南華大學九十六學年度 博士班 招生考試試題卷

系所別：企業管理系管理科學博士班	科目編號： B3
科　目：管理論文評析(二)	試題紙第1頁共10頁

管理論文評析(二)

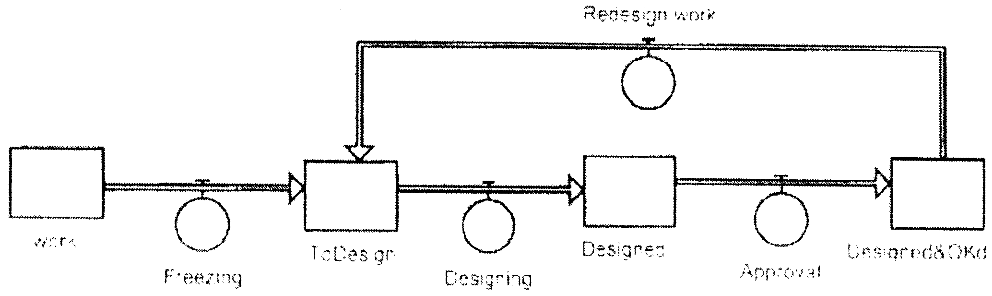
(請用中文回答下列各題，否則不予計分)

1. 請翻譯本文的摘要。(10 分)

2. 請詳細敘述何謂 SD。(10 分)

3. 請敘述 SD 的變數種類有那些。(10 分)

4. 請詳細說明下圖所代表的意義(節錄自本文圖 2)。(10 分)



5. 請詳細說明何謂 Cognitive mapping 和 Graphics COPE 。(10 分)

Safety regulation changes during projects: the use of system dynamics to quantify the effects of change

T.M. Williams

Management Science, Strathclyde University, Glasgow, UK

Abstract

Uncontrolled change can have an important effect on large design and development projects. Such effects are systemic and so are difficult to quantify. One particular source of change that can have a major effect is changes to safety regulations. The risk of such change needs to be recognised and quantified. This paper highlights this risk by describing two transport manufacturing projects that were evaluated post mortem as part of claims procedures. The types of effects caused are described, as are the issues involved in their quantification. Traditional tools were inadequate to quantify these effects. The use of System Dynamics is described to demonstrate the project dynamics, to model the inter-relationships between factors and to quantify their combined effect. This technique can be used for many areas of project modelling. © 1999 Elsevier Science Ltd and IPMA. All rights reserved.

Keywords: Project management; System dynamics; Safety

1. Background

It is well known that uncontrolled change can have an important effect on large design and development projects, and its importance is well-recognised. Change-control has always been an integral part of Project Management, forming a major sub-section to Project Integration Management in the standard repository of basic Project Management knowledge, the PMI Project Management Book Of Knowledge (or 'PMBOK'). [1] Indeed, this area has increased in importance in recent years as two compounding trends in projects have been observed. [2]

- Products being developed are becoming more complex (e.g., because of extra functionality, or reduction in physical size, or closer intra-connectivity). Many commentators therefore consider that the projects developing those products are subsequently also increasing in complexity.
- Projects have tended to become more time-constrained (see e.g., Clarke [3]), with ever-tighter time-constraints, and an ever-increasing desire to reduce 'time to market' times (this has been partly responsible for the development of Concurrent Engineering, supporting the integrated, concurrent design of products and their related processes [4]). To help achieve this, there is an increasing emphasis on tight contracts, often with high liquidated damages for lateness. However, as projects become shorter in duration, this enforces parallelism and concurrency, which by definition increases the project complexity further.

(The meaning of project complexity, and the effects of these trends in manufacturing projects upon project complexity, is discussed further in Williams, [5] which also contains a discussion by a number of practitioners about this issue.)

One particular source of change that can have a major effect on a project but whose effect can be difficult to predict is changes to safety regulations. The safety regime forms an essential part of the specification of a product to be developed. Changes to this regime during the period of development, after the specification has been agreed and design work started,

PII: S0263-7863(98)00063-5

necessitates a change to the specification and subsequent re-design and re-work. Furthermore, since the changes cause systemic effects, these effects can be very difficult to quantify and indeed often appear to give rise to over-runs and over-spends much greater than expected, as discussed below. Sometimes, the contractual liability for recovering this overspend is not clear. Even when liability clearly belongs to the client, the difficulty in quantifying both the initial effects and all of their ramification makes establishing a credible claim very difficult.

This paper will describe two medium-sized manufacturing projects of transport vehicles which have been evaluated post mortem as part of Delay and Disruption claims procedures, to demonstrate the type of effects caused, and the issues involved in quantification. The aims of this paper are thus to:

- point out the risk of changes to safety-regulations and the need to recognise this risk;
- illustrate how project dynamics operate, specifically in this case showing why the effects are larger than intuition would suggest;
- describe a technique for quantification of such systemic effects, which can and has been used for many areas of project modelling, but specifically can be used for modelling this risk, and is useful for prediction, in-project estimation and claims.

The two case-studies have been chosen to illustrate two distinctly different scenarios. The project in Case Study 1 was subject to a one-off change to international safety rules, and a fairly simple model was built to demonstrate the overall effects and illustrate to the project client how the over-spend had arisen. The project in Case Study 2 was subject to safety rules changing continuously over a time, and a much more detailed model was built as part of a formal claims procedure to explain in a supportable and quantified way the behaviour of the project and the resulting over-spend. In fact, Case Study 2 was carried out earlier than Case Study 1; some details of Case Study 2 have been published previously in the Project Management literature, [6] and these details will be summarised only here. Both projects were analysed acting for the contractor concerned in his claim against the client.

The paper will firstly describe the effects that occur when safety regulations are changed during the design phase of a project. It will then describe the System Dynamics method, and its use in modelling and explaining the dynamics of projects. It will then describe and discuss the two case studies. Finally, conclusions will be drawn about the use of this technique for analysing change within projects in general.

2. Changes

Typically, texts on change control (e.g., [7]) distinguish external from internal sources of change, external including such sources as political, legal, economic, social, technological etc.; the point being, of course, that these are not under the control of the project management, and often actions cannot be taken to affect either the timing or requirements of such change-sources (hence the suggestions for an 'environmental screening' role within projects). Design changes resulting from changes to safety regulations clearly are an important example of such external changes.

The effects of design changes on the progress of a project, as discussed in this paper, are described in detail in Williams et al., [6] but can be summarised as follows. The impact on a project can be traced back to the initial impacts, which are generally two-fold:

- additional requirements or additions to the scope of work are demanded during the course of the project (thus not envisaged or planned for); these not only increase the time required to carry out the design work but also might have cross-impacts on other parts of the system;
- if safety concerns or other design changes are being considered, there will normally be delays—often extensive delays—to the approval process; and while individual delays can be measured and sometimes their implications assessed, the cumulative impact of a number of delays is very difficult to assess.

These primary effects cause a number of secondary effects:

- The changes are systemic (within the product), so often a number of project elements must be re-designed simultaneously. As each element is re-worked mid-design, in a design process where design of cross-related parts of the product is occurring in parallel, each activity has to take cognisance of the others, and cross-impacts between elements mean there are secondary re-designs. Indeed, cross-impacts can be more complicated, with sequences of interactions and even feedbacks when a change to system A changes system B which changes system C…which changes system A.
- Most such changes increase complexity, producing increasing cross-relations between parallel activities developing cross-related parts of the product: this implies increasing difficulty in providing a system freeze, since changes in one component will increasingly cross-impact other components, creating a ripple effect across the system.
- Additionally, or alternatively, this re-design causes disruption to the design schedule, which often means

that system elements are being designed without having full specifications of necessary interfaces, because the lack of system freeze, combined with a tight time-constraint, forces management to work on project-elements for which the surrounding system is not yet frozen, and the design of such items will have to be re-worked if there are changes in the as-yet-unfrozen surrounding system.

Already, these effects are beginning to display the elements of feed-back. For example, a simple Influence Diagram could be drawn of the effects described above, as shown in the Influence Diagram of Fig. 1.

Already here, there are a number of effects which will set up a positive feedback, and thus effects will compound each other and thus be magnified beyond the level expected (for example, additional requirements take longer to design, which delays the design process, which, with the tight time-scale forces work on unfrozen designs, which causes re-work and thus exacerbates the design delay; both the additional requirements and this re-work (can) inhibit the ability to freeze the system, which both exacerbates the increased design-times and the enforced work on unfrozen designs.... And so on, as in Fig. 1) (here, 'work on unfrozen designs' is short-hand for 'work on elements of the system for which the design of the surrounding system has not yet been frozen').

But there are additional effects once necessary management response to the above is taken into account. The effect most often not predicted is the lower efficiency of the design-and-manufacture process, due to having to deal with the changes while keeping within either the same, or inadequately adjusted, time-scale. This lower efficiency is due to a number of inter-related effects, for example:

- more workers have to be taken on than originally planned, and/or extra shift-patterns and more overtime have to be worked in order to keep to the schedule; this exacerbates the feedback loops to cause increasing inefficiency (referred to as the '$2000 hour' in the famous work by Cooper [8]);
- such work has secondary effects, such as disincentivising the design staff as they work with unclear parameters and knowing that their work may turn out to be nugatory;
- when a concurrent Manufacturing phase is considered, there are additional effects, both because design activities finish later and thus increase concurrency, but also because items begin manufacture and are then changed, which leads to retrofit, degradation of manufacture learning (see Eden et al. [9]), but also because the products are no longer Designed For Manufacture (DFM) (or DFA, Designed For Assembly), a key element of Concurrent Engineering. [4]

For any individual project, a specific Influence Diagrams can be drawn, and these can show how dynamic feedback loops are set up. This means that these effects all compound and exacerbate each other, so that they do not add linearly but the impact of effects A and B occurring together is in general more than the sum of the impact of effect A occurring on its

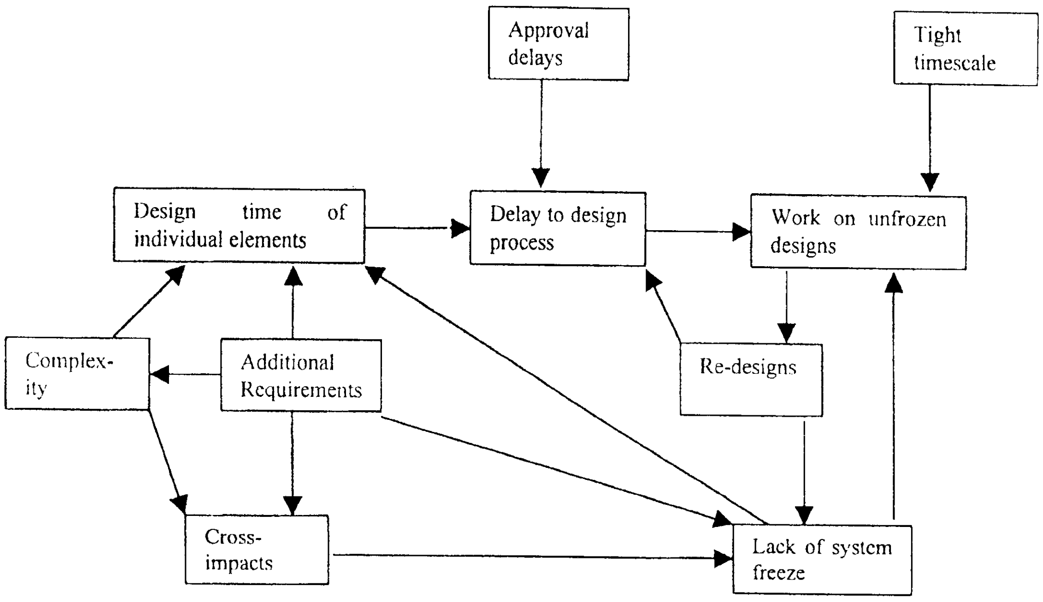


Fig. 1. Initial influence diagram.

own and impact of effect B occurring on its own, giving rise to the '2 + 2 = 5' idea. [6]

3. Changes to safety regulations

Changes to safety regulations in general have to be actioned within a project, so will cause all of the problems highlighted above. These changes often have major effects, as will be highlighted by the case-studies described in this paper. These two case-studies give examples of such projects in the transport field, which is an obvious area in which products are the object of national and international safety regulations, those regulations are subject to unexpected change (particularly resulting from transport disasters, which affected both of the case-studies below), and the regulations are rigorously enforced. Another such area is of course the nuclear field, which is subject to similar regulatory bodies. In the UK, Morris and Hough [10] describe the UK Advanced Gas-Cooled Reactor (AGR) programme up to 1986. In particular, they describe Hinckley Point B station, estimated in 1966 at £96M, which over-spent by £48M (£14M of which was due to inflation): £19M (40%) of the over-spend was ascribed to 'modification and development needed to bring the basic plant design to revised standards'. However, writing in 1987, they also state that the philosophy of safety-cases adopted by the Nuclear Installation Inspectorate had led to less 'regulatory ratchetting than in the United States' (where the Nuclear Regulatory Commission wrote and promulgated regulations. Canaday [11] analyses 35 US nuclear power-plan projects, which resulted in up to 400% cost overruns, highlighting increased safety requirements as one of the causes. Kharbanda and Pinto [12] devote a whole chapter of their book to such projects, quoting, for example, the Marble Hill Plant, 'thought to be the most expensive nuclear plant project abandoned in this way', abandoned because 'the cost of complying with additional regulatory safeguards simply became prohibitively expensive'.

4. Method: systems dynamics

The effects that need to be modelled are systemic. Early project-management methods were based on decomposing the project into its constituent parts in a structured way, in particular PERT, WBS, and C/SCSC.; similarly, project risk analysis has been based on decomposing overall effects into individual items on a Project Risk Register (see [13]). Legal claims have operated by decomposing projects into individual cost elements or, particularly, individual time elements (see e.g., [14]). However, it is clear that the systemic effects discussed above are not taken account of by such decomposition methods. [6]

The modelling method used in the case studies below is System Dynamics (SD). Wolstenholme [15] gives a good overview of the current state of the art; it can be distinguished from discrete-event simulation in that it is concerned with the state of the system and rates of change, it uses pseudo-continuous modelling, and the detail of discrete-events are not included. The modelling approach focuses upon an understanding of feedback and feedforward relationships, and the model construction requires the analyst to construct the relationships between the various state variables and rate variables. A key advantage is that if techniques such as cognitive maps and influence diagrams are used to construct these relationships (as discussed below), then SD is a natural technique to quantify these relationships [16] (as in Case Study 2 below).

SD has a track-record since 1964 of use in explaining and modelling the systemic effects in complex projects. It has been used particularly notably by Pugh-Roberts Associates (part of PA Consulting), and a number of successful applications have also been reported at NASA (see a discussion in Rodrigues and Bowers [17]). Because of its explanatory power, it has had particular application in the *post-mortem* analysis of projects in litigations such as Delay and Disruption (D&D). The first major success was the Ingalls Shipbuilding case against the US Navy in the late 1970's, in which an SD model was used to quantify the cost of disruption stemming from Navy-responsible delays and design changes; the total settlement was finally $447 million, and Cooper [18] claims that the model was the basis for at least $200–300 million of this. Since this major legal precedent, the method has been used on a number of such litigations.

The models below were built using the Stella package. [19] There are three types of SD variable. The rectangular tanks represent 'stocks' of material, and flows between them are represented by the 'rates' (the valve-shaped symbol). All other calculations are undertaken by 'auxiliary variables', represented by circles. In a full model, all relationships between the variables have to be shown by lines; it is this explicit representation of the intra-model relationships that makes such models so transparent.

5. Case-study 1

The first case-study was the life extension of an old naval support ship, involving the insertion of an additional mid-section and a complete re-fit. A design office was subcontracted for design services, and the work on the General Arrangement (GA) and composite drawings of services was scheduled to take place over 9 months in 1994/5. The contract specification required compliance with the regulatory and statutory regulations in force at the date of signature. However, in October 1994 the SOLAS (Safety Of Life At Sea) 92 safety regulations were ratified (as described in [20]), and shortly afterwards the UK Ministry of Defence (MoD) decided that this ship would be subject to those regulations. SOLAS are international regulations which have to be ratified by national bodies; one important effect was that during the course of the project the UK MSA (Marine Safety Agency) had to consider and interpret the regulations; indeed, at the end of the author's involvement the relevant UK Statutory Instruments had still not been issued; meanwhile, although not relevant to this case-study, the SOLAS Convention is again being amended in response to the *Estonia* tragedy in which over 900 died (see the Naval Architect [21]).

The effect of the changes caused by the SOLAS 92 regulations were many and various. Of particular relevance were two important effects:

- the air-conditioning (HVAC) system had to be re-designed and enhanced, and subsequent changes caused the HVAC line to be re-routed and related services adjusted round about (HVAC design was subcontracted, as was the design of certain other dependent systems);
- the deckhead spaces (thus the space available within the ceilings) had to be reduced.

These two effects, however are not unrelated: upgrading of the HVAC would have caused deckhead space to be very tight and the routing of services very complex anyway; reducing deckhead spaces exacerbated these problems, and indeed in a few cases made production of the composite drawing infeasible without lowering the ceiling below specification-height.

The contractors prepared a claim for the extra work caused directly by the introduction of SOLAS 92, called the 'Direct Claim', which covered the above two effects. However, the extra work caused a number of additional effects, exactly those described above in the section on 'Changes' above:

- all of the GA/composite work was inter-related: when items had to be re-designed other items had to be re-designed as a consequence, which themselves had the effect of further changing other parts of the system, including within the GA/composite work, into the wider project within the design contractor, and to sub-contractors (e.g., on the HVAC); and all of these changes caused secondary effects back on the GA/composite work;
- the design process was less efficient because much more work had to be done while still trying to keep within the schedule in order to avoid delay to the overall ship life-extension project (e.g., there were more workers, and three-shift working was introduced);
- the re-design was much more complex than the original design because there was less space to fit in more services, causing extra management attention, and making follow-on work more complex.

These effects are interdependent, each exacerbating the others. Thus, the extra time-pressure caused less efficient working, which caused more delay, which added to the time-pressure; design feed-backs and cross-impacts produced more re-design work which caused more delays and exacerbated this feed-back loop; and so on. Furthermore, the changes were not immediately well-defined, but time had to be taken by both the project and MSA to consider the full definition of the changes. This also caused delays to the re-design, exacerbating the time pressure and the need for secondary and tertiary re-design etc. Again, these compound each other.

The SD model built was fairly small, consisting of just 18 stocks, 18 rates and 29 other variables (a fair number of which were simply book-keeping variables to count up various values), but it was sufficient to demonstrate the effects that were present. The key flow was of work around the basic cycle as shown in Fig. 2.

Here, work that can be begun (i.e., the surrounding system is sufficiently frozen) is designed as fast as the available manpower and its productivity will allow, and those designs are approved. In the perfect case, that is all that happens (this would represent the project as originally conceived and budgetted for), but in case of changes, work can be extracted from the state of being 'Designed and OK'd' and moved back to be re-worked. There are two mechanisms controlling this flow.

The first is the flow of changes caused by SOLAS, represented by another set of stocks and flows, as shown in Fig. 3.

The SOLAS changes are released at a certain time, then some are delayed while MSA and the design office considered all the implications, then gradually all the changes flow until they are done. This flow of work represented the 'Direct Claim'. Changes here cause re-design work in the main flow.

The second is the management of manpower. A set of auxiliary variables controlled the addition and removal of manpower onto the project, and the transfer onto and off three shifts. This was controlled by simple logical rules dependent on the progress of the work compared to the original plan.

The other main flows of work showed both base SOLAS changes, and also subsequent changes, impacting upon the wider project and upon sub-contractors.

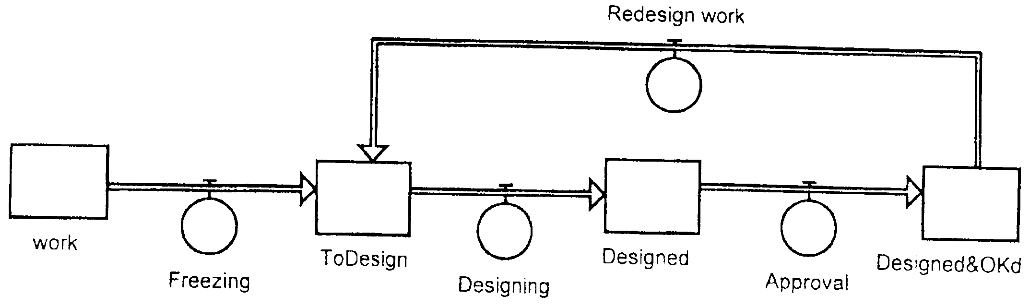


Fig. 2. Case study 1 flow of work.

These were needed as, while these changes are being worked upon, they each cause secondary changes back onto the GA/composite work. The model was very simple and did not take a number of factors into account, for example, work done out of the proper sequence (as discussed in Case Study 2). However, it did include the two main D&D effects, namely

a) re-designs due to secondary effects, since re-design work in Fig. 2 is determined by not only the *ChangesToBeMade* (from Fig. 3) but also work cross-impacted by such changes, and also the effects of cross-impacts from changes caused to sub-contractors and the rest of the project;
b) decreased effectiveness in trying to keep to the schedule: the model included a rules for recruitment and removal of workforce and for the use of two- and three-shift systems, which was a function of schedule pressure (calculated as a function of the work completed and the work planned to be completed by the current time), so allowed the model to attempt to keep to the schedule as far as possible given the external effects on the project. Thus the model tries to mimic the actions of management as they increase manpower (either by the number of workers or the use of multiple shifts or overtime), and the effects of reducing these actions can be studied, as noted below.

The output metric measured was the profile of man-hours used over time. Three main runs of the model were carried out:

i) The first had no SOLAS changes, so representing the project as initially expected. The timescale and man-hours expended was as budgetted, and the work-force followed the budgeted profile. This forms an important validation of the model, and also conversely helps to validate the original contract.
ii) The second introduced SOLAS changes but without D&D effects (a) and (b). Thus, no cross-impacts are modelled, and it is assumed that management takes no action to recover from the temporal effects of the changes. The maximum work-force is still on budget, and again only one shift is used; however the time-scale and man-hours were increased by 140% and 220% respectively. The difference between (i) and (ii) is likely to reflect the direct effects of the SOLAS changes, and thus to indicate the extent of a claim for the direct consequences of the changes (in terms of man-hours) and also as a statement of how much longer the project would have taken had management not increased work force (albeit therefore using less effective manpower).
iii) The third also included both D&D effects. Here, the workforce rose rapidly, then a three-shift operation had to be started, and operated over a period

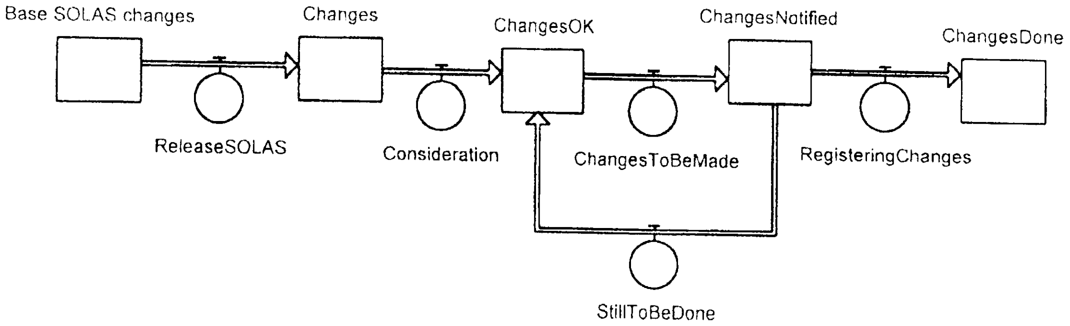


Fig. 3. Case study 1 SOLAS changes.

similar to that in which three shifts were actually used: the time-scale and man-hours were 50% and 340% over budget respectively. The difference between the man-hours in (ii) and (iii) shows the extent of a D&D claim, with the reduction in duration being the effect of the management actions described in (ii).

Since D&D combines two effects here, it is instructive to look at them individually:

- If the model included SOLAS changes and D&D factor (b) (decreased effectiveness in trying to keep to the schedule), but with no re-designs due to secondary effects, there was less work than in (iii) above, the project was only 25% late and 275% over the man-hour budget.
- If the model included SOLAS changes and D&D factor (a) (re-designs due to secondary effects), but with no schedule pressure, here the project was again allowed to continue 140% over the time-budget, with man-hours 240% over budget.

The model thus showed a number of indicative results:

- The model could be used to show the extent of D&D resulting from a Direct SOLAS claim.
- The model could be used to show the additional time that would have been taken on the work had the design office not taken action to reduce the duration and avoid delaying the overall project.
- The model showed the effects of the various components of D&D; it could also be seen that these individual effects add to well below the total D&D indicated, as is the nature of such systemic effects, so that the D&D has to be evaluated as a whole.
- Finally, the model's use for additional analyses could be seen; in particular to look at:

- the additional management effort caused by the SOLAS changes;
- the knock-on effects on the wider project;
- the effect on other projects in the design office.

6. Case study 2

The second case study is similarly of the design and manufacture of a transport vehicle: the Channel Tunnel *Shuttle* wagons. Eurotunnel had contracted TML to build the Channel Tunnel, and TML had subcontracted a consortium of rolling-stock manufacturers to build the Shuttle Wagons. A number of aspects of the design, construction and operation of the Channel Tunnel required approval from the Intergovernmental Commission (IGC), a body of British and French civil servants: during the development phase of the project, their major focus was on safety, defence, security and environmental issues (as described by the Major Projects Association [22]). It became clear part-way through the project that design changes required by the IGC were not only causing delays, but that work was having to proceed prior to gaining IGC approval, with the subsequent changes and re-work when IGC decisions turned out not to be favourable. It is instructive to read a newspaper report of 1991 (the concession had been granted in 1986, UK Parliamentary Approval gained in 1987):

> '[Eurotunnel] said delays were expected because of changes in the design of fire doors separating rail shuttle wagons to meet strict safety guidelines. The [IGC] has insisted that fire doors between wagons carrying passenger vehicles be widened by at least 10 cm to allow easier access...[Eurotunnel] warned yesterday that changes in the design of fire doors were likely to lead to a delay of up to 6 months...Eurotunnel was discussing the possibility of introducing bonus payments to encourage the Shuttle wagon manufacturers to make up any lost time caused by the design change....The [IGC] also warned that the design of semi-open-sided wagons to carry heavy goods vehicles would be unacceptable in its present form...discussions were continuing with the Commission....The need to complete the project as quickly as possible to start earning revenue to repay bank borrowings meant that design had to be completed and contracts placed before the [IGC] completed its deliberations.' (Taylor, writing in the *Financial Times* [23]).

The design and manufacture of the Shuttle Wagons was for this reason (and also, the manufacturers claimed, because of delays in approval design documentation) considerably over-spent. The author was part of a team brought in to determine the reasons the D&D caused to the project, and to quantify it with an auditable model, as has already been reported in the Project Management literature. [6]

The key technique used to interview managers and subsequently model the explanations given for the various circumstances of the project was 'cognitive mapping' (see Ackermann et al. [24]) using specialist computer software called 'Graphics COPE' [25] (an improved version of which is now sold under the name 'Decision Explorer'). This is a powerful technique to elicit the underlying structure of causes in a 'messy' problem from a group of managers, and results in a cause map (i.e., a 'map' of the various causes and effects, and arrows showing relationships between them) which can be stored, discussed, analysed and whose complexity can be managed. [26]. The resulting cause map was developed and validated working in a visual interactive mode with groups of senior members of the project team. The analysis and clustering methods within the software were then used to locate all the positive feedback loops (90 inter-related loops in this case). This in itself gave a qualitative understanding of the relationships between the elements and the feedback loops, and thus the basis of understanding of the D&D. But furthermore, it provides almost immediately Influence Diagrams which can provide the basis for the quantitative modelling.

The elements of the loops were those discussed above ('Changes to safety regulations'), with the added element of client-approval delays. Again, design of cross-related parts was occurring in parallel; there were tight timescale-constraints, so that after a delay, the project had to become more parallel as delayed activities overlap more with succeeding non-delayed activities. This loop was accelerated by other feedback loops. For example, parallel design of cross-related items increased difficulty in providing a system freeze; this forced work on items for which the surrounding system was not yet frozen, and so on as above, in particular increasing re-work and thus exacerbating delay. Particularly as the supply of trained design manpower began to be exhausted in the geographic region, the '$2000 hour' effect started to manifest itself. Further loops of course were set up when the concurrent Manufacturing phase was considered, both because design activities finished later and thus increased concurrency (and so on), but also because items began manufacture and were then changed, which led to retrofit, degradation of manufacture learning, increased load on production engineers, etc.

A key difference between Case Studies 1 and 2 was that in this latter case the safety regime was ill-defined at the start of the project and only gradually became clarified. This was not only because the environment of the Channel Tunnel was unknown to the safety regulators, but also because the implications of events such as the UK Kings Cross Fire in November 1987 fed into the consideration. This meant firstly that some design parameters were uncertain during the design phase, secondly that safety-driven changes came continuously as a slow trickle rather than as a one-off declaration in Case Study 1, and thirdly that some design approval took longer as safety aspects were considered.

The Influence Diagrams, then, provided the basis for the SD modelling. These models are described in the references, [6,27] but followed the general pattern of Case Study 1—with the main difference being that the model was fully calibrated to replicate the project as originally anticipated, the project as completed and also under the various different profiles of client behaviour and liability. This meant that the model was much more sizeable: it consisted of two inter-related parts, one dealing with Design and the second with Manufacture, with, in the Design part, 29 stocks, 43 rates and 120 other variables were used. Again, in the Design part, there was a basic flow of design work, which moved from unfrozen, frozen, being designed, approved and finished; again, work flowed from the 'unfrozen' stock if the work was sufficiently behind schedule; this increased the likelihood of work (even approved work) being fed back for re-design; and again there was extra work entering the system caused by comments by the client (some of which came late in the design process). There was a large part of the model dealing with managing a workforce consisting of designers, free-lance designers, and a capacity for recruiting designers inexperienced in the domain, and other parts of the model tracked aspects such as the type of work in the system, cross-impacts between systems, etc.

Williams et al. [27] also gives indicative results (although not the actual results, which were confidential): this reference shows how the three main variables compound together: (i) the time take to obtain client approval/comments on design documents, (ii) the proportion of documents commented upon by the client (but without requiring extra-contractual modifications to the product), and (iii) the proportion of project elements on which extra-contractual work was required. Thus, effects on each of these which, in isolation, would have little effect on the project out-turn, have a large impact when combined together. The reference shows that, when the design changes add 92% to the work-load; extra comments are made which would (on their own) add 11% to the work-load, and approval-delays occur which would (on their own) add only 0.4% to the man-power spent, then the combination of these three effects together adds 225% to the overall man-power, much greater than the three individual effects combined.

7. Conclusions

This paper has, through two case-studies, illustrated the effect that changes to safety regulations can have on a design-and-manufacture project. This risk must be considered at the start of the project, and contractual liability for the risk established at the start. Such changes cause systemic effects which are difficult to quantify, and, because of their systemic nature, are much bigger than intuition would suggest. The System Dynamics method is a proven technique which can and has been used for many areas of project modelling, but specifically can be used for modelling these effects, and is useful for prediction during the risk analysis stage, for estimation to support costing of Variation Orders (Rodigues and Williams [28] use this method in this role) and for quantification of D&D claims.

Acknowledgements

An earlier version of this paper was given at the PRM '97 conference in Helsinki, September 1997, as Williams, T.M. 'The risk of safety regulation changes in transport development projects'. In, K. Kahkonen and K. A. Artto (Eds) (1997). Managing Risks in Projects. E&FN Spon, London, pages 284–293.

References

[1] Project Management Institute. A guide to the project management book of knowledge. Project Management Institute. Upper Darby, PA, US, 1996.

[2] Williams TM. Holistic methods in project management. Proceedings of INTERNET Symposium, St. Petersburg, Russia, 14–16 September 1995. ISBN 5-87115-011-x, pp. 332–336.

[3] Clarke L. The essence of change. Prentice-Hall, Herts, UK, 1994.

[4] Syan CS, Menon U, editors. Concurrent engineering: concepts, implementation and practice. Chapman and Hall, London, 1994.

[5] Williams TM. The need for new paradigms for complex projects. In: Williams TM, editor. Managing and modelling complex projects, NATO ASI Series, Kluwer Publishers Ltd., 1997.

[6] Williams TM, Eden CL, Ackermann FR, Tait A. Vicious circles of parallelism. International Journal of Project Management 1995;13(3):151–5.

[7] Owens SD, Martin MD. Planning for change. In: Dinsmore PC, editor, The AMA handbook of project management. American Management Association, N.Y., chapter 23, 1993.

[8] Cooper KG. The $2000 hour: how managers influence project performance through the rework cycle. Project Management Journal 1994;25(1):11–24.

[9] Eden C, Williams TM, Ackermann F. Dismantling the learning curve: the role of learning in understanding disruption. To appear in the International Journal of Project Management.

[10] Morris PWG, Hough GH. The anatomy of major projects. John Wiley, Chichester, UK, 1987.

[11] Canaday HT. Quoted in Morris and Hough (ref. 9), 1980.

[12] Kharbanda OP, Pinto JK. What made Gertie Gallop?: learning from project failures. Van Nostrand Reinhold, New York, USA, 1996.

[13] Williams TM. Using the risk register to integrate risk management in project definition. International Journal of Project Management 1994;12(1):17–22.

[14] Scott S. Dealing with delay claims: a survey. International Journal of Project Management 1993;11(3):143–54.

[15] Wolstenholme EF. System enquiry: a system dynamics approach. Wiley, 1990.

[16] Eden C, Sims D. On the nature of problems in consulting practice. OMEGA 1979;7:119–27.

[17] Rodrigues A, Bowers J. The role of system dynamics in project management. International Journal of Project Management 1996;14(4):213–20.

[18] Cooper KG. The rework cycle: benchmarks for the project manager. Project Management Journal 1993;24(1):000–111.

[19] Stella is a registered trademark of High Performance Systems Inc, Hanover NH, US.

[20] Payne S. Tightening the grip on passenger ship safety—the evolution of SOLAS. Naval Architect, 1994, page E.482.

[21] Naval Architect 1995 SOLAS conference amendments. Naval Architect, 1996, page 19.

[22] Major Projects Association Beyond 2000: a source book for major projects. Major Projects Association, Oxford, UK, 1992.

[23] Taylor A. Article. Financial Times (London, UK), 9th April 1991, pgs. 1, 8.

[24] Ackermann F, Eden C, Williams T. A persuasive approach to delay and disruption—using 'mixed methods'. To appear in Interfaces 1997; 27(2): 48–65.

[25] Graphics COPE is developed and supplied by the Department of Management Science, University of Strathclyde, Glasgow. It runs in the Windows environment.

[26] Williams TM, Ackermann FR, Eden CL. Project risk: systemicity, cause mapping and a scenario approach. In: Kahkonen K, Artto KA, editors (1997). Managing Risks in Projects. E&FN Spon, London. ISBN 0 419 22990, 343–352.

[27] Williams TM, Eden CL, Ackermann FR, Tait A. The effects of design changes and delays on project costs. Journal of the Operational Research Society 1995;46(7):809–18.

[28] Rodrigues A, Williams TM. Systems dynamics in project management: assessing the impacts of client behaviour in project performance. Systems Dynamics Conference, MIT, Boston, 22–26th July 1996.