regional (Czada, 1990) and international (Sagan, 1983) implications. Today, many analysts will be speculating about the California (power) syndrome. In the context of both Chernobyl and, earlier, Three Mile Island, it is a disastrous situation not to be able to make deductions first as computer programmes (qua algorithms) and then as heuristic emergency procedures. Effectiveness, in this context dominates, analytically, both costs and efficiency.

If the machine at Chernobyl had been left to perform its intended controlled *routine* functions there is no evidence to suggest that it would have exploded. However, the engineers' attempt at 'cost-efficient' optimally failed; in this case, disastrously. Human *environmental* error, as failed simulation, caused the disaster, not systematic malfunction as a consequence of normal operations. This was not a 'normal' accident as Perrow (1984) would state the issue.

Near-Optimal system failure

Much more normal, and as a consequence of design-taking risk, is the issue of near-optimal systems. In this decision context, it is to be expected that the need to optimize, as design, interacting physical conditions will render the design and performance of the system nearer to optimal than 'maximal' (the case of Determinism). While 'factors of safety' will still exist, more design effort will be taken by the designers to save 'sensibly' money; especially where the trade-offs relate to issues of required recurrent operational costs such as fuel, people and other expensive 'factors of production'. Therefore, in terms of the environment/technology interface, such systemic optimality can come at a price: the ultimate price being lost lives caused by stochastic 'normal accidents'.

The explosion of the US Space Transportation System (STS or Shuttle) constitutes an 'aircraft safety' example, albeit of a somewhat exotic variety. But like all aircraft, even the Concorde, the STS had to be designed with the knowledge that many important trade-offs would have to be made. In addition to the calculation of the size (capacity) of the cargo bay were the factors of the maximum weight of the payload (especially military reconnaissance satellites), the resultant fuel requirements, the low-earth orbit limits of the entire system for re-entry to earth's atmosphere and the need for weighty cooling systems - including the tiled, nose-cone system, all of which could have failed.

In general terms, therefore, the STS constitutes an example of a near-optimal system. The above list of issues would appear to some system designers as sub-optimality to others, 'necessary risk'. However, as the conditions of near-optimality might be explained, it was possible to both design and manufacture an operational 'shuttle' service to inner-space (if not geo-stationary orbit). In this 'engineering' context (qua Perrow, 1967), such sub-optimality do not necessarily constitute compromises to 'satisficing' means (Simon, 1957). Any needles in haystacks, 'good enough' or, in this country, 'she'll be right, no worries', should not be the language of serious engineers who know how to calculate the limiting constraints of sub-optimality forms of trade-off. It is not necessarily the dependent variable (as payload) which should suffer from such constraints (although, at the limit, this could determine project calculation). More likely,

it will be the weight, fuel, trade-offs acting as constraints which compel careful calculation and (unlike Chernobyl) controlled simulation studies.

Technically, therefore, a near-optimal system is by definition more 'complex' than a nuclear reactor. Whereas, the reactor must be considered to be a 'simple' system containing numerous levels of redundancy, the STS is a more complex system because the design trade-offs exist in the first place. In the case of the Shuttle, on re-entry the key aspect of heat control (the surface tiles of the Shuttle) lies outside the direct control of the operators, both inside the Shuttle and outside of Houston's 'control' centre. Tiles do come off and this has happened on numerous occasions; to date without serious consequence.

The explosion of the STS 26 was not caused by any of these trade-offs (although it could have been). More important, in the context of near-optimality, human-related, environmental variables did play a key role in the disaster. Two such factors deserve special attention: first, the key technical failure of the O-ring (which was the most pronounced cause as stated in the Rogers Commission Report (1986). Secondly, and importantly, were the 'environmental' pressures for systemic 'commercialization' emanating from the White House through the National Space Council (a topic which was not so prominent in the Commission report (Jarman and Kouzmin, 1990).

As would be expected, the failure of the O-ring was studied exhaustively. But it must be added that the issue of cause and effect became confused. This is a 'complex' issue because the launch data (as heuristics) did not include any confirmed knowledge of sub-zero temperature Solid Rocket Booster (SRB) behaviour: this launch in such 'environmental' conditions constituted a 'precedent'. The normal bureaucratic mind-set would fly into a spin at such precedent (provided they remained 'risk-averse'). But what of more commercially-minded bureaucrats who might be judged as risk-takers? The Rogers Commission (1986) enquiry does not speculate in this regard - so one needs to return to this issue.

Also environmental was the issue of the role of the company-based technologists who actually were involved with the design and analysis of SRB operations after each flight. At Morton Thiokol (the SRB suppliers), the thought of such a 'precedent' was carefully and professionally considered. They recommended (at first) - no launch. The reason is technologically obvious: if no data (regarding temperature-related, O-ring behaviour) - no standards - and, therefore, a probable high-risk - unsafe system. This less stable environment became 'connected' and so compounded the systemic complexity.

Again, as with Chernobyl, human agents pushed beyond the known limits of the 'envelope'. In the case of the STS, what had been a relatively 'routine' system (much to the irritation of NASA's scientists) all of a sudden became a nightmare (from which some truly irresponsible people might still sense the trauma). The Rogers Commission (1986) did not clarify these additional issues of risk, complexity and failure (Romzek and Dubnick, 1987).

In conclusion, the explosion of the STS also highlights a further weakness in complex systems analysis and their environments. If the STS was regarded by NASA as being such a 'safe' system *before* the explosion, why did the cancellation of all other scheduled flights need to occur (and so stop earning much-needed revenue for more than thirty months)? Why not just launch the next ready system making sure that the temperature was above 52⁰F for which the engineers had a usable data set? Or does this imply not just guilt but, more importantly, a self serving or, even, ideological, 'riskiness' of the STS unacknowledged *before* the fateful and tragic launch of STS 26? One will probably never know the answers to these difficult questions; but with regard to the 'technology-environment' interface they are relevant and important questions.

Subjective group uncertainties: Squishy problem solving

The first two typological categories have constituted the initial focus of the environmental/technology discussion. In these respective circumstances, it should be noted that the increasingly uncertain environmental states have led to ever-complex forms of problem solving. The third such context is even more 'complex' and, indeed, extends the STS case by also involving *physical* with organizational aspects of such environmental instability (Nijkamp, 1994). In the case of the STS, the weather created an unfamiliar state of problem solving, whereby the known 'standards' of risk could not/did not apply, a similar situation will obtain in 'squishy' problem solving (Strauch, 1975).

And worse - in this case, unlike the previous two, 'market-related' aspects of environmental uncertainty, enter now the situation bringing with it more stakeholders, new performance criteria (for example, profit, return on investment, share of market) and the demand-related aspects of consumer satisfaction. Therefore, given these additional contingent factors, one can use the issue of technological change as it affects the private airline industry as an example, especially the emerging use of communications' networks which are meant to enhance capital/consumer safety.

How might this theoretical context and its related empirical data sets constitute an example of 'squishy' problem solving? There are three aspects to this reply. First, technologically speaking, the 'craft' (qua Perrow, 1967) that is relevant here is software design and engineering. This emphasis on craft is especially relevant as more and more airline systems depend on expert systems as 'fly-by-wire' command and control systems. Secondly, environmentally, the skies must become more spatially 'complex' as airports seek to land and take-off ever more flights to meet ever-rising consumer demand. Finally, the issue of airport and flight economics can impact on the private sector performance of competitive airlines. PAN AM at the time of the Lockerbie crisis, seemed to have relaxed some of its risk-management practices and some would argue not necessarily without the knowledge of the US/CAA (Foster, 1994).

Each of these issues will be considered in order. First, computer-based 'command and control' systems have been related to air-based system control for decades (Bracken, 1983). The US Defence Department (DOD) helped develop radar systems: inter-continental defence early warning systems do not constitute some mysterious 'state-of-the-art' mission analysis. In the context of simplicity/complexity, defence analysts have concluded that they agree that the most vulnerable parts of the US strategic forces are the command-and-control-and-communication (C³) system. Such vulnerability is not likely to diminish: indeed, many see defence reliance on commercial communications and satellites likely to increase.

Two decades later this situation has changed, at least in technical (and of course political) terms dramatically (Winner, 1986). The contention is that software - related 'craft-related' writing is even more pronounced as such terrestrial and space communications' systems become more digital rather than the conventional analogue signals still used today. To be even more provocative, how much of total communications system will actually be analogue by the Year 2005? This 'digitized' world will become increasingly software-dependent. Today, throughout Australia's government lies concern and confusion about the 'standardization' of software-based PC-networking based on 'future-perfect' product promises marketed by skilled multinational 'players' (Kosnik, 1990).

To the conservative reader all of this may be 'squishy enough'. But with regard to airline safety, it is barely a start (*The Australian*, 2002). The second point concerns not merely the digitizing/software discussion but also the significant issue of airline and especially urban airport-related safety. The research conducted in the Netherlands by the University of Leiden's Crisis Research Centre (LCRC) recommended that the following lines of inquiry be considered (Rosenthal *et al.*, 1994):

1. A metropolitan government should be able to handle most large-scale disasters on their own.

2. Assertive political and operational leadership is a key asset in counter-disaster operations and crisis management.
3. Disaster managers should avoid a technological bias in designing and implementing counter-disaster strategies. No matter what technological system triggers them - the essence of urban disasters is the collective uncertainty and disruption they set in motion.
4. Urban crisis managers have to reckon with the fact that, increasingly, major disruptions will affect ethnically diverse populations, confronting them with the need for a differentiated approach to warning, relief, communication and after-care.
5. Effective public information policies succeed if crisis managers implement a comprehensive, consistent and attentive approach to the mass media. This compels crisis managers to develop a realistic perspective on the pivotal importance of mass media in contemporary urban disaster situations.

It should be noted that some earlier research lauded the contribution of *non-conventional* communications' systems, for example the use of mobile car phones at the time of Zeebrugge Ferry accident (Pijnenburg and van Duin, 1991).

Thirdly, the 'business-end' of the airlines situation must also be considered in some detail. What is known is that the capital requirements of airport facilities will rise dramatically in Australia if the tourist visit forecasts prove to be accurately stated. The financing and safety aspects of this development cannot be underestimated (Graham-Rowe, 1999).

To bring this matter to the attention of an international audience, aeroplane crashes in Australia have led to the following findings concerning local 'regulated' air-safety (Stewart, 2001).

1. Management placed a continuation of revenue operations ahead of safety.
2. Inadequate resources were allocated to safety because of the airline's financial problems.
3. Poor planning and operational procedures, poor control of flight operations, poor maintenance management and the poor training of flight crew were identified.
4. Latent organizational failures within the Civil Aviation Authority (CAA) identified by the Bureau of Air Safety were also considered.
5. Differences between the corporate mission statements of the CAA which placed clear primacy on air safety, and that of its 'safety division' which appears to emphasize the viability of the industry as its major concern.
6. Poor planning of flight operations' surveillance, poor division of (organizational) responsibilities and ineffective internal communications.
7. Inadequate resources (mainly financial).
8. Poor control of the management of surveillance.
9. Poor operating procedures, particularly its then practice of issuing open-ended Air Operations Certificates - a company's licence to fly.

These examples show the role governments increasingly play in making the rules of the commercial game even more 'complex'. The public service is riddled with this issue of latent conflict of interest - can they be diligent control 'watchdogs' and revenue-earners at the same time? It is clear that all sorts of technological fixes will not solve such worsening organizational problems concerning air-travel related safety. The focus has very much shifted from disaster recovery to disaster 'avoidance' (Kouzmin and Jarman, 1990; Jarman and Kouzmin, 1993, 1994a, 1994b). To return to Brewer and De Leon,

(1983: 125), 'indeed, there may be a complexity threshold beyond which precision and significance (or relevance) become almost mutually exclusive characteristics'.

Physical Disasters

This paper has chosen to study exclusively the issue of technological disasters. No attempt has been made to be comprehensive in the way that Perrow (1984) sought to be in his book *Normal Accidents*. Further, the authors have not sought to reach any normative conclusions regarding social risk in the way that Perrow has in that book.

In this more mundane manner, the authors have decided to extend the contingency-related modelling begun in 1987 and continued until now. Such conceptual 'incrementalism' is clearly of the 'jointed' variety and in this instance high-technology disasters have constituted the empirical data-set (Winner, 1986; Shrivastava, 1994). In order, the Chernobyl explosion, the STS explosion and aeroplane crashes have provided ample information for such a regrettable task. Better that such 'accidents' were never to have happened at all.

But they did - so the analytical task is to seek some defining conceptual explanations for some of the key factors which may analytically have contributed to the abrupt termination of peoples' lives and the termination of an otherwise 'routine' situation. In contra-distinction to Perrow's (1984) concept of the *normal accident*, perhaps usual operating circumstances should be changed to *Routine Operation Procedure* (ROP), as the stochastic meaning of the term 'normal' become ambiguous with regard to ongoing operations as they exist daily, especially (one would hope) for nuclear reactors.

To summarize the putative three paths toward disaster is the remaining task of this paper. At the beginning of the paper, it was stated that these contingency-related situations were meant to be illustrative of a heuristic method. Specifically, (high) technology skills would be related conceptually to three different 'environmental' states and in so doing various types of decisions rules would be explicated. These variables have been titled as being: Deterministic, Near Optional or Squishy. Any physical system can be designed, within their respective environmental 'states', namely:

- stable environments lead to Determinism;
- less stable environments lead to Near-Optimality; and
- relatively unstable environments lead to squishy status.

All these systems can become ever more complex and, thereby, increasingly conducive to systemic failure. In the three examples, it should be understood that various combinations of the role of skilled expertise is possible. In our studies, the physicist (for nuclear reactors), the engineer (for space flights) and the software designer (for aviation/airport systems). These three contingent forms of expertise compel one to re-examine Perrow's original formulation of 1967. The contingent set presented here can be stated as follows (see Figure 1):

1. Algorithm is Perrow's Routine.
2. Opportunity-Cost is Perrow's Engineering.
3. Muddling is Perrow's Craft.
4. Crisis is Perrow's Non-Routine.

Such a new formulation of Perrow (1967) is consistent with his analysis of the terms Routine (1) through to Non-Routine (4). Our three concepts, as connected to the case-study data analysed above, can now be summarized.

Conclusion

A summary of the three antecedent states which can all lead either quickly or slowly to the crisis state can now be stated.

Deterministic: In the case of the Deterministic, the most desirable congruent environment would be where the necessary resource inputs would be readily available irrespective of cost and of any need to break-even financially. Further, the physicist would generally dominate the design relationship with others. However, conflict might arise between physicists (as designers) and engineers (as builders and operators); the more novel the system the more likely the conflict. Both will seek, however, to maximize rather than optimize redundancy. This situation will cause conflict with the 'Near-Optimizers'.

Near-Optimal: In this second case, the role of the engineer/economist is critical to the design and operations of this technically more 'complex' system. Whereas a nuclear reactor may be considered to be a 'simple' (but necessarily a large-scale 'complicated' device), the STS was always regarded as having been more 'risky' in the sense that the design compromises were known and could be compensated for. However, in launching under unfavourable and unfamiliar weather conditions, the system could not withstand such additional pressure and failed accordingly. Therefore, unlike Chernobyl, the environmental/technical systemic instability did not begin from within but was rather the result of natural forces. This increased level of environment-to-technology risk was ignored, not by the engineers but, more directly, 'management'.

Squishy Problem-Solving: By definition, this third situation represents the most 'complex' of the three case types. While aeroplanes do not represent the highest level of the technologies, the known environmental/political state is decidedly more turbulent than in the previous two instances. The new, seemingly more political, 'risky' systems involving the 'Free Flights' approach to control should test the software designers to a very significant degree. The additional pressures toward even more pronounced 'sub-optimality' will be intense - with 'fly-by-wire' aircraft avionics, airport sky-located holding patterns, all-weather operations and even ground radar systems which might increase the likelihood of smashes and fatalities.

These technological/physical environmental aspects of the air industry of the future would seem to be onerous enough. But to add the competitive financial pressures which, as we have demonstrated, can compromise maintenance and routine flight operations must constitute a further challenge to management in this context. Such squishiness is not made any the less complex by the actual behaviour of some of the 'regulatory' defaults of governmental agencies. Indeed, 'who guards the guardians' may prove to be most relevant issue concerning this lowest technology example of the three.

In the final analysis, the authors would contend that the third case study substantiates our assertion that increased levels of environmental instability makes any commercial air system inherently more 'complex'. As to this issue of 'riskiness' this is a more socially-relevant topic of public policy and the authors acknowledge the work of Douglas and Wildavsky (1988) in this regard. Becoming more 'futuristic', it is surely a topic of significance especially when the controlling 'guardians' can become institutionally confused about their attendant 'commercial' role as public entrepreneurs (Polsby, 1984) - are they revenue 'earners' or regulators? This issue constitutes a fruitful source of further research which is now being taken up by others. Our more limited ambition is to define and illustrate how new and emerging technologies operating, or designed to operate, in varying environments can allow us all to reliably work and learn.

Appendix A: Figures and tables

Figure 1: A Typology of Crisis Decision-Making

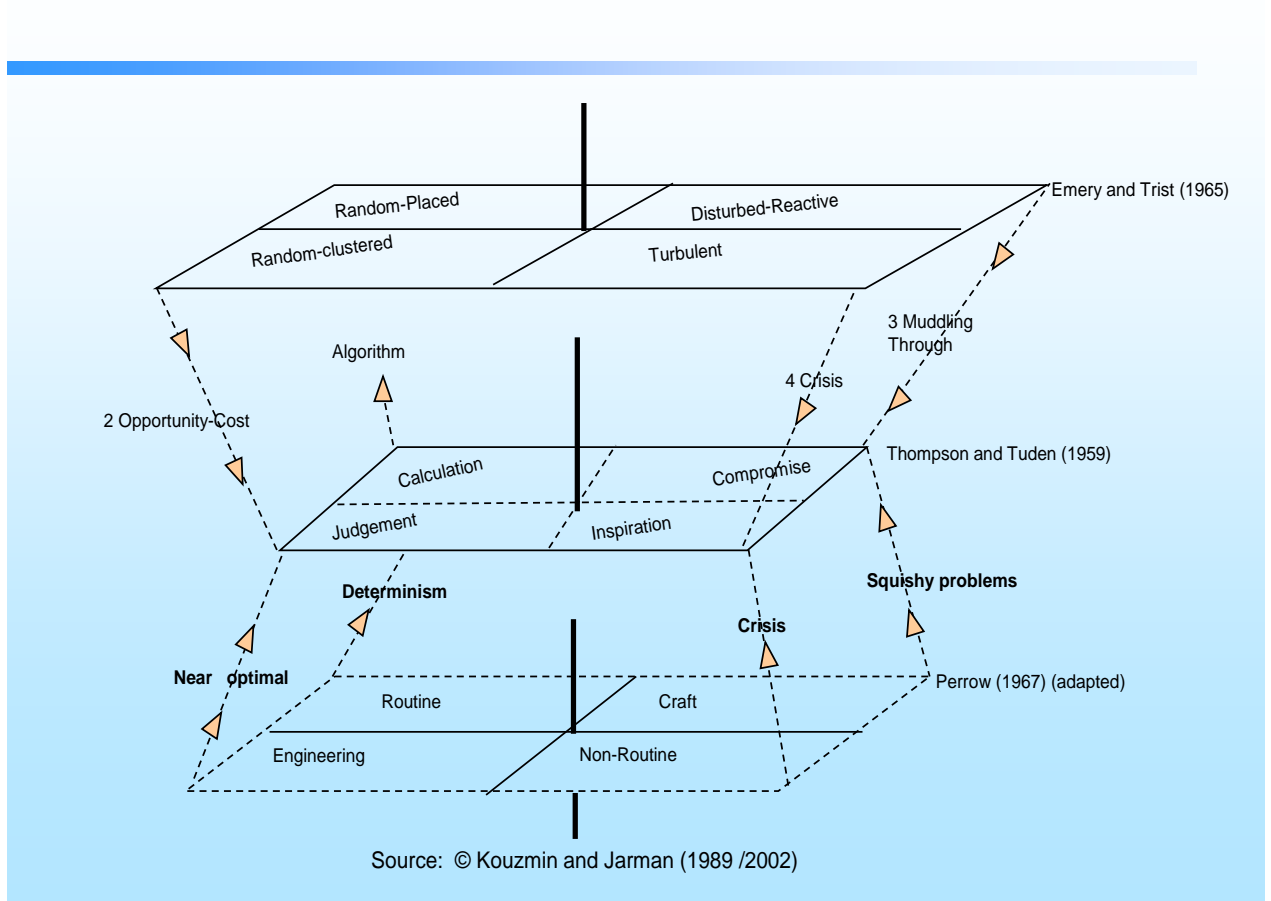


Table 1: A typology of decision processes

| 1989 Schema | | Technology-Related Schema |
|-------------|------------------|---------------------------|
| 1 | Algorithm | Determinism |
| 2 | Opportunity-Cost | Near Optimal |
| 3 | Muddling Through | Squishy Problems |
| 4 | Crisis | Physical Disaster/Crisis |

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