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The impact of disruption and delay when compressing large projects: going for incentives?

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Demands by clients for earlier delivery after a project has started are increasing. This paper investigates the consequential disruption and delay that follows from the contractor accepting these demands. Explorations are carried out using a System Dynamics model based upon a large model constructed to represent the complexity of a claim for disruption and delay in relation to a specific mega-project. The model used for the explorations has been validated further using information gathered during work on other claim projects. The model enables the impact of disruption and delay resulting from the holistic and dynamic impact of a compressed delivery date to be assessed in relation to two specific and typical options. Use of the model suggests that the probability seems slight of finding the highly specific circumstances where there is any certainty in an outcome of early delivery at little extra cost.

Keywords: project management; risk, disruption and delay; simulation

Introduction

It is our experience that it is becoming common for customers to try and negotiate a compressed delivery date after a project has been already planned, budgeted and started. Following our involvement in the analysis of several major projects as a part of litigation, we have been approached by companies seeking advice on the likely costs of compressing a project. Their request typically asks whether there is a useful 'rule-of-thumb' that can be applied to indicate the likely costs associated with a given proportional acceleration of the project. In seeking a compressed delivery date, clients offer incentives that can appear attractive. In assessing whether or not to accept the offer, those managing the projects need to be able to assess the costs involved with compression in relation to the level of incentive. In particular, they wish to evaluate the disruption associated with seeking to meet such incentives. We have always refused to offer such a rule-of-thumb and have argued that knowing about the particular characteristics of the project, in particular the extent of disruption and delay (D&D) already in the system but not yet realised, are essential to making such a judgement. Nevertheless, their request is reasonable and they will, in any event, have to make a judgement. This paper reports on attempts to be more helpful.

The above request is all the more reasonable, given the trend we observe amongst organisations with which we have been involved. They argue that their strategic future lies with bigger 'turnkey' projects that are more complex and more time-constrained. Within major manufacturing and technological projects, products are becoming more complex. As product development times and market windows are shrinking, requiring new products to be introduced quickly and effectively, it follows that project or programme management is also becoming more complex.[1] Increasingly projects demand multi-organisational collaboration through joint ventures, strategic alliances, and partnerships. Collaboration, on its own, is riddled with difficulties.[2,3] When projects involve multi-disciplinary teams, from several organisations, operating from different parts of the globe there is a 'particularly pervasive source of uncertainty'[4] which escalates project complexity. The high levels of risk and complexity create increased opportunities for severe disruption, and consequential delay to projects.

Previous work commenting on the nature of project compression is limited. For example, Graves' brief article[5] references empirical work on the cost of accelerating hardware and software projects, but these results are not generalised to the field of complex engineering projects. Other work focuses on models using CPM/PERT[6] and time impact analysis.[7] Research, carried out by Cooper,[8] reports on the use of simulation modelling to explore the effect of using overtime, schedule pressure and hiring additional labour on the overall cost and schedule of a project. In carrying out his investigations, Cooper identified the type of effects these managerial actions would have on the so-called 'rework cycle'.[9–13] He modelled the impact on such variables as worker productivity and quality of work through paths of cause and effect which feedback on

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themselves. Cooper suggested that, if these effects could be recognised and understood during a project, managerial intervention could aid the mitigation of these effects. Whilst this work is relevant, it discusses, *in a general manner*, the impact of the rework cycle in a project management environment. The research carried out here explicitly considers the issue of a contractor freely accepting project compression and its associated costs. It explores whether the effects presented by Cooper can be identified when exploring the use of the same managerial actions in search of a compressed delivery schedule for a project.

Background to research

Over the past seven years we have been involved in six major disruption and delay claims in Europe and North America. The value of these claims has ranged from \$50 m to \$350 m, and five of these have addressed production line projects. Each claim involved the construction of a large and detailed System Dynamics simulation model as the primary form of both demonstrating causality of D&D and the value of the claim.[14] These claim models typically took a team the equivalent of 12 person-months to construct and contained in the region of 100 stocks and 400 auxiliary variables. They were based upon data gathered during extensive interviews with those involved with the project, through consultation with international experts and extensive research carried out at the relevant manufacturing plants. This approach is not unusual; there is now a history of the use of System Dynamics models to account for that part of a cost overrun which cannot be attributed to the direct consequences of D&D.[15,16] However, although there is reasonable evidence to support their positive role in settlement, there is less case history describing their impact in court. Nevertheless each model is constructed with the prospect of it being critically examined in a courtroom situation—we have found this a severe test for the validity of a model. In each case the model had to be validated against modes of behaviour such as:

- the time series behaviour of the original budget. Part of this process involved validating the original budget estimate, a process often undertaken by estimating experts in the particular field of the project. In some cases we have acted in this role.
- the time series behaviour of the actual outcome.

In some cases internationally renowned System Dynamics experts have necessarily been used as part of the validation process.

Each model was highly unique to the specific project circumstances, this being one important requirement for success in claim situations. Each was constructed using a *bottom-up approach*, where the modelling process is not driven by generic notions of project behaviour; rather, the model is customised to the specific project.[15,17] Detailed 'cause-maps'[18] are constructed from 'cognitive maps' developed in one-to-one interviews[19] and group sessions through the use of networked computers in a Group Support System environment.[20,21]

For the research reported in this paper we took the model constructed for the largest of these claims and altered it so that it reflected the character of the other claims.[22] In doing so we:

- retained the core causal structure,
- retained the process flow of design engineering to methods engineering to manufacturing, and the behaviour patterns, and relative proportions, of design, methods and manufacturing work which is common to transportation and aerospace projects,
- removed idiosyncratic aspects (such as the impact of an acquisition of a participating organisation),
- took the number of items produced as 100 (a reasonably typical production run for advanced engineering products) depicting medium run programmes which are subject to learning curve benefits,[23,24]
- retained qualitative factors such as the impact of overtime on productivity. Although largely based on research and 'expert' witness evidence, these were nevertheless consistent with their use and impact in each of the other claim models.

The general model contained the core features of all five production line claim circumstances and remained as large and complex as these models. It was constructed for two related purposes: (i) training of senior project managers in considering the importance of D&D for the management of complex projects, and (ii) enable exploration of the impact of different managerial actions. Thus, further validation of the general model has also been achieved through its use as a senior management training tool. Several hundred Presidents, Vice-Presidents and Directors, from different companies, have attended a series of senior management seminars where the model has been used to demonstrate project management issues. Those who attend the seminars continually identify with the issues raised during the use of the model as those they face during day-to-day contact with large projects. These comments add further credibility for the simulation model to be used as a mechanism for the explorations discussed in this paper. We cannot claim overall generalisability; however, the research certainly goes well beyond a single case.

What is a compressed project?

An exploration of compression cannot be undertaken without first discussing the state of the project before the compression that follows from the requested earlier delivery. This provides an anchor point for exploration using the simulation model. The state at which any particular project commences informs the management team about whether or not the budgeted time contains any initial slack or if the project is already compressed. This initial position will have an impact on the D&D resulting from any compression.

Although project compression has been discussed so far as a request from the customer, it is, nevertheless, important to remember that it is not unusual for a project to suffer major compression because of an under-estimation of the amount of work required. For example, a recent analysis of a large project we have been involved with is founded on the difficulties in estimating a fixed firm price contract when there are high levels of uncertainty about the amount of work required. The analysis estimated the impact of the under-estimation, and so compression against the original delivery, to determine the likely cost overrun.

This paper assumes that the project has been planned to be competitive, with optimal time and cost budgets, taking account of reasonable risk factors or contingencies. Thus, there is no unnecessary time slack in the planning budget. This is important for the following reasons:

- the existence of slack in the original plan for the project would mean that it is possible to compress without any penalties and so the incentives would certainly be worth accepting;
- in competitive bidding it is likely that delivery will have been an important aspect of a successful bid; thus the original project schedule will be tight. This means that optimality must reflect the following considerations:
  - the project will be being managed with some degree of pressure (which will be normal for other projects obtained under competitive bidding positions);
  - no overcrowding will have been admitted in the original plan for fear of the associated lower productivity of the labour force. Overcrowding occurs when the employment of too much labour results in workers getting in each other's way;
  - Critical Path Analysis (CPA) constraints have not been *unduly* broken. For example, it is likely that in practice the project will unfold with some degree of parallelism and so suffer the consequences of carrying out tasks out of sequence. But these negative consequences will have been optimally balanced with respect to the gains from earlier delivery.

There is no way of ever determining in practice if projects are optimal, other than to assume that management responds appropriately in competitive bidding situations. There is anecdotal commentary within the industries in which we have worked that, in the past, some organisations have gone out of business because they have offered tight, non-optimal deliveries and so assumed an unattainable cost base.

Nevertheless, in the experiments reported here, it is possible, and indeed essential, to determine the optimum initial state for the project and use this as the anchor point. Cooper[8] does not discuss this issue and so the anchor point used in his studies is unclear. In our explorations we assume a clean, undisturbed project, although this is rarely the case in any real project.

Disruption and delay

This research explores the nature of D&D[25] in the context of project acceleration, particularly those aspects of D&D that are difficult to track because they derive from feedback dynamics. The 'trigger' for such 'dynamic' D&D may be a, sometimes small, disruption or delay. For example, a change order/variation order interrupts and slows progress, leading to the use of overtime to catch up, which (once it reaches a given level) results in labour force fatigue, increasing level of mistakes, additional rework and so a further interruption and slowing of progress—creating a vicious cycle which is a positive feedback loop (see Figure 1).

When exploring any potential D&D which may arise from the compression of a project, we have to look beyond the D&D which is triggered simply by the act of compression. In the context of project risk management, Simon *et al*[26] suggest that '... for a project to be successful it must not rely upon the absence of problems, but must predict and manage the inherent risks so that when problems do occur they can be overcome'. As D&D is a risk involved in any project, management should be able to predict and manage any D&D that arises. D&D triggered by factors other than compression are important in two ways:

(i) *Prior to the point of compression*—this will take the form of already triggered D&D that has yet to be fully realised. This could add to and further escalate any future D&D in the project. It will therefore add to any cost or time overruns. An awareness and assessment of this type of D&D will be required for a full understanding of how compression will affect the overall project outcome.

(ii) *Sometime in the future*—in this case a risk assessment

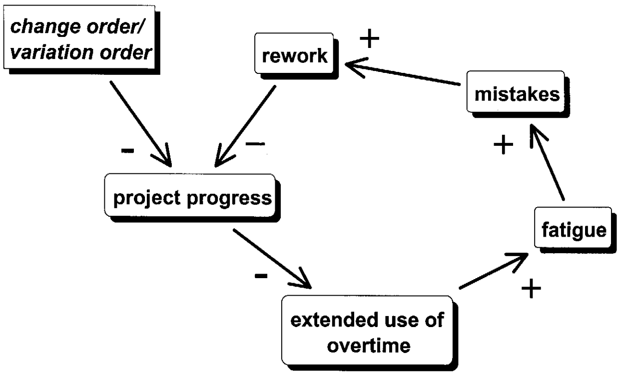

Figure 1 An example of a rework positive feedback loop following a variation order.

would be required about any likely 'triggers'. The resulting D&D could also add to the time and cost overrun and potentially escalate the effects of any acts of compression.

If the above assessment of D&D was possible, then those managing projects would be likely to turn their attentions to the possibility of taking managerial actions to mitigate at least some of the D&D. Skills at recovery from D&D then become important, as management attempts to improve the future of the project. This could potentially improve any outcome from project compression. However, if recovery from D&D is not expected to be feasible, then there has to come a point at which the project delivery must be renegotiated.

Modelling disruption and delay

The explorations discussed in this paper are carried out using a System Dynamics model. System Dynamics is a simulation modelling technique that was specifically designed to model and explore feedback. Since it enables the modeller to explore the D&D caused by feedback dynamics, System Dynamics has been used for the analysis of cost or delivery overruns on large projects.[16,27] It also appears to have formed the basis of the investigations of Cooper's work mentioned above (although he does not explicitly mention the nature of the simulation modelling technique he uses).

System Dynamics was originated by Jay Forrester at MIT as 'Industrial Dynamics' in the early 1960s,[28] but established recently as a widely used tool of operational research through the impact of visual interactive modelling software (eg 'Stella',[29] 'Powersim', 'Vensim'*). This followed the original mainframe batch processing approach (DYNAMO[30] and DYSMAP[31]). System Dynamics not only enables hard, quantitative effects to be captured, but also the softer 'human' effects (such as fatigue and morale) which can play an important role in the life of any project. The effect of 'soft' variables on the progress of a project has been modelled using System Dynamics in several contexts—for example, R&D,[32,33] product development,[34,35] and software development settings,[36,37] as well as the analysis of project behaviour (a review of which can be found in Rodrigues and Bowers[38]).

Key features of the generalised model

Model structure

The System Dynamics model consists of three main work functions: design engineering, methods/industrial engineering, and manufacturing. The normal procedure for designing our generalised product is as follows: from an 'unfrozen' state where additional information is required from work on conceptual design and customer-provided data, the designs becomes 'frozen' and ready for detailed design activity. Work is then carried out by the design engineering function. On completion by engineering, the designs move onto the client for approval, then proceed to the methods engineering function. The designs then arrive in the manufacturing function. Once the manufacturing function receives the designs they can begin to construct the product. A run of products is assumed during the life of the project, thus disruption to expected learning gains (both corporate and personal) is an important aspect of the impact of compression as we have modelled it.[39,40] The simplified flow of the designs is illustrated as a part of Figure 2.

Another critical aspect of the model is the rework cycle. Rework can occur at various stages of the engineering and manufacturing phases. Design engineering work may require rework because, for example, an internal error has been discovered, or the client requires a change to the design. This will involve the design being sent back to the engineering function for additional work. Due to cross-impact in designs (where a change in one design has ramifications for changes to others), rework on one design can cause other designs to be recalled and can lead to design 'unfreezing'. A similar situation may arise within the methods engineering function. In the manufacturing function rework can lead to completed work having to be undone and then redone. Also, manufacturing cross-impact can result in one piece of rework leading to other elements of the product being redone, or even rework occurring on previously completed units. Manufacturing rework can also lead to designs having to be reworked, causing the engineering rework situation described above.

The model used for the explorations conducted here does not take a detailed account of a network of activities required for the project. However, it should be noted that, if the model were enhanced to include detail of networks, then the impact of compression would be more severe.[25,41] This severity arises from parallelism that follows from the act of compression. Thus, assuming a project started from an optimal position, then by attempting to compress the project, cross-related activities may now have to occur in parallel (for a fuller explanation of the effects of parallelism refer to Williams *et al*[42]).

When using the model various managerial decisions have to be made on a weekly basis. These include the type of workers to hire and fire, the use of overtime and managerial pressure. The progress of the project will then depend upon the actual productivity achieved in each of the functions. Productivity losses can occur from situations such as the workforce experiencing low morale, fatigue or idleness due to a bottleneck occurring in the system, and from time spent on rework.[43] Thus we consider productivity losses from the system (rework) as well as losses due to

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*Stella, Powerism, and Venism are proprietary products of High Performance Systems Inc., Powerism AS, and Ventana Systems Inc., respectively.

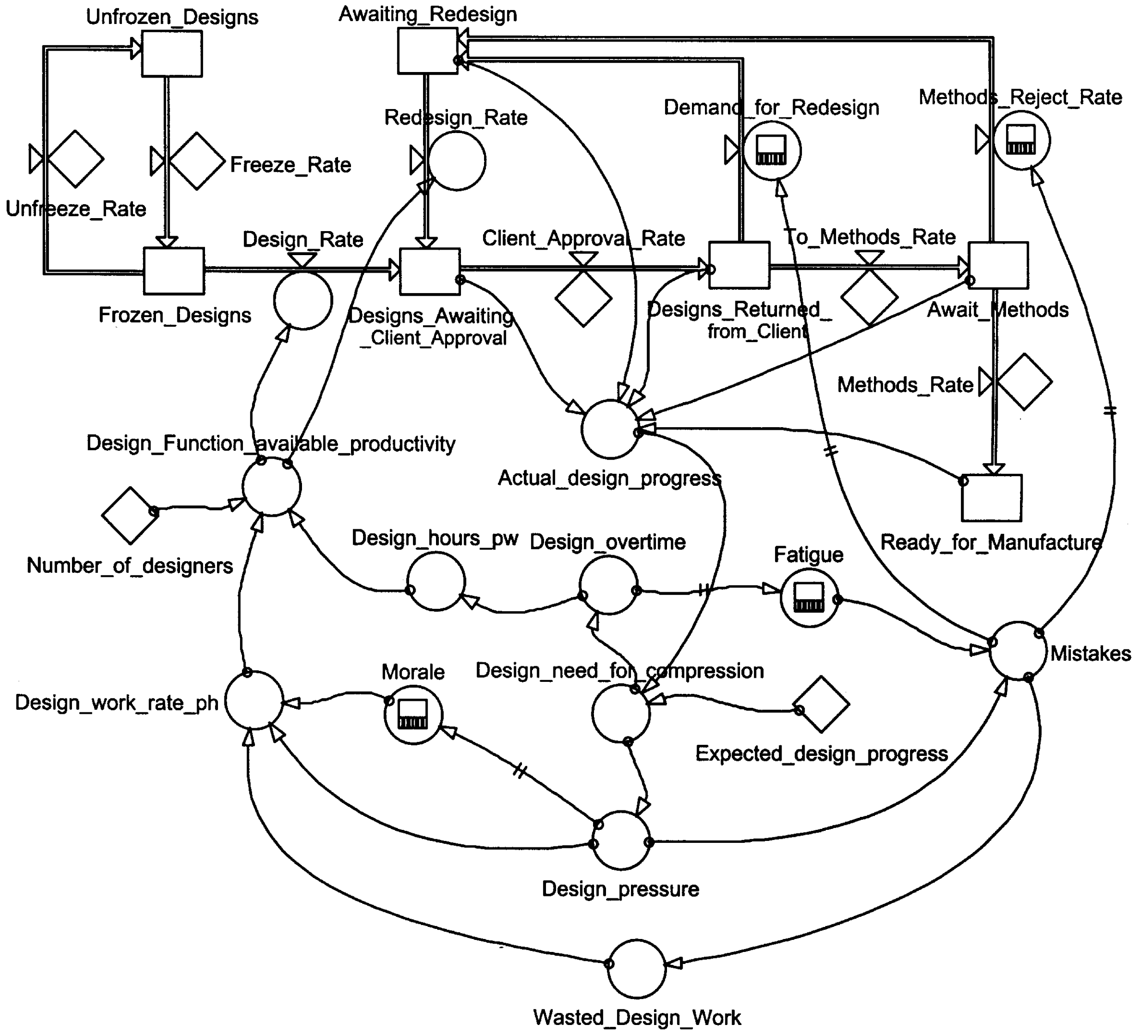

Figure 2 A simplified illustration of the way in which overtime and managerial pressure are modelled in the generalised System Dynamics model. This diagram is a significantly simplified representation of a small part of the flow of designs of the generalised System Dynamics model. In this diagram, managerial pressure (Design_pressure) causes workers to work faster, thereby increasing 'Design_work_rate_ph'. However managerial pressure can also cause a reduction in morale, thereby reducing 'Design_work_rate_ph'. Managerial pressure on workers also leads to mistakes, which may be noticed immediately by designers, causing a wasted amount of work, or may be noticed later in the process by the client or the Methods function. The amount of over-time used will mean that there are additional hours being worked each week by the designers, ie increasing 'Design_hours_pw'. However, designers can suffer from fatigue if too many hours of overtime are used for an extended period of time. The results of fatigue are that designers will make mistakes.

a slower rate of working of the labour force. These situations will slow down project progress and thereby cause a time overrun and so further compression.

The analysis carried out assumes that the company is in the situation where it has a full order book. It is further assumed that the company will wish to prevent any interference to any other projects being managed by the company. If this were to occur then D&D would be experienced by the other projects and would need to be properly computed.

Options

In this research we have constrained the options to the use of overtime and managerial pressure. In all of the claim circumstances and during the use of the training simulation, these options are the primary strategies used to accelerate projects because they are extremely flexible. Other strategies typically considered and rejected as initial strategies are:

- Transferring labour from other projects
  - Because the project has been planned optimally and so any further hiring would result in immediate productivity losses from overcrowding. We have further assumed that options such as 2-shift working and the use of sub-assembly lines have been fully exploited in order to arrive at the best bid. Also, as mentioned above, this would result in D&D on other projects and would need to be computed.

- Hiring new labour
  - It takes a long time to hire people.
  - New hires become a future and possibly unnecessary obligation
  - Finding good labour is usually taken to be difficult.
  - Significant personal learning losses occur.
- Sub-contracting work
  - Loss of control of the project follows.
  - Sub-contractor has to start at the front-end of the learning curve; thus the cost of sub-contracting is high.
- Using sub-contract/freelance labour
  - Personal learning losses occur.
  - Increased supervision compared to direct employees, thus increased costs.

Note that these options are available in the simulation model and the use of them is invited in the training environment.

Pressure—Typically, in order to win a contract the project delivery has to be better than that of competitors. It is likely that the management team will be under some degree of pressure from the start of the project (this is discussed further in the next section when considering the project's optimum position). In such a situation, management expects to pass this down the line to other staff in the form of managerial pressure. This has been confirmed from discussions with senior project managers. Any additional pressure used in an attempt to accelerate the project schedule is, for example, more than just managers looking over worker's shoulders. The pressure will be different from 'normal' projects: staff will feel they are under an unusual amount of pressure to deliver to a compressed schedule.

Although pressure initially induces a faster rate of work, negative effects arise through mistakes and reduced morale. This leads to additional rework and overall productivity losses.

Overtime—This option produces additional person-hours; however, if continued over an extended period of time, it can cause fatigue which results in mistakes which again leads to rework. The model used was based on a project whose budgeted time scale was two years where each of design, methods and manufacture can stretch beyond the period for continuous overtime to have a significant impact.

Figure 2 illustrates how the effects of overtime and managerial pressure were modelled as part of the generalised System Dynamics model. This figure represents a significantly simplified part of the overall model. It should be noted that, for the purposes of the experiments discussed in this paper, the links between 'Design_need_for_compression' and 'Design_overtime' and 'Design_pressure' are broken in the model. The amount of 'Design_overtime' and 'Design_pressure' used during a simulation run is based upon the experiments discussed in the next section.

Design of the experiments and indicative results

In order to be able to report on the effects of overtime and managerial pressure in attempting to accelerate the project, a benchmark simulation run is required. This benchmark represents the *earliest possible completion date* for the project under the circumstances of the project management attempting to apply pressure to a point where the benefit is not outweighed by any additional indirect costs of, for example, mistakes and rework. We shall assume that good project managers will naturally employ such tactics on all projects. For the purposes of this research the benchmark needs to be established through experiments with the generalised simulation model. This will be taken as the project's *optimum* position against which all other circumstances are compared.

In the generalised simulation model the expectations of the time taken to undertake tasks within the project are based on standard estimating procedures and these determine the labour requirements. The estimated labour usage over time follows the normal S-shaped profile. Based on these labour requirements, the project's optimum position is determined by experimenting with managerial pressure. The reason for this is that there are no direct costs attached to this decision, whereas, for example, overtime and increased labour force result in additional direct costs. The experiments relating to determining optimality, in effect, determine the difference between the project as conceived by the estimators and that negotiated and expected under commercial pressures.

A variety of managerial decision profiles were run through the model. The results of these runs show that the optimum position does indeed follow from increased managerial pressure with respect to the budgeted labour profile. This optimum position produces a delivery that is 3% earlier than originally determined by the estimators. This position follows from the application of managerial pressure of 10%. It is important to note that this index is meaningless in any *absolute* way—rather, it represents a mechanism for testing the net impact of productivity gains and additional mistakes. Thus, x% pressure relates to actions by management which are intended to increase the overall work rate of staff by x%.

Once the optimum project position was found, a benchmark existed for other managerial decision profiles to be compared against. Many different profiles were run through the model, and indicative results are shown in the tables below. Here we report on a summary of explorations where overtime and pressure were used in an attempt to seek a compressed delivery for the budgeted model. The different profiles run tested overtime and pressure at varying levels to ensure that the following results did not misrepresent the behaviour of profiles close to the ones shown.

In the tables below we have shown model outcomes as a percentage variance, where a variance for ‘late delivery’ implies a proportion of lateness *relative to the optimum delivery time.* The variance for ‘cost overrun’ implies an increase in project cost *relative to the original budget*, which is also the cost of the optimum simulation run. It is important in reading these tables that a spurious sense of accuracy is not presumed. Through the experiments, we seek to derive robust and meaningful general statements about the behaviour of the system under a variety of input conditions. A summary of the results are shown in Table 1.

Only two of the options considered resulted in the project being successfully accelerated to an early delivery. However, the cost of one of these options (overtime applied throughout) is very high at a ratio of 3.25 (13%/4%); that is, the minimum incentive required for this profile of actions to produce a pay-off for the contractor is a return which is the equivalent of 3.25 times the average original cost per week for the overall project. The second option (overtime applied for one month) only results in minimal delivery success. These results suggest that it is very difficult in any specific project to be able to determine the exact profile of actions that will result in early delivery which does not result in the ratio of extra cost to delivery gains being substantial.

These results are based on one set of reasonable assumptions regarding the impact of overtime and pressure on, for example, mistakes and fatigue. To explore the robustness of the results the profiles were re-run assuming that the impact of the negative effects of increased pressure and overtime were reduced by half to a level below that which ‘expert’ evidence and project managers would regard as implausible. A summary of the results are shown in Table 2.

In these ‘unlikely’ extreme cases, three options result in a successfully accelerated project; however, two of these options show a high cost/delivery gain ratio; overtime applied for 2 months results in a ratio of 3.0 (3%/1%) and overtime applied throughout results in a ratio of 2.4 (12%/5%). The third option does not result in a cost overrun: this is the only successful mix of strategies. The extensive range of experiments did not reveal other significantly different circumstances where this can occur.

Taken together, the results indicate that:

(i) Small increases in pressure, applied throughout at an equal level, produce significant overruns against the original budgeted, and feasible, delivery date.

  Although the assumption used is that pressure is applied at an equal level throughout the life of the project, pressure would be likely to increase as delivery was seen to be getting worse. The model outcomes replicate the way in which managers keep pressure on throughout the project, because they are unable to anticipate the long-term side effects until it is too late. Indeed, the tracking variables which indicate forecast delivery and cost, which are available to a manager, continue to suggest to the manager that increased pressure is having the desired effect—until it is too late to do anything other than extend managerial action, such as increasing pressure further.

(ii) Overtime, at a moderate level applied throughout the project, results in early delivery but with a substantial increase in cost.

  Many managers are aware that a short burst of overtime has little deleterious effect on productivity, unless it is a substantial proportion (for example, over 25%). Thus, it may seem unreasonable to run our experiment with overtime applied throughout the project. However, as for increases in pressure, the forecast long-term impact of overtime seems to be good and so there is a great temptation to keep it in place and push for further incentives. As Sterman[44,45] reports, the mental models and processes managers use to make decisions do not anticipate feedback dynamics. Similarly our own experience, in using complex simulation models for training senior managers to appreciate feedback dynamics, amplifies this phenomenon. Even when feedback is explained, and that it is going to occur, they find it difficult to go beyond trend extrapolation and simple forecasting models. They seem to use current experience of their decisions to extrapolate and ignore the extent to which

Table 1 Summary of explorations using a set of reasonable assumptions regarding the impact of overtime and pressure

Managerial action	*Late delivery*	*Cost overrun*
5% pressure throughout	16%	20%
3% pressure throughout	13%	18%
12.5% h overtime throughout	4% early	13%
12.5% h overtime for one month (applied at peak)	1% early	0.4%
12.5% h overtime for two months (applied at peak)	0%	3%
5% pressure and 12.5% overtime applied throughout	11%	36%

Table 2 Summary of explorations using a set of extreme assumptions regarding the impact of overtime and pressure

Managerial action	*Late delivery*	*Cost overrun*
5% pressure throughout	6%	8%
3% pressure throughout	6%	8%
12.5% h overtime throughout	5% early	12%
12.5% h overtime for one month (applied at peak)	1.5% early	0%
12.5% h overtime for two months (applied at peak)	1% early	3%
5% pressure and 12.5% overtime applied throughout	1%	21%

current decisions create dynamics having consequences that show at a later time in the project life.

(iii) The application of both overtime and pressure together results in an improved delivery compared to the use of pressure on its own. However, the delivery still overruns and the total costs overrun is greater than the summation of the individual cost overruns.

(iv) When short bursts of overtime (that is, for periods of 1 or 2 months at a time) are applied there is an improvement on overall costs compared to using overtime continuously.

It must be noted that, although some of the profiles resulted in an early delivery, the cost involved was high in most cases (relative to the average cost per week of the project as originally budgeted). This represents the incentives that management would *at least* require for it to be worth their while to attempt compression. As we state above, the probability seems slight of finding the highly specific circumstances where there is any certainty in an outcome of early delivery at little extra cost.

Conclusion

The quantification of the impact of pressure on productivity, morale, etc. is difficult. Even though our modelling follows from the use of 'good' expert evidence and careful approaches to parameter estimation from those witnessing the projects, we were hesitant to draw conclusions unless we could be certain that, for example, *small* increases in pressure produced large impacts on delivery and cost. As we suggested above, the use of quantitative data in research of this nature brings with it the danger of a spurious accuracy. We have sought to derive robust and meaningful general statements about the behaviour of the system under a variety of input conditions. However, in testing a range of relationships, our experiments suggest that the conclusions described above are reasonably robust, given the state of research knowledge about the micro impact of one variable on another.

Thus, with a reasonable amount of caution, we believe that it is useful to report the outcome of these experiments. To repeat our earlier argument: we have had the privilege of access to in-depth forensic analysis of project cost overruns, and this is likely to mean our experiments are, at least, informed by the realities of complex projects.

In summary, we suggest that the use of overtime and/or managerial pressure in seeking to compress the delivery schedule on a 'reasonably' planned project can have serious side-effects. The effects on fatigue and morale are likely to lead to impacts on both worker productivity and the quality of work carried out, which in turn generates self-sustaining disruption and consequential delay. The delays force new compression and so exacerbate the situation. In using either pressure or overtime to compress a project, managers should use caution, as their use is likely to be more costly than most managers imagine.

We stated in the introduction that our work was partly driven by the need to say something helpful, and reliable, to managers wishing to make decisions about whether to go for incentives for early delivery. If pushed, we would submit that any bonuses offered by the client would have to be very large for project compression to be worth considering. Information from companies suggests that the 'typical' bonus figures are usually insignificant compared to the costs of compression, providing the original contract was bid for under competitive conditions and therefore no slack was inherent at start-up. The probability of profiting from incentives for accepting the compression of a project is likely to be slender.

This research goes beyond Cooper's[8] *general* conclusions on the rework cycle (the details of which are stated in the introduction) by drawing more specific conclusions to aid managers who are seeking advice on the likely costs of compressing a project. Based on a range of data and projects, this work confirms that an analysis of embedded D&D is essential to any evaluation of gain from incentives. Cooper[8] concludes that:

> 'By understanding the paths of influence, and where in each path we as managers can exert influence, we can achieve enormous leverage on the project by changing the performance of the rework cycle'.

An understanding of the paths of influence is certainly a step in the right direction, but we need to take this further. Some form of system which provides early warning of the future impact of emergent D&D is required to aid project management. This system would aid the identification of feedback loops caused by D&D as early as possible. Management could then attempt to manage them before they get out of control and lead to the massive time and cost overruns which have occurred in so many of the projects we have analysed.

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