# Resource allocation and project scheduling for an internal consultancy organisation

## Executive summary

### Overview and background

The managers of the 'Application Development Group' (ADG) face a regular stream of often conflicting requests for internal projects that call upon their limited resources. The projects tend to bring varying levels of business benefits to the company and have different levels of costs associated with their execution.

The challenge of prioritising projects, scheduling them in a way that smoothens the work load, changing or re-skilling the staff complement if need be and maximising the benefit to the company is ongoing. At the same time, we need to be able to defend and justify our decisions to the requestors and business sponsors.

### The decision

The key decision that needs to be made is to decide which projects to drop and which to carry out given limited resources while maximising the benefit to X&Y Corporation & its group companies. There is also the added challenge of deciding the best time to start a given project off given the time scheduling of all the other projects.

### Challenges for decision makers

Given the large number of inputs to decision making, it is not possible to intuitively arrive at an optimum (or even near-optimum) decision. This is so because

- there are conflicting demands from clients for projects that bring varying levels of business benefits,
- each project can start on a number of various possible dates and use different kinds of resource inputs that can cost differently, and
- it is possible to manage with different levels of staff shortages.

The number of solutions that are feasible, even though not optimum, often run into thousands, and clearly cannot be considered using intuition or professional judgement alone. Often, the first 'workable' solution is adopted and resources committed, thereby potentially destroying value.

### Traditional approach to project decisions

Traditionally, managers in the ADG have largely relied upon their business judgement and experience when deciding what projects to undertake, how to schedule them within client specified constraints, while minimising costs at the same time.

### Building the model

It is possible to build a spreadsheet model that shows the impact of a particular decision on all other variables, particularly resource utilisation, and the effect on the objective function that we seek to maximise.

In modelling terms, the objective to maximise is:

- A summation of the 'value added' by each project undertaken (typically 'business benefits *minus* estimated costs')

*Less*

- Cost of any external contract resources that had to be hired to ride over peaks in work load

*Less*

- Cost of any idle staff ('on the bench') that was not charged to projects

Using the above function, we use the power of Excel to go through a repeated iterative process of evaluating a large number of possible solutions, and present to us the 'best' alternative given the exogenous variables and constraints we have specified.

**Results of the modelling exercise**

The modelling exercise provides the benefit of making transparent the effects of decisions on project scheduling, resourcing and value added. The modelling exercise was carried out for a very limited part of the entire ADG organisation – viz. the projects handled by the Geneva based operations of the group. Some of the insights are documented in the 'what-if' analysis section of the report that follows. The model can help ascertain:

**Appropriate staffing levels –** by revealing any persistent over or understaffing for a particular skill type. For example, in one of the variants of the model that was examined, it was found that increasing the headcount for developers by one starting March onwards has an effect of increasing the value to the company from GBP 497k to GBP 642k, an increase of GBP 145k!

**Appropriate project selection –** Depending upon staffing levels, cost of alternate contractor resources, and the different earliest and latest start dates of various projects, different projects are "profitable" in different situations. While projects that have a very large value addition will always have an absolute advantage over others, it is the 'borderline' projects that fall in and out of the 'best project portfolio' as different variables are changed. This form of decision making is not intuitive and a model such as this is essential to understand the dynamics of the different choices.

**Deciding acceptable shortage levels –** When there are more projects than the existing staff can handle, a certain level of 'shortage' can be managed by increasing the workload on existing staff. Allowed beyond a certain point, this can cause staff burnout and serious client dissatisfaction. Different 'shortage' levels can lead to different projects being selected, and different values of the objective function. This relationship has been reviewed later in the document.

**Acceptable level of contractor costs –** For the collection of available projects for which a simulation was carried out, it emerged that it is not worthwhile to hire external contract resource when they cost more than GBP 30k/month. The relationship between the total value addition, and varying levels of contractor costs has been examined later in this document.

**Conclusion**

Decision modelling permits us to build a rational framework for our decisions and allows us to see the impact of various inputs into the decision process on what we seek to maximise. It is an extremely powerful tool for carrying out 'what-if' analysis and provides a strong logical basis for managerial decisions. The model that has been built as part of this exercise is a fair approximation of a true business situation, though of course further refinements are always possible.

The purpose of a mathematical model is to lay bare in quantitative terms all the 'fuzzy' issues that go into making a decision. The clarity that such an exercise brings is intended to provoke thinking about everyday decisions in new ways. With this, I invite you to read the rest of this document and discover how the ADG can plan to better serve its clients and the company.

## OAG: Overview and background

The Application Development Group within the Information Systems department of X&Y Corp. is an internal service department within the company. It provides internal consulting on financial systems to X&Y Corporation.

The X&Y group has offices in over a hundred countries and about three hundred subsidiaries, each of which needs financial accounting and transaction processing systems. In 1993, after an analysis of the various solutions available in the market, X&Y Corp. selected Oracle as the as the financial systems application and technology provider. The Application Development Group (hereinafter referred to as the ADG) was established about 7 years ago to implement the "Oracle Financials" suite of ERP systems.

By reducing the need to approach expensive outside consultants, the ADG has over the past seven years saved many millions of pounds for X&Y Corp.. Today, the ADG employs over 50 people world-wide who are primarily engaged in supporting, upgrading and customising Oracle Financials for X&Y Corp. globally. The ADG is modelled as an internal consultancy organisation, and service levels are agreed with internal clients in the form of formal service level agreements before services are provided.

Most work in the ADG, as in a typical consultancy, is project based and "clients" (who are all X&Y Corp.' group companies) are charged for services provided by the ADG by means of internal debit notes. (These charges find a place in the profit and loss accounts of regional and divisional business units, and are on par with the charges that are paid to external providers).

The ADG is open to external competition from the likes of KPMG, Oracle Consulting etc, and for new projects clients are free to go directly to these companies if it will save money. The ADG charges costs on a 'time plus materials' basis. In nearly all cases, it is able to beat external competition on the price front. (The only situation where an external vendor may be cheaper is when it has already developed a product for another client, in which case its marginal cost to sell the same product to X&Y Corp. is zero.) In all the ADG runs in a fairly competitive situation and is not an internal monopoly.

## The project process - Nature of projects

The nature of work at the ADG is project based. Project tend to fall into three broad categories:

(a) New implementations – These are completely new implementations carried out from scratch in a X&Y Corp. subsidiary or business area. However, with increasing global coverage and most of the X&Y Corp. world having already moved to Oracle Financials, these are now increasingly limited to new acquisitions.

(b) Upgrades – These are product upgrades carried out as newer versions of software are released by Oracle Corporation. This is an on-going process, as when X&Y Corp. decided to implement Oracle Financials, they committed to remain with the most recent and latest technology.

(c) Ad-hoc requests – These are the most numerous, and often the most complex projects. These relate to efficiency enhancing product customisations applicable often to a single unit or country, or occasionally to the entire group. For example, X&Y Corp. Belgium may require a special Electronic File Transfer to its bankers in Brussels which has to be custom built, and Italy may require a special accounting report to submit to its tax authorities (e.g. the *Libro Giornale*), and so on.

## The decisions required

Managers at ADG are constantly faced with a variety of requests from clients, each a project, and at the same time have limited resources with which to carry out these projects. The objective is to maximise total value for the company, which happens only when value adding projects are undertaken, and scheduled to best utilise staff resources.

Because of the project oriented nature of the work, the workload is not evenly spread across months in an year, and peaks and troughs in resourcing requirements are quite common. Peaks can be accommodated by hiring contract staff on an as-needed basis, and at every 'peak' the manager has to grapple with the question of whether to hire permanent staff or engage contractors. (On an average, permanent staff costs 25% of the cost of a contractor).

**Interchangeability of skills**

A key characteristic of the services we provide (i.e. implementation and new developments) is that skills are fairly commoditised and contractors with the right skills can be hired from the market with literally 2 weeks notice. These contractors are employed on short term contracts, with a notice period of as little as 2 weeks. There is a very liquid market all across Western Europe and North America for Oracle Financials contractors and most of these contractors are interchangeable with staff with similar skills. They can even be hired from Oracle Corpn themselves who maintain a large army of Oracle consultants for exactly this purpose. Because of their experience in other companies, the training period, if it can be called that, is extremely short, and most contractors (except the particularly bad ones!) hit the ground running when they join us.

We use contractors to ride over temporary peaks in our work.

**Key decisions**

The key decisions facing a manager are as follows:

- Given the existing staff strength and skills, what is the most effective way to schedule projects so that value addition to the company is maximised and peaks and troughs are offset against each other to the extent possible.
- Given each project's contribution to value, and that there will always be some skill shortages, what is the minimum level of external contract resource that we can hire.
- Given how projects are scheduled, do we have a perpetual surplus of a particular set of established staff skills that can be shed (or alternatively, can existing staff be retrained), or a perpetual shortage that would best be covered by new hires.

## Traditional approach to the problem

Traditionally, this problem has been sorted in the ADG using rules of thumb and intuition. For example, after running short of project management skills for six months, we will go out and hire a project manager. Hiring decisions tend to be long term in nature and are not easily reversible, and therefore are reviewed very carefully before being finalised.

Project scheduling & prioritisation has often happened on the basis of very limited and unstructured analysis, and is greatly influenced by whichever client shouts the loudest.

## What do we know, i.e. what inputs to decision making are given?

At any point in time, when deciding upon the projects to undertake and their scheduling, we know a few things – some of these are a given, and for others we have a bit of flexibility.

Building a spreadsheet based model allows us to carry out a number of 'what-if' analyses on these inputs, for example can we increase the total value add to the company if we were to hire more established staff, or if we were able to hire contractors at a cheaper rate, say from an software outsourcer in India.

The inputs in the decision making process are outlined below:

1. **Skill requirements:** A variety of skills are required for carrying out projects, and these can be classified in broadly the following non-overlapping categories.

   **PM = Project Management**
   Project Managers are responsible for co-ordinating a project, ensuring project deliverables and milestones are met, and client expectations are satisfied. They are the primary contact with senior client management and responsible for the project team.

   **Dev = Development (programming)**
   Developers are responsible for writing code (i.e. computer programs) that meet the particular business needs.

   **BA = Business Analysis**
   Business Analysts are people who understand both the business and the technology and are able to translate client requirements into documentation that the developers can convert into code. They are also responsible for training, testing, data migration and may also perform project management on small projects.

   **DBA = Database Administrator**
   DBAs take care of the physical databases that house the client's applications. They are responsible for releasing code into production environments, managing backups, performing maintenance on servers, disks, and other operating system level tasks such as creating user accounts.

   From our experience, we know the kind of skills and the numbers in which these will be required for different projects. We are able to make a fair estimate of how many developers, business analysts or projects managers would a project require, and for how long.

2. **Staff skills:** We know the skills of all existing staff, and are able to classify each one of them as belonging to one of the four skill sets outlined earlier. As part of their career development, staff will move between categories, but at any given time most staff normally actively engage in only one role.

   Given below is an example of a matrix with staff names along one dimension and the skill set they bring along the other, and totalling them up along the skill dimension tells us the total numbers for each skill type that we have.

| Staff name | PM | Dev | BA | DBA |
|---|---|---|---|---|
| Naveen G. | | | 1 | |
| Pascal Mercier | | 1 | | |
| Richard Bates | | 1 | | |
| Neil Campbell | | | | 1 |
| Michael Kroon | 1 | | | |

| Staff name | PM | Dev | BA | DBA |
|---|---|---|---|---|
| Etc… | X | x | x | x |
| Total | 1 | 2 | 1 | 1 |

3. **Reservation price for projects:** This relates to the business benefit derived by the clients from a particular project requested. The reservation price is the maximum amount of money that the budget owner or project sponsor in the requesting country is willing to spend for the particular project.

   We are able to make a reasonable estimate of the client's reservation price by using one of the following approaches:

   (a) **Measuring business benefit:** In nearly all cases, the ADG requests that an estimate of the business benefit be made. This is generally measured by cost savings that a particular project may bring.

   For example, switching to automatic cheque printing instead of manually written cheques brings savings in clerical time, and reduced errors, and it is possible to put a fair dollar value on it.

   (b) **Measuring external opportunity cost:** In some cases, the benefits are indirect, in which case the test is to find out how much is the particular business unit willing to pay for that development to an external vendor.

   (c) **Past experience:** For requests that have been carried out for other business units, we are able to place a fair value on what the reservation price should be.

4. **Estimated cost of carrying out projects:** This is estimated using the time cost of the staff involved. Staff costs are known, and average around £ 6k per month, which includes all benefits and payroll costs. These do not tend to vary by skill, i.e., a business analyst costs about as much as a DBA, though the actual cost of a particular staff can be expected to vary a little depending upon seniority and experience.

5. **Notional "profit" from the project:** This equals the reservation price minus the estimated cost, and is an estimate of the value added to the company by carrying out a particular project.

6. **Earliest project start date:** This is the earliest date that a project can start. Often this depends upon the availability and convenience for the client. Since change of accounting systems can cause significant disruption and extra work for the finance staff, they tend to request a start date based upon their own time schedules for budgeting, year end reporting, audit visits etc. Normally, local businesses tend to speak to the ADG at a very early stage, often to discuss feasibility of their ideas, and we have a fair idea of what the earliest start dates of projects will be.

7. **Latest project start date:** This is the 'drop-dead' date by which the project must begin in order to meet the required deadline. The deadline is generally fixed by the managers commissioning the project.

8. **Project duration:** This is the total elapsed time required for completing the project.

9. **Staff availability:** We can also predict the availability of staff (classified by skills) over a reasonably long period, say a up to an year ahead. Where we have planned headcount increases, these are forecast in the headcount budget.

10. **Skill shortages, and the threshold before external resources are hired:** It is possible to manage with a limited level of skill shortage as the members of a particular team make up by working a little extra, or working on a different project a few hours every week till the 'peak' is over. If the shortage is severe and cannot be managed by existing staff, contractors are hired. It is possible to take a conscious decision on what level of shortages are acceptable and fix a threshold after which contractors are hired. High levels of shortages create staff burnout and decrease client satisfaction, and are therefore not desirable.

11. **Contractor costs per month:** Contractors charge on a daily rate basis, and charges go up to GBP 2,000 per day. These vary depending upon where these contractors are hired from – those from Oracle Consulting and any of the Big-5 cost up to GBP 2k per day. Those hired from smaller consultancy companies (called "body shoppers", or "pimps" as they are more affectionately called) cost as little as GBP 600 a day. Contractors hired from Indian outsourcing companies cost lesser – around GBP 400 a day, though visa and work permit issues put limitations on how quickly and for which countries can Indian outsourcers be employed. All of these equate to a monthly cost that can vary between GBP 11k to GBP 25k per month (given 22 or 23 working days in a month).

    Effectively, hiring contractors creates a 'penalty' in the value function as contractors are far more expensive. At the same time, we do not charge the extra cost of employing contractors to the projects they are working on as skills are interchangeable and no project should be penalised for the staffing decisions for a particular project.

12. **Staff costs per month:** Staff costs, including payroll taxes, leave pay etc, average around GBP 6k per month.

## The decision problem

Given an estimate of the benefits from a project, the cost of the project, the available skills, the earliest and latest start dates for a project, what is the most efficient way to schedule projects so that value addition to the company is maximised.

The objective function to maximise over a medium term period:
The value addition resulting from a particular scheduling of a set of projects is equal to:

*The notional value addition from the project (i.e., reservation price – estimated cost)*
***Minus*** *Cost ('Penalty") for hiring contractors*
***Minus*** *Cost of unutilised staff who are 'sitting on the bench' for projects to arrive.*

## Building the computer based model:

### Recording the known inputs: Skills required

As we know the skills requirements of different projects, it is easy to record the skills requirements in a spreadsheet as follows:

Skills required:

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA |
|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 |

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA |
|---|---|---|---|---|---|
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 |
| R11i UK | **10** | 2 | 3 | 4 | 1 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 |

Example – Project 1, writing the "GL report for UK", requires one developer and one business analyst, and no (0) DBAs or project manager.

## Recording the known inputs: Skills available

| **Staff availability and usage** | | | | | | |
|---|---|---|---|---|---|---|
| **Available skills** | | 1 | 2 | 3 | 4 | 5 |
| | Staff | Jan | Feb | Mar | Apr | May |
| | PM | 2 | 2 | 2 | 2 | 2 |
| | Dev | 2 | 2 | 2 | 2 | 2 |
| | BA | 3 | 3 | 3 | 3 | 3 |
| | DBA | 1 | 1 | 1 | 1 | 1 |

## Recording the known inputs: Other project related information

| Project name (taken from real order book) | Project number | Client's reservation price | Project duration | Earliest Start | Latest Start |
|---|---|---|---|---|---|
| GL report for UK | **1** | 50 | 1 | 1 | 4 |
| EFT for Belgium | **2** | 75 | 2 | 3 | 6 |
| Interface for Singapore | **3** | 50 | 2 | 11 | 13 |
| Italy customers report | **4** | 25 | 2 | 6 | 9 |
| Greece fiscal reports | **5** | 150 | 3 | 2 | 2 |
| Changeover to Euro | **6** | 200 | 3 | 4 | 7 |
| Currency change for CH | **7** | 50 | 1 | 7 | 8 |
| R11i Benelux | **8** | 300 | 4 | 3 | 5 |
| R11i Nordics | **9** | 250 | 3 | 5 | 7 |
| R11i UK | **10** | 600 | 4 | 8 | 10 |
| R11i Singapore | **11** | 200 | 3 | 10 | 13 |

What the above table records are:

- Client's reservation price – explained earlier
- Project duration – in months of elapsed time
- Earliest start – for the project, decided in discussion with the client
- Latest start – for the project, decided in discussion with the client.

## Recording the known inputs: cost variables and other inputs

| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | 1 | Staff shortages affect project success and client perception. Small shortages can be managed with existing staff. However, beyond the threshold noted here, new resource, whether permanent staff or contract resource, need to be hired. |
| Contractor cost per month | 25 | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

## Model outputs

Given the inputs as described above, the model determines the following outputs:

- Best possible project start dates that maximise the objective function, i.e. the value addition as defined earlier,
- The related project schedule, i.e. the months in which each of the projects are going on,
- The actual utilisation of the skills available, and the resultant shortages (if any) or excess capacity of the staff complement.

Each of the above represents very useful information to ADG management – while they are not bound by the model outputs, it can certainly provide very useful information for decision making as projects are assigned to staff and months.

The modelling exercise also helps determine an optimum staffing level by revealing any perennial shortages or surpluses for a particular skill type. It can also help reveal the sensitivity of the total value added to varying levels of contractor rates, staffing levels, and varying project start dates.

## Assumptions

The following assumptions are implicit in the model:

- Projects complete in units of 1 month – This is not too unreasonable an assumption, and the model can be enhanced to take care of half-months, weeks, or even days.
- Staff are engaged on a single project and cannot work simultaneously on other projects – while this may not be true in the initial stages of a project as the project is picking up speed, it is largely a valid assumption.
- For the moment, the model is designed to deal with a completely blank slate, i.e. it deals with month 0. However, it can be easily modified to take care of the fact that some months have already elapsed, and that some projects have already begun and cannot be reversed.

## Model logic – how does it work?

The output function for this modelling problem is not only non-linear, it is also discontinuous as changing the skills availability, the earliest/latest start dates, shortage threshold for projects causes projects to be accepted/rejected/rescheduled and the total value added suddenly jumps or drops at different points along each of these dimensions. The discontinuities are represented by a large number of "IF" statements in the Excel based model.

Therefore, the use of Excel's solver utility is ruled out as it is unable to deal with discontinuous output functions. The only feasible way to arrive at a solution close to the optimum is to use Excel's simulation capabilities using the RAND() function.

Subject to the constraints of the earliest and latest start dates, the model randomly selects different start dates for each of the projects and calculates the value of the output function. It does this many times – and if this simulation is performed many times, it can reach quite close to the optimum solution. The number of times the simulation is performed is a user supplied variable at run time. The model then determines the maximum possible value of the output function and plugs it into the spreadsheet, giving a solution close to the maximum.

The larger the number of iterations the model is requested to plough through, the larger is the time required to perform the simulation – on a PIII 500 MHz with no other applications other than Excel running, it takes about 1 minute to check 10,000 possibilities.

## The innards of the model

The various formulae used to calculate various things in the model, such as shortages, actual utilisation, the objective function, the project scheduling etc are straightforward and can be looked at in the Excel spreadsheet that has been submitted with this paper.

At the heart of the model is small piece of Visual Basic for Excel macro that carries out the simulation. Basically, it works as follows:

1. When the macro is run, it asks the user how many times is the simulation to be run. This is important as about 1,000,000 iterations take us very close to the optimum, and for a 'final' run a higher number may be supplied to fine tune the answer.

2. When the macro is started, there is already a "seeded" solution in place in the spreadsheet in the form of various start dates, these could be any numbers that the user may input before starting the macro (and they could all be zero), or it may be the result of a previous run of the macro. The macro remembers this combination and only tries to improve upon that.

3. It calculates a random start for each project – a start value of "2" for instance implies February and a start value of "0" implies that the project is rejected/dropped as there are more profitable things to do with the available skills. In calculating this random start, the macro generates a random number that is between the earliest and the latest start date for the project, and can also be zero.

   (The formula it uses to calculate this random number is `=IF(RAND()<0.05,0,(INT(Earliest_Start+RAND()*(Project_Duration))))`. This formula gives us a random integer between the earliest start date and the latest start date, with a 5% possibility of randomly considering that the project not be taken on at all.)

4. After putting in these random numbers, the macro calculates the objective function, and takes the combination of the different random start dates and the resultant objective function, and compares it to what it already had from the "seeded" values. If the new combination represents an improvement, that replaces the seeded values, otherwise the macro moves on to try another random combination.

5. This process goes on till the number of iterations it has been asked to perform have been carried out.

6. At the end when it is done, the combination that gives the maximum value of the objective function is plugged in the spreadsheet model for the analyst to look at.

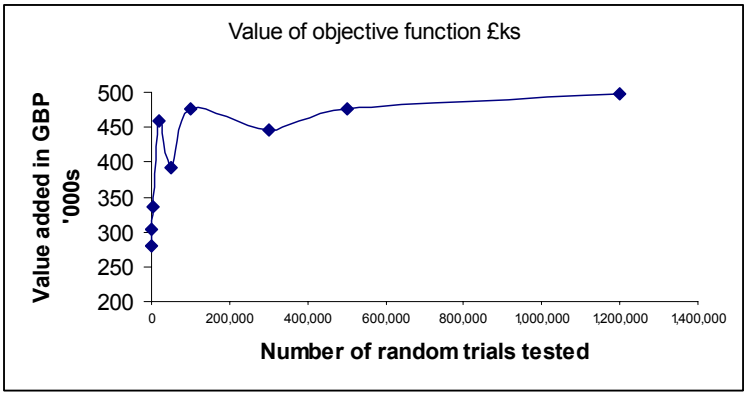
The code used for running the simulation is given in Appendix 2, much of this was generated using the 'recorder' and the Do While…Loop, IF statements etc were added by hand later.

## Accuracy of the model – does the maximum value of the output function change significantly as the number of simulation trials to evaluate are increased?

Yes it does, though the improvements are most visible with the first increases in the number of simulation trials. For example, significant improvement is often visible when increasing the number of trials from 5000 to 50,000, however, *on an average* no benefit seems to be visible when the number of trials is increased from 45000 to 55000.

The value of the objective function was seen to be increasing as follows with the number of different trials:

| Number of trials | Value of objective function £ks |
|---|---|
| 500 | 279 |
| 1,000 | 304 |
| 5,000 | 336 |
| 20,000 | 458 |
| 50,000 | 392 |
| 100,000 | 477 |
| 300,000 | 446 |
| 500,000 | 477 |
| 1,200,000 | 497 |
| 5,000,000 | 497 |




In other words, it seems that 1,000,000 random simulations should lead us fairly close to the best possible solution.

## Determining an optimum solution

The simulation was run for the maximum of 25,000,000 trials and a "good" result was obtained. The result of this simulation is reproduced in appendix 1.

The advantage of simulation is that once the model determines a particular solution, the manager using it can change a few variables, such as moving a project start date forward and backwards and see if the adjoining points give a better solution.

On repeated trials, it was discovered that the possibility to increase the gain from what was determined by the model as the maximum after 5,000,000 random simulations was close to zero. Always, all adjoining points gave a result less optimum than the one determined by the simulation exercise.

This in itself is a very powerful tool – both as a means to justify a decision, and also as a means to convince senior managers of the formal nature of the exercise.

## Sensitivity and "what-if"analysis

The most significant advantage of the modelling exercise is the ability to see what happens as we change various "known"inputs to different values.

The following what-if analysis was carried out:

**Sensitivity of maximum value addition to changes in 'maximum allowable skill shortages'**

Intuitively, it is easy to see that the larger are the maximum allowable skill shortages, the higher is the objective function. However – the relationship between max allowed skill shortages and the value of the objective function is not linear, and this is because as the threshold is changed, the model changes the start dates of the projects and also drops/includes different projects.

Higher shortages do have a cost in terms of dissatisfied clients, project delays and overworked staff. It is possible to include in the objective function a value of these costs, but this has not been done in the given model due to the high subjectivity involved.

Here is a graph of the sensitivity of the value addition to the maximum shortages allowed. This was obtained using the following input data:

**Skills requirements, by project**

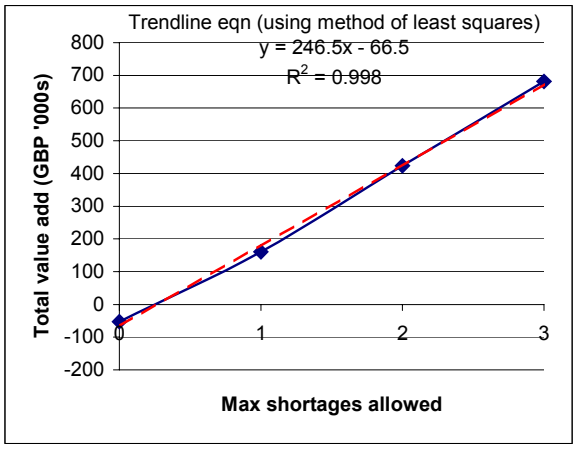
| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA | Client's reservation price | Project duration | Earliest Start | Latest Start |
|---|---|---|---|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 | 50 | 1 | 1 | 4 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 | 75 | 2 | 3 | 6 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 | 50 | 2 | 11 | 13 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 | 25 | 2 | 6 | 9 |
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 | 150 | 3 | 2 | 2 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 | 200 | 3 | 4 | 7 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 | 50 | 1 | 7 | 8 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 | 300 | 4 | 3 | 5 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 | 250 | 3 | 5 | 7 |
| R11i UK | **10** | 2 | 3 | 4 | 1 | 600 | 4 | 8 | 10 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 | 200 | 3 | 10 | 13 |

| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | variable | |
| Contractor cost per month | 25 | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

**Staff availability and usage**

| | | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|
| | Staff | Jan | Feb | Mar | Apr | |
| **Available skills** | PM | 1 | 1 | 2 | 2 | |
| | Dev | 1 | 1 | 1 | 1 | ...same staffing continues for all the remaining periods... |
| | BA | 2 | 2 | 2 | 2 | |
| | DBA | 1 | 1 | 1 | 1 | |

The interesting thing that emerges is that for the set of input variables chosen, the relationship is close to linear, though not exactly that. The non-linearity becomes clearer when there is greater pressure on resources. When resources are plenty, the relationship between shortages allowed and the total value-added is not linear. (Because of the large number of input variables that could be varied simultaneously, I was unable to test all possibilities).




(All data points arrived at using 1 million iterations)

Not only that, more importantly we also observe that the portfolio of projects undertaken and their best start dates also change as follows:

| Project name (taken from real order book) | Project number | 0 shortages | 1 shortage | 2 shortages | 3 shortages |
|---|---|---|---|---|---|
| GL report for UK | **1** | 3 | 3 | 3 | 2 |
| EFT for Belgium | **2** | 5 | 5 | 4 | 3 |
| Interface for Singapore | **3** | 12 | 0 | 0 | 0 |
| Italy customers report | **4** | 0 | 0 | 0 | 6 |
| Greece fiscal reports | **5** | 2 | 2 | 2 | 2 |
| Changeover to Euro | **6** | 5 | 5 | 0 | 0 |
| Currency change for CH | **7** | 7 | 7 | 7 | 7 |
| R11i Benelux | **8** | 0 | 0 | 0 | 0 |
| R11i Nordics | **9** | 0 | 0 | 5 | 5 |
| R11i UK | **10** | 8 | 8 | 8 | 8 |
| R11i Singapore | **11** | 0 | 12 | 12 | 12 |
| ***Total value added (in GBPs k)*** | | -£53 | £161 | £424 | £681 |

**Sensitivity of the max value addition to changes in contractor costs**

As contractors become cheaper or more expensive, the model again changes the projects that are decided to be taken on, and reschedules others, and there is no simple linear or continuous relationship between these variables.

The only real way to examine this relationship is to vary the contractor cost and run the simulation to obtain the best possible start dates/projects that are identified to be dropped (dropped projects are signified by the "0" in the start date).

The following input data was used:

**Skills requirements, by project**

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA | Client's reservation price | Project duration | Earliest Start | Latest Start |
|---|---|---|---|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 | 50 | 1 | 1 | 3 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 | 75 | 2 | 3 | 5 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 | 50 | 2 | 11 | 12 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 | 25 | 2 | 6 | 8 |
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 | 150 | 3 | 2 | 2 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 | 200 | 3 | 4 | 6 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 | 50 | 1 | 7 | 7 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 | 300 | 4 | 3 | 4 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 | 250 | 3 | 5 | 6 |
| R11i UK | **10** | 2 | 3 | 4 | 1 | 600 | 4 | 8 | 9 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 | 200 | 3 | 10 | 12 |

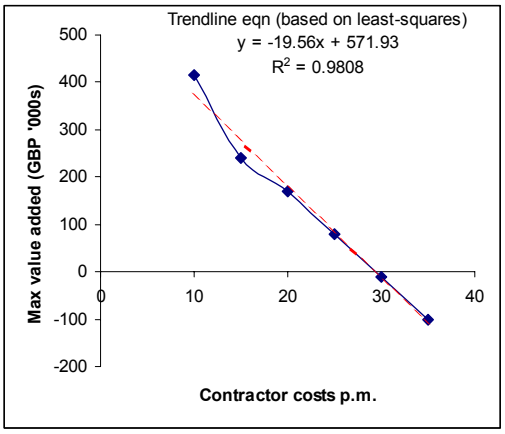
| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | 1 | |
| Contractor cost per month | variable | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

**Staff availability and usage**

| | | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|
| | Staff | Jan | Feb | Mar | Apr | |
| **Available skills** | PM | 1 | 1 | 2 | 2 | |
| | Dev | 1 | 1 | 1 | 1 | ...same staffing continues for all the |
| | BA | 2 | 2 | 2 | 2 | remaining periods... |
| | DBA | 1 | 1 | 1 | 1 | |

Here is a graph of the maximum value addition to the company at various levels of contractor costs. This information is very significant as it shows how important contractor costs are to X&Y Corp. when maximising the value addition, and whether the impact when contractor costs increase from GBP 15k/month to GBP 20k/month is significant or not. This information helps in determining the kind of contractors to hire.

| Contractor costs per month (GBP ks) | Value of objective function |
|---|---|
| 10 | 415 |
| 15 | 240 |
| 20 | 169 |
| 25 | 79 |
| 30 | -11 |
| 35 | -101 |




Again, we witness changes in the project portfolio as follows:
Best project portfolios at varying levels of contractor costs:

| Project name (taken from real order book) | Project number | 10k pm | 15k pm | 20k pm | 25k pm | 30k pm | 35k pm |
|---|---|---|---|---|---|---|---|
| GL report for UK | **1** | 1 | 1 | 1 | 1 | 1 | 1 |
| EFT for Belgium | **2** | 3 | 3 | 3 | 3 | 3 | 3 |
| Interface for Singapore | **3** | 0 | 0 | 11 | 11 | 11 | 11 |
| Italy customers report | **4** | 0 | 0 | 0 | 0 | 0 | 0 |
| Greece fiscal reports | **5** | 2 | 2 | 2 | 2 | 2 | 2 |
| Changeover to Euro | **6** | 4 | 4 | 0 | 0 | 0 | 0 |
| Currency change for CH | **7** | 7 | 7 | 7 | 7 | 7 | 7 |
| R11i Benelux | **8** | 0 | 0 | 0 | 0 | 0 | 0 |
| R11i Nordics | **9** | 5 | 5 | 5 | 5 | 5 | 5 |
| R11i UK | **10** | 8 | 8 | 8 | 8 | 8 | 8 |
| R11i Singapore | **11** | 11 | 11 | 0 | 0 | 0 | 0 |

| Project name (taken from real order book) | Project number | 10k pm | 15k pm | 20k pm | 25k pm | 30k pm | 35k pm |
|---|---|---|---|---|---|---|---|
| ***Total value added (in GBPs k)*** | | 415 | 240 | 169 | 79 | -11 | -101 |

## Sensitivity of the max value addition to changes in earliest and latest project start dates

'What-if' analysis on individual projects can be carried out quite easily using the spreadsheet. As the earliest and the latest project start dates are changed, it adds flexibility in project scheduling and allows 'unprofitable' projects to be taken up at slack times in the department.

## Staffing levels and value addition

Once an optimum portfolio of projects is determined, the staff utilisation schedule reveals whether there are any persistent long term shortages or surpluses in the staffing levels. These can be modified on the model and the impact on the total value addition seen.

Example I

For example, consider the optimum solution below (all inputs shown in blue)

| Project name (taken from real order book) | Project number | Client's reservation price | Est cost | Project duration | Profit | Value added % | Earliest Start | Latest Start | Value added per month | Actual start | End date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GL report for UK | 1 | 50 | 12 | 1 | 38 | 317% | 1 | 4 | 38 | 1 | 1 |
| EFT for Belgium | 2 | 75 | 24 | 2 | 51 | 213% | 3 | 6 | 25.5 | 3 | 4 |
| Interface for Singapore | 3 | 50 | 36 | 2 | 14 | 39% | 11 | 13 | 7 | 0 | 0 |
| Italy customers report | 4 | 25 | 24 | 2 | 1 | 4% | 6 | 9 | 0.5 | 0 | 0 |
| Greece fiscal reports | 5 | 150 | 72 | 3 | 78 | 108% | 2 | 2 | 26 | 2 | 4 |
| Changeover to Euro | 6 | 200 | 90 | 3 | 110 | 122% | 4 | 7 | 36.66666667 | 4 | 6 |
| Currency change for CH | 7 | 50 | 6 | 1 | 44 | 733% | 7 | 8 | 44 | 7 | 7 |
| R11 Benelux | 8 | 300 | 168 | 4 | 132 | 79% | 3 | 5 | 33 | 0 | 0 |
| R11 Nordics | 9 | 250 | 108 | 3 | 142 | 131% | 5 | 7 | 47.33333333 | 5 | 7 |
| R11 UK | 10 | 600 | 240 | 4 | 360 | 150% | 8 | 10 | 90 | 8 | 11 |
| R11 Singapore | 11 | 200 | 126 | 3 | 74 | 59% | 10 | 13 | 24.66666667 | 12 | 14 |
| | | | | | | | | Total value added: | | £497 k | |

**Available skills**

| Staff | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Dev | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| BA | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| DBA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

However - looking at the staff utilisation schedule, we find that there is a continuous shortage of Development skills from March onwards. **If we hire an extra developer starting March, the value add increases to GBP 642k, which will more than offset the cost of the new developer**. This is an extremely important insight that can form a very informed basis for hiring new staff!

Example II

Consider the following staffing schedule:

**Staff availability and usage**

**Available skills**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Staff | Jan | Feb | Mar | Apr | May |
| PM | 1 | 1 | 2 | 2 | 2 |
| Dev | 1 | 1 | 1 | 1 | 1 |
| BA | 2 | 2 | 2 | 2 | 2 |
| DBA | 1 | 1 | 1 | 1 | 1 |

Now consider the following staff schedule (all months after May have the same staff strength in both the cases):

**Staff availability and usage**

**Available skills**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Staff | Jan | Feb | Mar | Apr | May |
| PM | 2 | 2 | 2 | 2 | 2 |
| Dev | 2 | 2 | 2 | 2 | 2 |
| BA | 3 | 3 | 3 | 3 | 3 |
| DBA | 1 | 1 | 1 | 1 | 1 |

There is a big difference in the optimum solution and the optimum portfolio of projects to undertake in each of the above cases.

- For the second staff schedule, projects 4, 6, 8 and 11 will be dropped producing a maximum value added of GBP 79k.

- For the second staff schedule, projects 3, 4, and 8 will be dropped producing a maximum value added of GBP 497k.

This kind of analysis cannot be performed using mere intuition and that is where this model helps.

## Is there any money to be made from this model?

Yes, there is. The main opportunity to make some money from this model lies in the transparency the model creates of the effects of decisions on staffing, project rescheduling, and decisions on contractor costs and shortage thresholds.

For any set of given variables, it is possible to find out the near-optimal solution and see exactly how much is the additional expense (or additional flexibility in scheduling decisions) is worth.

For example, increasing the staff strength from 2 to 3 starting month 3 increases total value added from £497k to £642k - an increase in £145k - *after* accounting for the cost of the new staff.

This kind of knowledge is cannot be obtained by mere intuition and experience, and you have to run the model to determine the exact benefits. Not only this, the model provides a very strong basis for putting forth a business case for senior management to approve headcount increases, reject or reschedule projects etc, as has been shown in the sensitivity analysis section.

## Critique of the model

**The model needs enhancements**

The model can be enhanced to be more representative of reality by:

1. Using weeks instead of months,
2. Using more projects - currently the model that is exhibited with this paper is relevant only to the Geneva office of the Application Development Group and therefore does not consider all the projects, or the transferability of staff and skills from other offices in London, Singapore and New York.
3. Allowing for a multi-skilled staff to use one skill for one project and a different one for another - as some staff possess more than one skill set.
4. For the moment, the model considers staff shortages on an overall basis, and not for each individual skill pool. The model can be enhanced to have different thresholds for each skill type.

**The model ignores politics**

Some projects are political and have or have not to be done, no matter what the value or the cost. A project that is the "baby" of a senior enough manager will have to be done, and other ideas that do not find favour with senior management will need to be shelved no matter what the monetary payout. These constraints can be built-in into the model by introducing a political capital variable into the model, which would be a weighted average of the political

strengths of the managers and the political capital they are willing to spend to support or oppose the project.

**The model is slow**

It can test about 100 random iterations a second on a PIII-500MHz (the best I have) . Theoretically, the range of possibilities with the various start dates etc as in Appendix 1 is about 5 million. To ensure that all possibilities are covered, it is necessary to run it for about 20 million times, a task that will take about 32 hours on my computer.

**The model assumes a 'start from scratch'**

The model currently does not deal with situations where some months are already past and some projects are already underway with resources committed. This is the situation that a manager is most likely to encounter in real life. However, this is quite easy to take care of by "freezing" the cells containing the information for projects that have already started.

## Conclusion

The modelling exercise provides the benefit of making transparent the effects of decisions on project scheduling, resourcing and value added. The modelling exercise was carried out for a very limited part of the entire ADG organisation – viz. the projects handled by the Geneva based operations of the group. Some of the insights are documented in the 'what-if' analysis section of the report that follows. The model can help ascertain:

**Appropriate staffing levels –** by revealing any persistent over or understaffing for a particular skill type. For example, in one of the variants of the model that was examined, it was found that increasing the headcount for developers by one starting March onwards has an effect of increasing the value to the company from GBP 497k to GBP 642k, an increase of GBP 145k!

**Appropriate project selection –** Depending upon staffing levels, cost of alternate contractor resources, and the different earliest and latest start dates of various projects, different projects are "profitable" in different situations. While projects that have a very large value addition will always have an absolute advantage over others, it is the 'borderline' projects that fall in and out of the 'best project portfolio' as different variables are changed. This form of decision making is not intuitive and a model such as this is essential to understand the dynamics of the different choices.

**Deciding acceptable shortage levels –** When there are more projects than the existing staff can handle, a certain level of 'shortage' can be managed by increasing the workload on existing staff. Allowed beyond a certain point, this can cause staff burnout and serious client dissatisfaction. Different 'shortage' levels can lead to different projects being selected, and different values of the objective function. This relationship has been reviewed later in the document.

**Acceptable level of contractor costs –** For the collection of available projects for which a simulation was carried out, it emerged that it is not worthwhile to hire external contract resource when they cost more than GBP 30k/month. The relationship between the total value addition, and varying levels of contractor costs has been examined later in this document.

Decision modelling permits us to build a rational framework for our decisions and allows us to see the impact of various inputs into the decision process on what we seek to maximise. It is an extremely powerful tool for carrying out 'what-if' analysis and provides a strong logical basis for managerial decisions. The model that has been built as part of this exercise is a fair approximation of a true business situation, though of course further refinements are always possible.

**Simulation based optimisation of resource usage and project project prioritisation** - By Mukul Pareek, EMBA-Global 2003

**Appendix 1**
Showing the optimum start dates and the maximum value added for a given set of inputs

**Skills requirements, by project**

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA |
|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 |
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 |
| R11i UK | **10** | 2 | 3 | 4 | 1 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 |

| Client's reservation price | Est cost | Project duration | Profit | Value added % | Earliest Start | Latest Start | Value added per month | Actual start | End date |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 12 | 1 | 38 | 317% | 1 | 4 | 38 | **1** | 1 |
| 75 | 24 | 2 | 51 | 213% | 3 | 6 | 25.5 | **3** | 4 |
| 50 | 36 | 2 | 14 | 39% | 11 | 13 | 7 | **0** | 0 |
| 25 | 24 | 2 | 1 | 4% | 6 | 9 | 0.5 | **0** | 0 |
| 150 | 72 | 3 | 78 | 108% | 2 | 2 | 26 | **2** | 4 |
| 200 | 90 | 3 | 110 | 122% | 4 | 7 | 36.66667 | **4** | 6 |
| 50 | 6 | 1 | 44 | 733% | 7 | 8 | 44 | **7** | 7 |
| 300 | 168 | 4 | 132 | 79% | 3 | 5 | 33 | **0** | 0 |
| 250 | 108 | 3 | 142 | 131% | 5 | 7 | 47.33333 | **5** | 7 |
| 600 | 240 | 4 | 360 | 150% | 8 | 10 | 90 | **8** | 11 |
| 200 | 126 | 3 | 74 | 59% | 10 | 13 | 24.66667 | **12** | 14 |
| | | | | | | Total value added: | | **£497 k** | |

**Blue** cells require data entry
**Black** cells are calculated cells
**Red** cells represent optimum solution

Key to skills:
PM = Project Management
Dev = Development (programming)
BA = Business Analysis
DBA = Database Administrator

| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | 1 | Staff shortages affect project success and client perception. Small shortages can be managed with existing staff. |
| Contractor cost per month | 25 | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

Reservation price: Maximum a client will pay for a project.
Est Cost: Staff employed x number of months x cost per staff per month
Earliest and Latest start dates: relate to each project
Available skills: number of staff for each skill type available each month

**Staff availability and usage**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Staff | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
| **Available skills** | PM | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Dev | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | BA | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | DBA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Used skills** | PM | 0 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 |
| (Based on project start | Dev | 1 | 2 | 3 | 5 | 4 | 4 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 |
| dates and schedule as | BA | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| below) | DBA | 0 | 0 | 0 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **Over/under utilisation** | PM | 2 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| | Dev | 1 | 0 | -1 | -3 | -2 | -2 | 0 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 2 |
| | BA | 2 | 2 | 1 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 3 |
| | DBA | 1 | 1 | 1 | 0 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Penalty for shortages:** | | | | | | | | | | | | | | | | |
| Total shortages: | | 0 | 0 | -1 | -3 | -3 | -3 | 0 | -2 | -2 | -2 | -2 | 0 | 0 | 0 | 0 |
| Shortage to be filled in by contract resourc | | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Unutilised staff | | 6 | 4 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 8 |

Schedule of ongoing projects: (shows which projects are going on in which month, 1 indicates ongoing, 0 (zeros have been conditionally formatted to be not visible below) indicates not happening in that month)

| Project | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1 | | | | | | | | | | | | | | |
| **2** | | | 1 | 1 | | | | | | | | | | | |
| **3** | | | | | | | | | | | | | | | |
| **4** | | | | | | | | | | | | | | | |
| **5** | | 1 | 1 | 1 | | | | | | | | | | | |
| **6** | | | | 1 | 1 | 1 | | | | | | | | | |
| **7** | | | | | | | 1 | | | | | | | | |
| **8** | | | | | | | | | | | | | | | |
| **9** | | | | | 1 | 1 | 1 | | | | | | | | |
| **10** | | | | | | | | 1 | 1 | 1 | 1 | | | | |
| **11** | | | | | | | | | | | | 1 | 1 | 1 | |

**Objective function to maximise: (amounts in GBP)**

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value addition from jobs | 897 | 38 | 26 | 52 | 88 | 84 | 84 | 91 | 90 | 90 | 90 | 90 | 25 | 25 | 25 | 0 |
| Penalty for contractor hi | 250 | 0 | 0 | 0 | 50 | 50 | 50 | 0 | 25 | 25 | 25 | 25 | 0 | 0 | 0 | 0 |
| Cost of unused staff | 150 | 36 | 24 | 18 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 48 |
| Total value add | **497** | 2 | 2 | 34 | 38 | 34 | 34 | 85 | 65 | 65 | 65 | 65 | 19 | 19 | 19 | -48 |

## Appendix 2

Visual Basic for Excel code used for testing the random iterations

```
Sub Macro1()
'
' Macro1 Macro
' Macro recorded 12/2/2001 by Mukul Pareek
'

'
    ITERATIONS = Val(InputBox("Number of times to simulate? (takes about 1 minute for
10000 trials)"))

    'Improve upon the current solution, do not start afresh
    Range("P16").Select
    Application.ScreenUpdating = False
    PROFIT = ActiveCell.Value
    Range("P5:P16").Select
    Application.CutCopyMode = False
    Selection.Copy
    Range("X5").Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
            False, Transpose:=False
    Application.CutCopyMode = False

    'Put the Random Number formula in the Start Dates
    Range("P5").Select
    ActiveCell.FormulaR1C1 = "=IF(RAND()<0.05,0,(INT(RC[-3]+RAND()*(RC[-2]-RC[-3]))))"
    Range("P5").Select
    Selection.Copy
    Range("P5:P15").Select
    Selection.PasteSpecial Paste:=xlFormulas, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False

    'Loop here number of times prescribed by the user
    Do While x < ITERATIONS

    Application.StatusBar = "Checking iteration " & x & " of " & ITERATIONS & T1
    Calculate
    Sheets("Model").Select
    Range("P16").Select
    CRNTPRFT = ActiveCell.Value

    If CRNTPRFT > PROFIT Then
        Range("P5:P16").Select
        Application.CutCopyMode = False
        Selection.Copy
        Range("X5").Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
            False, Transpose:=False
        Application.CutCopyMode = False
        PROFIT = CRNTPRFT
    End If
    x = x + 1
    Loop

    Range("X5:X15").Select
    Selection.Copy
    Range("P5").Select
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False
    Application.CutCopyMode = False
    Application.ScreenUpdating = True
    Application.StatusBar = False
    MsgBox ("Simulation done.  The seeded initial solution was not changed if a better
solution was not found!")
End Sub
```

Run Simulation

**Simulation based optimisation of resource usage and project project prioritisation** - By Mukul Pareek, EMBA-Global 2003

**Appendix 3a**
Optimum solution showing changes as shortage levels are changed. Also see Appendix 3b

**Skills requirements, by project**

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA |
|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 |
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 |
| R11i UK | **10** | 2 | 3 | 4 | 1 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 |

| Client's reservation price | Est cost | Project duration | Profit | Value added % | Earliest Start | Latest Start | Value added per month | Actual start | End date |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 12 | 1 | 38 | 317% | 1 | 4 | 38 | **2** | 2 |
| 75 | 24 | 2 | 51 | 213% | 3 | 6 | 25.5 | **3** | 4 |
| 50 | 36 | 2 | 14 | 39% | 11 | 13 | 7 | **0** | 0 |
| 25 | 24 | 2 | 1 | 4% | 6 | 9 | 0.5 | **6** | 7 |
| 150 | 72 | 3 | 78 | 108% | 2 | 2 | 26 | **2** | 4 |
| 200 | 90 | 3 | 110 | 122% | 4 | 7 | 36.66667 | **0** | 0 |
| 50 | 6 | 1 | 44 | 733% | 7 | 8 | 44 | **7** | 7 |
| 300 | 168 | 4 | 132 | 79% | 3 | 5 | 33 | **0** | 0 |
| 250 | 108 | 3 | 142 | 131% | 5 | 7 | 47.33333 | **5** | 7 |
| 600 | 240 | 4 | 360 | 150% | 8 | 10 | 90 | **8** | 11 |
| 200 | 126 | 3 | 74 | 59% | 10 | 13 | 24.66667 | **12** | 14 |
| | | | | | | Total value added: | | **£681 k** | |

**Blue** cells require data entry
**Black** cells are calculated cells
**Red** cells represent optimum solution

Key to skills:
PM = Project Management
Dev = Development (programming)
BA = Business Analysis
DBA = Database Administrator

| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | 3 | Staff shortages affect project success and client perception. Small shortages can be managed with existing staff. |
| Contractor cost per month | 25 | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

Reservation price: Maximum a client will pay for a project.
Est Cost: Staff employed x number of months x cost per staff per month
Earliest and Latest start dates: relate to each project
Available skills: number of staff for each skill type available each month

**Staff availability and usage**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Staff | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
| **Available skills** | PM | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Dev | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | BA | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | DBA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Used skills** | PM | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 |
| (Based on project start | Dev | 0 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 |
| dates and schedule as | BA | 0 | 2 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| below) | DBA | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **Over/under utilisation** | | | | | | | | | | | | | | | | |
| | PM | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| | Dev | 1 | -2 | -2 | -2 | -1 | -2 | -2 | -2 | -2 | -2 | -2 | -1 | -1 | -1 | 1 |
| | BA | 2 | 0 | 0 | 0 | 0 | -1 | -2 | -2 | -2 | -2 | -2 | -1 | -1 | -1 | 2 |
| | DBA | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Penalty for shortages:** | | | | | | | | | | | | | | | | |
| Total shortages: | | 0 | -2 | -2 | -2 | -1 | -3 | -4 | -4 | -4 | -4 | -4 | -2 | -2 | -2 | 0 |
| Shortage to be filled in by contract resource | | 0 | -1 | -1 | -1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | -1 | 0 |
| Unutilised staff | | 5 | 1 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6 |

Schedule of ongoing projects: (shows which projects are going on in which month, 1 indicates ongoing, 0 (zeros have been conditionally formatted to be not visible below) indicates not happening in that month)

| Project | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | 1 | | | | | | | | | | | | | |
| **2** | | | 1 | 1 | | | | | | | | | | | |
| **3** | | | | | | | | | | | | | | | |
| **4** | | | | | | 1 | 1 | | | | | | | | |
| **5** | | 1 | 1 | 1 | | | | | | | | | | | |
| **6** | | | | | | | | | | | | | | | |
| **7** | | | | | | | 1 | | | | | | | | |
| **8** | | | | | | | | | | | | | | | |
| **9** | | | | | 1 | 1 | 1 | | | | | | | | |
| **10** | | | | | | | | 1 | 1 | 1 | 1 | | | | |
| **11** | | | | | | | | | | | | 1 | 1 | 1 | |

**Objective function to maximise: (amounts in GBP)**

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value addition from jobs | 788 | 0 | 64 | 52 | 52 | 47 | 48 | 92 | 90 | 90 | 90 | 90 | 25 | 25 | 25 | 0 |
| Penalty for contractor hir | -25 | 0 | -25 | -25 | -25 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | -25 | -25 | -25 | 0 |
| Cost of unused staff | 132 | 30 | 6 | 12 | 12 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 36 |
| Total value add | **681** | -30 | 83 | 65 | 65 | 41 | 42 | 61 | 65 | 65 | 65 | 65 | 44 | 44 | 44 | -36 |

Run Simulation

**Simulation based optimisation of resource usage and project project prioritisation** - By Mukul Pareek, EMBA-Global 2003

**Appendix 3b**
Optimum solution showing changes as shortage levels are changed. Also see Appendix 3a

**Skills requirements, by project**

| Project name (taken from real order book) | Project number | PM | Dev | BA | DBA |
|---|---|---|---|---|---|
| GL report for UK | **1** | 0 | 1 | 1 | 0 |
| EFT for Belgium | **2** | 0 | 1 | 1 | 0 |
| Interface for Singapore | **3** | 0 | 1 | 1 | 1 |
| Italy customers report | **4** | 0 | 1 | 1 | 0 |
| Greece fiscal reports | **5** | 1 | 2 | 1 | 0 |
| Changeover to Euro | **6** | 1 | 2 | 1 | 1 |
| Currency change for CH | **7** | 0 | 0 | 1 | 0 |
| R11i Benelux | **8** | 1 | 2 | 3 | 1 |
| R11i Nordics | **9** | 1 | 2 | 2 | 1 |
| R11i UK | **10** | 2 | 3 | 4 | 1 |
| R11i Singapore | **11** | 1 | 2 | 3 | 1 |

| Client's reservation price | Est cost | Project duration | Profit | Value added % | Earliest Start | Latest Start | Value added per month | Actual start | End date |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 12 | 1 | 38 | 317% | 1 | 4 | 38 | **3** | 3 |
| 75 | 24 | 2 | 51 | 213% | 3 | 6 | 25.5 | **5** | 6 |
| 50 | 36 | 2 | 14 | 39% | 11 | 13 | 7 | **0** | 0 |
| 25 | 24 | 2 | 1 | 4% | 6 | 9 | 0.5 | **0** | 0 |
| 150 | 72 | 3 | 78 | 108% | 2 | 2 | 26 | **2** | 4 |
| 200 | 90 | 3 | 110 | 122% | 4 | 7 | 36.66667 | **5** | 7 |
| 50 | 6 | 1 | 44 | 733% | 7 | 8 | 44 | **7** | 7 |
| 300 | 168 | 4 | 132 | 79% | 3 | 5 | 33 | **0** | 0 |
| 250 | 108 | 3 | 142 | 131% | 5 | 7 | 47.33333 | **0** | 0 |
| 600 | 240 | 4 | 360 | 150% | 8 | 10 | 90 | **8** | 11 |
| 200 | 126 | 3 | 74 | 59% | 10 | 13 | 24.66667 | **12** | 14 |
| | | | | | | Total value added: | | **£161 k** | |

**Blue** cells require data entry
**Black** cells are calculated cells
**Red** cells represent optimum solution

Key to skills:
PM = Project Management
Dev = Development (programming)
BA = Business Analysis
DBA = Database Administrator

| Other inputs into the model: | Value | Comments |
|---|---|---|
| Max shortage allowed before contractors are hired | 1 | Staff shortages affect project success and client perception. Small shortages can be managed with existing staff. |
| Contractor cost per month | 25 | in GBPs per month |
| Staff cost per month | 6 | in GBPs per month |

Reservation price: Maximum a client will pay for a project.
Est Cost: Staff employed x number of months x cost per staff per month
Earliest and Latest start dates: relate to each project
Available skills: number of staff for each skill type available each month

**Staff availability and usage**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Staff | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
| **Available skills** | PM | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Dev | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | BA | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | DBA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Used skills** | PM | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 |
| (Based on project start | Dev | 0 | 2 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 |
| dates and schedule as | BA | 0 | 1 | 2 | 1 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| below) | DBA | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **Over/under utilisation** | | | | | | | | | | | | | | | | |
| | PM | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| | Dev | 1 | -1 | -2 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | -2 | -1 | -1 | -1 | 1 |
| | BA | 2 | 1 | 0 | 1 | 0 | 0 | 0 | -2 | -2 | -2 | -2 | -1 | -1 | -1 | 2 |
| | DBA | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Penalty for shortages:** | | | | | | | | | | | | | | | | |
| Total shortages: | | 0 | -1 | -2 | -1 | -2 | -2 | -1 | -4 | -4 | -4 | -4 | -2 | -2 | -2 | 0 |
| Shortage to be filled in by contract resourc | | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 0 |
| Unutilised staff | | 5 | 2 | 2 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 6 |

Schedule of ongoing projects: (shows which projects are going on in which month, 1 indicates ongoing, 0 (zeros have been conditionally formatted to be not visible below) indicates not happening in that month)

| Project | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | | 1 | | | | | | | | | | | | |
| **2** | | | | | 1 | 1 | | | | | | | | | |
| **3** | | | | | | | | | | | | | | | |
| **4** | | | | | | | | | | | | | | | |
| **5** | | 1 | 1 | 1 | | | | | | | | | | | |
| **6** | | | | | 1 | 1 | 1 | | | | | | | | |
| **7** | | | | | | | 1 | | | | | | | | |
| **8** | | | | | | | | | | | | | | | |
| **9** | | | | | | | | | | | | | | | |
| **10** | | | | | | | | 1 | 1 | 1 | 1 | | | | |
| **11** | | | | | | | | | | | | 1 | 1 | 1 | |

**Objective function to maximise: (amounts in GBP)**

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value addition from jobs | 755 | 0 | 26 | 64 | 26 | 62 | 62 | 81 | 90 | 90 | 90 | 90 | 25 | 25 | 25 | 0 |
| Penalty for contractor hi | 450 | 0 | 0 | 25 | 0 | 25 | 25 | 0 | 75 | 75 | 75 | 75 | 25 | 25 | 25 | 0 |
| Cost of unused staff | 144 | 30 | 12 | 12 | 18 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 36 |
| Total value add | **161** | -30 | 14 | 27 | 8 | 31 | 31 | 75 | 15 | 15 | 15 | 15 | -6 | -6 | -6 | -36 |