

FEAST/2 Final Report - Grant Number GR/M44101

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Background: The FEAST/2 project was a follow on of the two year FEAST/1 project under grant GR/K86008 which was successfully completed in September 1998. As reported in the final report on that project it yielded over almost 30 journal, conference and workshop publications and many more presentations in meetings, universities and industry. Moreover, the project generated process understanding and hypotheses, explanatory and prescriptive, that provided the basis for the FEAST/2 proposal and project.

Personnel: FEAST/2 commenced work in April 1999 with two research associates, Dr Goel Kahen and Mr Juan Fernandez-Ramil and a part time personal assistant/secretary, Ms Siew Lim, under the general direction of the principal investigator Prof. M M Lehman. Of these, Mr Ramil's appointment continued his FEAST involvement, building on and continuing his earlier outstanding contributions to FEAST/1. In the 6 month interregnum between FEAST/1 and FEAST/2 Mr Ramil was the recipient of a BT Short Term Visiting Fellowship at their Martlesham Research Laboratories. The basis of the award was to permit him to apply the FEAST investigation techniques to BT's main administrative system, CSS, and to develop a model that would assist BT in reaching a decision about its future. BT, which has expressed interest during FEAST/1 subsequently joined the FEAST/2 project as an active collaborator.

Dr Kahen was specifically recruited to take over the Systems Dynamics process modelling for FEAST/2 the responsibility of Dr Paul Wernick in FEAST/1. On completion of his FEAST/1 assignment Dr Wernick received a one year appointment as a lecturer at Birkbeck College before moving to a permanent senior lectureship at the University of Hertfordshire. He continued, however, to visit the project and guide Dr Kahen in his initiation into Systems Dynamics modelling so greatly reducing the problem of transition.

Ms Lim joined the project as a half-time secretary but proved so capable in many technical areas that the appointment was extended to 66% and she undertook many of the technical tasks that would normally have been done by the RAs. In particular she was largely responsible for developing a maintaining the FEAST web page at <http://www.doc.ic.ac.uk/~mml/feast>

The project also benefited significantly from the active involvement of Professor W M Turski of Warsaw University Professor, Dwayne Perry, initially of Bell Labs Lucent Technologies and now of the University of Texas at Austin. They had worked with the Principal Investigator for a number of years in establishing many of the foundations on which the FEAST studies were based, had participated in FEAST/1 as EPSRC Senior Visiting Fellows and were enabled to continue that involvement in FEAST/2 through the grant of a further one year EPSRC SVF Award under grant number GR/N02412.

Collaborators: The FEAST/2 industrial collaborators were BT Labs (Martlesham), DERA, Matra - BAe Dynamics, ICL High Performance Systems and Logica plc (Banking division). Dr David Freestone and Messrs Mike Ashton, Dave Nuttall, Brian Chatters (subsequently Iain Malcom) and J Halberstadt, respectively, were the principal contacts. As a result of Dr Perry's involvement in the project, Lucent Technologies continued the *de facto* collaboration that had already existed in FEAST/1. Other individuals from these organisations, Mr Les Barker of BAe, in particular, also made important contributions through their interaction with the project team.

Of these collaborators, BT, ICL, and Lucent provided the data on which the FEAST/2 modelling and analysis was based. As a result of management changes DERA, though a sponsoring collaborator, had withdrawn the project that was to have been studied in FEAST/1. For FEAST/2 they sought to come up with an alternative but the basically short-term nature of their software development projects and preoccupation with other assignments blocked the provision of relevant data. They, however, shared their experience and insight during active participation in the FEAST workshops and other meetings. The data provided by Matra – BAe Dynamics during FEAST/2 did not prove relevant to the study. The contact person in Logica was moved to a different position which hindered the availability of new data.

FEAST/2 Goals:

- i refine set of models and their interpretations and formulate laws and rules derived from them
- ii develop and refine FEAST methods and conclusions to forms suitable for transfer to industry
- iii develop models of mechanisms underlying observed behaviour
- iv monitor systems studied in FEAST/1 and extend techniques to new systems and data sets

Summary of Results: These goals have all been achieved, to a greater or lesser extent, as follows.

i. As reported in the almost thirty FEAST/2 publications (see list of papers at <http://www.doc.ic.ac.uk/~mml/feast>) the various black box models developed in FEAST/1 have been re-examined and refined, a process that has strengthened earlier conclusions without substantial change and also produced new insights and results. As an example we mention the identification in all of the release based system evolution studies (to exclude the Matra-BAe system which represented an *ab initio* development) of segmented growth trends as per the example in figure 1 where S/S1 stands for the ratio of the system size at each release over the time period for which data was available and S1 is the size of the first release of the sequence. RSN is the pseudo time measure of each release.

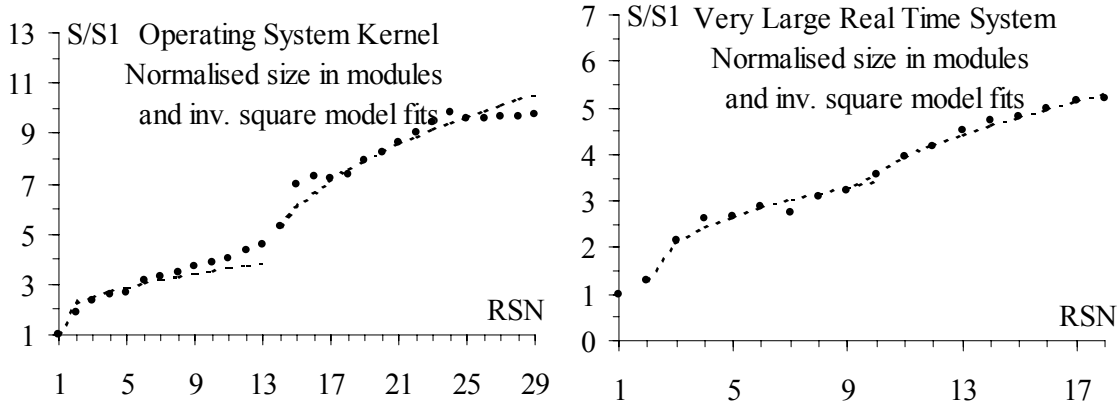


Figure 1. Two Examples of Growth Trend Segmentation

Tables 1 and 2 below, which present the models and summarise some of the results obtained [leh01c]. They record that fitting the inverse square and other related models [leh01c] (Table 1) has provided high predictive capability. The models were fitted as appropriate, either over the entire data set or, where inflexion points observed in the trends indicated a significant trend change, over two consecutive data point sets. This has produced improved fits with MMRE (Mean Magnitude of Relative Error of actual to predicted size) between 2 and 17 percent as indicated in Table 2

Table 1. Growth models (black box). Details in [leh01c]

Model 1 Normalised size as a function of the release sequence number	Model 2 Normalise size as a function of the normalised work-rate	Model 3 Normalised size as a function of the release sequence number
$\underline{S}_i = S_1 (i)^{1/g}$	$\underline{S}_i = S_1 (H_i/H_1)^{1/g'}$	$\underline{S}_i = S_1 [\underline{S}_{i-1}/S_1 + [e (S_1)^2/(\underline{S}_{i-1})^2]]$ For $i \geq 2$

Note: \underline{S}_i is the predicted size (total number of modules) at release i . H_i is an indicator of work-rate (e.g. modules handled) during preparation of release i , where i indicates an RSN. g , g' and e are model parameters

Table 2. Modelling accuracy in MMRE (in percent) of models presented in Table 3 (MMRE: mean magnitude of relative error). Details in [leh01c]

System	Model 1 MMRE %	Model 2 MMRE %	Model 3 MMRE %
A (*)	9.1	10.1	8.4
B (*)	11.1	8.6	9.7
C (*)	9.4	5.0	9.8
D (*)	11.7	8.4	16.8
D (segment 1: $1 \leq i \leq 8$)	2.8	2.7	5.7
D (segment 2: $9 \leq i \leq 13$)	5.6	2.3	1.7

(*) model fitted to and MMRE calculated over entire data set

Notice, of course, that even the models with the larger MMRE have precision that is quite remarkable when one considers that the predictability of a human planned, managed and implemented process is being estimated. This remarkable fit precision is interpreted as strong evidence in support of the hypothesis that system dynamic forces are

present and exercise a powerful, probably dominant, effect on *E*-type software processes. The observed declining growth is compatible with the hypothesis that increasing complexity plays a constraining role in system evolution. However, a decrease in the effort applied, considered irrelevant in previous studies [leh85], appears to have also played a role in the declining growth trends in at least one of the systems [ram00b]

Recognition of the segmented growth trend represents progress in the achievement of means for management of the evolution process. The segments observed bear some relationship with a recently proposed staged model of the software lifecycle [raj00]. In the period just before or over the break between two segments there must have been significant changes in the software system (e.g. code and/or structural clean up, complexity, improvement of documentation), the process (e.g. process structure, changed inter-release time interval, personnel) or the implementation or user domain (e.g. release content policy, organisational structure, user support) that restored the declining growth rate trend to its previous level. This, in fact, has been confirmed for one of the systems. It is encouraging that in all cases a declining rate trend has been restored, starting off a new cycle of decline. While not having then had available an analysis such as the present *post factum* analysis, managers and developers appear to have been able to sense increasing resistance to growth and to devise means to rectify the situation. FEAST/2 systems dynamics analysis, modelling and simulation have addressed this issue. A model that suggests that it is possible to achieve a continuing growth trend close to linear has been developed, will be discussed in subsection iii.

ii. The methods and techniques used in studying evolution and in the development of predictive models have been presented to and discussed with the collaborators several times. A summary report "Rules and Tools for Software Evolution Planning and Management", has been prepared and circulated to the collaborators. This presents in some detail the general observations and generalisations that have come out of the FEAST/1 and FEAST/2 studies and their practical implications. It provides details of some 35 guidelines and rules for use by project managers in planning and managing software development and evolution activities. A modified and extended version of the report has been accepted by the Annals of Software Engineering for a special issue on software project management [leh01b]. It will be appearing later this year and should receive wide industrial and academic exposure.

In principle they should be in a position to apply them within their current projects. They have also been presented, by direct invitation, to wider industrial audiences, IBM and Microsoft, in two EPSRC-Outreach seminars, at a number of international conferences and workshops and in the project publications. We do not know to what extent the techniques have been applied though our willingness to guide and assist has always been emphasised. The experience probably illustrates very well the challenges of technology transfer to an industry under daily pressures, schedule and financial, that blocks their willingness to adopt, or even try out, new methods however well they have been demonstrated.

A frequently raised point in our outside presentations has, while accepting the FEAST results in their context, questioned their relevance in the fast emerging environment of reuse and COTS (Commercial of the Shelf Software). The hypotheses on that topic, a direct outcome of the FEAST studies, have been aired at workshops and published in [leh00]. Supported by technical reasoning, we have expressed a view that the results, possibly modified, will remain largely valid, that this new trend may well raise as many problems than it solves. We also recognise the need to engage in a systematic investigation of these issues and to solve the anticipated problems and are preparing a proposal for such an investigation to be submitted shortly.

iii The approach to identifying the mechanisms underlying the observed behaviour follows from the FEAST feedback hypothesis that underlies the investigation. The evidence, empirical and from insight into the software process, indicates that the process is a multi-level, multi-loop, multi-agent feedback system. The question of whether one can apply advanced control theory to the process depends at least on two factors. The first is the availability of adequate behavioural models of the process. The second relates to management willingness or not to adopt control-theoretical inspired approaches to manage the process. The first factor is essential and the only one that we can readily address. Even an experienced control engineer can do nothing without a model of the system to be controlled. But the achievement of accurate behavioural models entails many challenges due to the level of complexity, uncertainty (e.g., human behaviour) and lack of discipline in the process. However, FEAST, together with the work of the software process simulation modelling community have been made advances in this regard. Given the domain, systems dynamics modelling [coy96] became an appropriate choice, and Vensim [ven00], the software tool to construct executable models and run them to obtain simulated behavioural measures of the selected processes. However, contrary to the approaches of other systems dynamics users in the software areas we had concluded that processes were not to be modelled in all their gory detail. In our judgement that approach yields models that are difficult to debug or to calibrate, behaviour that is equally difficult to interpret and, above all, models that cannot be fully appreciated (understood) in themselves and in relation to the real world processes to which they must be related. Instead we adopted a successive refinement approach starting with the simplest possible, meaningful, models. As, at each level, the model was understood and its behaviour could be interpreted as reflecting real world

process behaviour to some level of detail. Once the behaviour of the model and, with it, the implicit behaviour of the real process was understood, the model was refined to add new further detail reflecting actual process behaviour. The resultant model was then recalibrated and reinterpreted and according to the success of these operations, the model refinement was accepted or rejected. We have termed this the FEAST approach to behavioural process modelling and discussed it in several papers [ram00,leh01b]. We consider the FEAST approach an important contribution in particular when, for example, process modelling formalisms, and not methodology, have received the wider attention. We consider that the achievement of an appropriate modelling methodology is essential to ensure industrial take up of behavioural process modelling.

The approach and its results are illustrated by the most recent model, a model ready for further refinement [leh01d]. It reflects the level of *anti regressive* activity [leh74] in the software process and its impact on the rate of growth. Anti regressive activity is defined as activity that appears to have no immediate market value, no direct value to the user or, more generally, to the system stakeholders. What it does is to ensure that, as the name suggests, the system will continue to have value in the future. Such activity may be exemplified by updating of system documentation (for future developers and maintainers), component or module re-writing, complexity control, system restructuring, removal of dead code, architectural clean up and so on. It is a matter of fact that, for reasons now well understood, the complexity of real world software systems that are in regular use grow with time unless work is undertaken to control and reduce it. The phenomenon is reflected in the second law of software evolution [leh74] and has been extensively discussed in the literature. Increasing complexity makes evolution of the system through the development of new versions increasingly time consuming, costly and error prone. A tool to evaluate the need for complexity reduction and help identify the process locality to be improved to get less rapid build-up, can therefore be expected to be a powerful management aid. Figure 2 illustrates the model structure using standard systems dynamics symbols as implemented in Vensim.

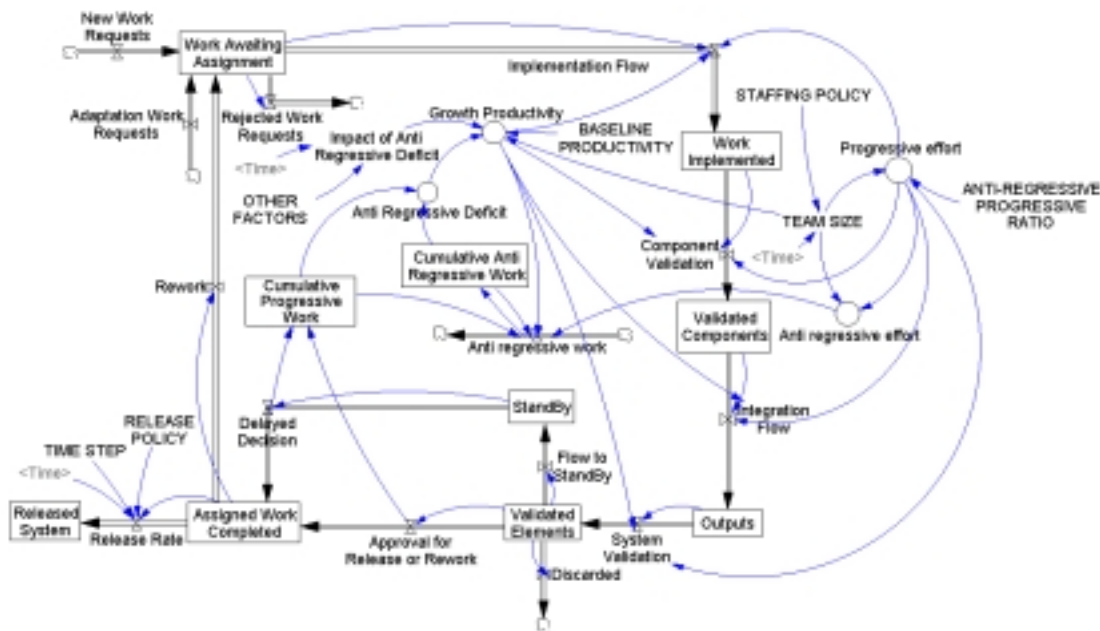


Figure 2. A System Dynamics Model of Antiregressive Activity in the Software Process

A key question to be asked about any SD model is the extent to which the result of model execution is a reflection of clever calibration and the extent to which it is an indication that model mechanisms reflect mechanisms of the real world process. This issue may be resolved, confidence that the model mechanisms reflect process mechanisms may be increased, by the degree to which further model refinement replicates observed process behaviour more closely. Absolute confirmation is approached if process changes that reflect model changes produce process behavioural changes that may be interpreted in terms of model behavioural changes.

The simplicity of the model compared to that of others in the software literature [e.g., abd91] is self-evident. It would be even more so if the space available permitted reproduction of all 4 diagrams that display the development step by step. Figure 3 and 4 exemplify the typical model outputs and are more fully discussed in [kah01].

iv. Accomplished to the extent permitted by the available data. Limitation in this regard are mentioned below, under “difficulties”.

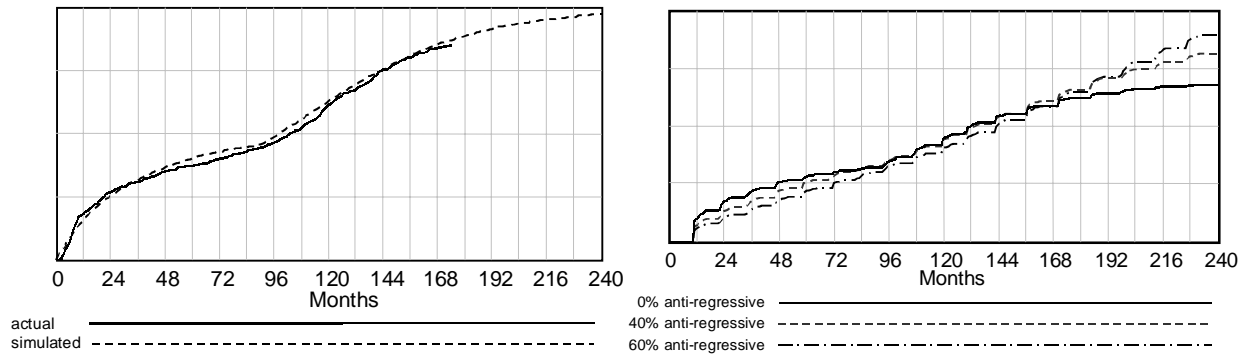


Figure 3 (left) Close Fit of the Model to an Actual Process and
 Figure 4 (right) System Growth - Various Progressive-Anti Regressive Ratios

Difficulties: The segmentation effect was detected for most of the systems for which data was available. The primary difficulties that emerged in following through the planned FEAST/2 investigation arose in connection with the provision of additional data. This affected various areas of the work, both black and white box, which in general was heavily dependent on the provision of data. For example, the investigators could not explore in detail the triggers behind the inflexion points and hence the segments. In one of the cases, personnel who were involved and are still available were able to identify events occurring about that time that explain the above patterns. Thus, at least in one system, specific explanations were available and related to technological changes which prompted system restructuring and re-writing. In other cases, personnel with knowledge and detailed memory about events at the time of interest were no longer around. Thus, it was, however, very difficult to be certain about the common trigger or triggers of the new segment after an interval of many years. A recent study [ant01] identifies a phenomenon of *punctuated evolution*, suggesting that triggers for the jumps observed in feature space (very possibly corresponding to the inflexion points in our growth trends) are external and driven by technological changes in the domain.

Workshops: The majority of the collaborators and the two EPSRC SVFs took an active role in the studies outlined above. The progress made would, indeed not have been possible without their strong and continuing interest and active support. In particular, all participated in the one day (approx.) quarterly workshops at which progress was reported, results critically discussed and extended, and further direction of the investigation agreed. Invited visitors included Professor Uzziel Sandler from Jerusalem College of Technology, Dr. Audris Mockus, from Lucent Technologies, Tom DeMarco from The Atlantic System Guild, Stephen Cook from U. of Reading and Siv Sivzattian, a mature PhD student were invited to participate in one or other of the workshops to contribute from their relevant experience and to comment on the FEAST/2 results.

In addition to the internal workshops one open workshop was held from 10-12 July 2000 with invitations based on submitted position papers. The three day event held at Imperial College, attracted over 40 participants from 14 countries and provided the basis for a Software Evolution week with the FEAST workshop from Monday to Wednesday mid-day, a joint session featuring Professor Barry Boehm as the keynote speaker, Wednesday PM, and followed by two events, the International Workshop on Software Process Simulation Modelling (ProSim) and the Software and Organisation co-Evolution (SOCE) (meeting which ran through to Friday PM. Preprints were circulated to the FEAST workshop participants before the workshop and an edited book based on the submitted papers but also including some invited contributions is now in preparation.

Dissemination: This evolution study is inherently difficult, essentially inter disciplinary and pioneering. Objective difficulties must be overcome in studying software evolution and seeking exploitation of feedback phenomena in the software process. The potential industrial significance of the findings as evidenced, for example by a paper [leh01b] to be published in volume 11 of the Annals of Software Engineering and the fact that there is little, if any, parallel work going on elsewhere led to a major effort to keep the academic and industrial software engineering communities in general, and the software process community in particular, continually aware of the work and the progress being made. As indicated in the attached list of publications and presentations some 20 were presented at conferences, workshops, etc., of which 5 or so were invited or keynote lectures with publications in associated Proceedings or Journals such as JSS and the LNCS Springer series. In addition, some 9 seminars or so have been given in the UK, Europe, and the USA during duration of FEAST/2 at both academic and industrial locations. There is, therefore, solid evidence of the extent to which the work has become known nationally and internationally. The preparation of major journal publications has been held back to await the availability of more complete results and analysis

expected to be (and now) available at the conclusion of the project. A full list of publications is included in the appendix to this report and texts of those whose copyright is not held by others are available via links from the FEAST web page at <http://www.doc.ic.ac.uk/~mml/FEAST/>.

Awards: At the recent ICSE 2001 conference in Toronto, the FEAST principle investigator, Professor M M Lehman was presented with the prestigious Harlan Mills Award of the (International) Computer Society, only the third recipient since its inception. There can be little question that this award is to some considerable extent due to the FEAST work and to the dissemination of its results.

Some significant results - no significance to be attached to the ordering:

- Greatly increased understanding of software evolution, its regularities, patterns and constraints
- Support for refined version of the laws of software evolution
- System dynamics has significant impact on the software evolution process with regularities stronger within segments or stages of the lifecycle
- Inflection points in evolutionary trajectories possibly driven by changes in the domain (e.g. technology, demand) with resource level (e.g. team size) also playing a role
- Inverse square and related models (Table 1) and their pointing to complexity growth of applications and of implementing software as a significant constraint on continuing (and necessary) application and system evolution
- Incremental growth limits as a planning tool
- Advances in software process modelling, the application, analysis and interpretation of process metrics
- Simple SD models can produce meaningful results and insights
- Approaches to and procedures for behavioural process modelling and exploitation of software process metrics
- Design principals and seeds for specific software process analysis, planning, management and control procedures, tools with long term potential for generic stand alone or integrated tools
- Emerging understanding of and design principals for tools for software process improvement

References A full list of publications is attached to the attached individual grant review form

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