MONTE CARLO SIMULATION AND PARETO TECHNIQUES FOR CALCULATION OF MULTI-PROJECT OUTTURN-VARIANCE

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Cleland and King in 1986 described a scenario in which project data could also be used within a project management MIS for the purposes of portfolio management. Their approach assumed equal treatment in terms of data management. This research is a refinement of their model. A combination of Monte Carlo techniques and Pareto effects are used to simulate the probabalistic range of outturn performance for the portfolio in terms of expenditure if the high spend projects are managed to achieve the best ten percent of the range of performance achieved by the firm. The range of probable outturn variance between the planned and the actual expenditures of a portfolio of projects is calculated assuming that the probability distribution representing the best ten percent of the range of empirical performance achieved in reality is applied to increasing percents of high-spending projects in the portfolio.

Keywords: Monte-Carlo simulation, multi-projects, Pareto technique, project management.

INTRODUCTION

The management of a portfolio of projects with the intention of achieving an optimum outcome is commonplace in construction management. Cleland and King published in 1983 a functional specification for a Project_Management_Information_System (PMIS) that also served as a tool for the management of a portfolio of projects. They did not define an optimum outcome for the portfolio instead they proposed that the project level data used to measure the performance of each project in a portfolio of projects could also be used to provide aggregated measures of performance for the entire portfolio. They saw this capability as a further benefit to be derived from the use of the information pipeline that could be created within computerized project management processes. On the basis of this, managing a portfolio of projects as a by-product of project management appears to offer considerable added value to the use of a computerized PMIS. Advances in Information Technology (IT) since 1983 have increased the practicality of this proposition. However, there remain difficulties in this arrangement: especially the burden of data administration. According to the principles of Cleland and King, data must be collected at a uniform level of detail at frequent intervals, and then processed quickly to produce consistent snapshots of overall progress for use in a trend analysis. Such systems are intensive users of project level data that is costly to capture. They require the same range of detailed data, at the same frequency, from all the projects in the portfolio irrespective of their significance.

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The aggregation of this fine detailed data shows macro performance overall, but it does not easily operate in reverse to indicate at the higher end of the pipeline the micro problems existing within deviant projects.

What is intriguing about Cleland and King's proposition is that twenty years on it is not apparently a commonplace approach adopted by the construction industry for the management of their portfolio of projects (Futcher and Rowlinson, 1998).

AN ALTERNATIVE APPROACH

An alternative to the Cleland and King proposition is to apply Pareto heuristics to focus attention on the lesser number of significant projects within the portfolio and to ensure that their performance is excellent because of their impact on the results for the portfolio overall. The methodology described in this paper is one element of a larger piece of research that sets out to prove that the satisfactory performance achieved by the lesser number of significant projects is a reasonable approximation of the outcome for the portfolio overall, other things being equal. Horner (1991, 1992) has taken a similar approach with construction estimating. He proposes using heuristics, based on the cost significance of items within the Bill of Quantities, that substantially reduce the overall estimating effort with only a minor loss of accuracy overall. In a similar manner, this research investigates the effectiveness of managing a portfolio of projects by basing success primarily on the outcome of the projects that have a high impact. It tests this proposition using empirical data.

Empirical Data

The empirical data is taken from the audited accounts of the 'Category A' public works projects of the Public Works Programme (PWP) of the Hong Kong Government (HKG SAR) over the ten year period 1989-90 to 1998-99. 'Category A' projects have a planned expenditure within the financial year. The data for each financial year is managed as a separate entity by the HKG SAR and used in that manner in this research i.e., as ten successive data sets of consistent heritage. This is a good source of data because it is a large portfolio that contains a diverse range of public works. Look to Table 1 for an indication of the range of this diversity. The attributes of the data within each data set are measured to indicate the representation and the consistency of the projects within the ten data sets. A good degree of representation exists within each portfolio of projects in terms of:

'Heads of Expenditure' – these are a sub-division of the PWP into broad groups of construction classification that correspond to the disciplines of each of the public works departments.

'Categories of work' – these are the type of architectural/engineering work according to a HKG SAR classification index of seventy eight types of public works.

The diversity within each of the ten successive portfolios of projects is displayed in Table 2. The planned expenditure per annum changes as the project progresses, thus making the portfolios of projects more than ninety eight percent mutually exclusive, year on year. The expenditure of the funds budgeted per annum for each project is taken as a measure of satisfactory project achievement. The 'outcome performance' for each project in these terms is the difference between the actual expenditure compared to the planned expenditure, i.e., it is an 'outturn variance' that is expressed as a percent of the planned expenditure, or in differential Hong Kong Dollars.

Table 1: General statistics of the annual portfolios within the 1989-1999 period of this analysis

	Portfolio statistics in terms of project planned expenditure (HK$ '000s)					
Year	Project Nos	Low Value	High Value	Mode Value	Mean Value	Median Value
89-90	1196	0	510,000	100	11,543	2,330
90-91	1286	0	484,415	1	14,035	2,615
91-92	1224	0	955,980	113	16,164	2,961
92-93	1143	0	1,482,000	11	18,550	2,310
93-94	1130	0	2,580,000	10	24,533	1,668
94-95	1131	0	2,838,000	10	23,075	1,604
95-96	1086	0	1,935,741	0	21,041	533
96-97	1096	0	1,777,380	10	26,012	1,929
97-98	1048	0	866,000	0	17,497	450
98-99	1082	0	818,299	10	22,902	2,684

Table 2: Indicators of the diversity of projects within annual PWP portfolio of projects, 1989-1999

Aspects of Diversity	Financial Years beginning . . .									
	89	90	91	92	93	94	95	96	97	98
By Heads of Expenditure				702 – Port and Airport Development						
% of Nos	-	2	3	4	4	5	6	6	6	5
% of planned exp	-	4	16	38	40	48	42	36	24	16
				703 – Buildings						
% of Nos	23	24	24	21	22	22	35	37	36	36
% of planned exp	28	29	22	15	31	14	23	30	28	32
				704 – Drainage						
% of Nos	-	4	5	6	6	5	7	7	7	10
% of planned exp	-	6	7	6	3	3	3	4	5	11
				705 – Civil Engineering						
% of Nos	10	5	6	7	7	7	7	6	5	4
% of planned exp	8	6	8	11	7	9	6	5	11	7
				706 – Highways						
% of Nos	10	10	9	9	9	9	9	8	9	9
% of planned exp	18	12	9	6	4	7	8	9	10	9
				707 – New Towns						
% of Nos	49	47	46	47	44	43	27	28	27	25
% of planned exp	40	38	32	21	11	13	13	11	14	13
				709 – Waterworks						
% of Nos	7	7	7	7	8	8	8	8	8	7
% of planned exp	6	5	5	4	5	5	5	4	3	3
				710 – Housing						
% of Nos	-	-	-	-	-	<1	1	1	2	4
% of planned exp	-	-	-	-	-	<1	1	1	4	10
By Categories of work										
Nos of types	52	51	51	53	59	63	61	53	48	47
% (of 78 types)	67	65	65	67	76	81	78	68	62	60

Table 3 shows the Spearman's Rank Correlation between the dollar value of the 'planned expenditure' compared to the dollar value of 'outturn variance' of the projects and also the 'percent outturn variance' of the projects. These indicate that empirical outcome achieved by the portfolios overall was not sensitive to the performance achieved by the significant projects.

Table 3: Correlation Coefficients between values of Amended Estimate and Outturn variance

Year	Correlation coefficients of 'Planned Exp' Vs Outturn variance	
	$ Vs Outturn variance	$ Vs % Outturn variance
1989-90	0.592	-0.017
1990-91	0.564	-0.034
1991-92	0.805	-0.016
1992-93	0.655	0.013
1993-94	0.640	0.031
1994-95	0.375	0.014
1995-96	0.548	0.024
1996-97	0.680	0.005
1997-98	0.563	-0.010
1998-99	0.540	-0.003

TESTING A SIGNIFICANCE APPROACH TO THE MANAGEMENT OF A PORTFOLIO OF PROJECTS

The portfolio management approach used by the Government of Hong Kong is to individually manage all of the projects so that each one achieves a close match with its spending target. If this is successful, the total spending target for all the projects becomes a close match with the overall budgeted expenditure. The research proposes a more selective approach whereby the management effort given to each project is varied to ensure a high degree of success for the high impact projects and a routine outcome for the less significant remainder of the projects. In case of the HKG SAR the projects of greatest planned expenditure are deemed as being the more significant.

Mathematical validation of a significance approach

The mathematical validation assumes that the significant projects within the portfolio perfectly achieve their planned expenditure, i.e., zero outturn variance. The mathematical calculation is carried out for increasing numbers of significant projects in terms of percent of the portfolio. The constituent projects in the portfolio of projects are ordered in descending value of planned expenditure. The effect is calculated of an increasing percent of the highest value projects achieving a zero value outturn variance, whilst the outturn variance for the remainder of the projects is unchanged. The relationship between the percent of significant projects that achieves a perfect outcome, and the overall success achieved by the portfolio overall, is then considered. The methodology is shown in Figure 1.

Stochastic validation of a significance approach

The mathematical validation is an idealistic approach as it is improbable that the highest value (high impact) projects will all achieve a perfect outturn of nil variance. The stochastic validation assumes that if the significant projects in the portfolio are given sufficient management attention they can achieve the premier performance exhibited within the portfolio. Using Monte Carlo methods the stochastic outcome of each significant project can be derived from a probability curve that represents the better project performance found within the portfolios of projects. This curve is derived from the frequency distribution of project 'outturn variance'i.e., for all the projects in the portfolio by a best fitting to the ten continuous probability distributions listed in Table 4.

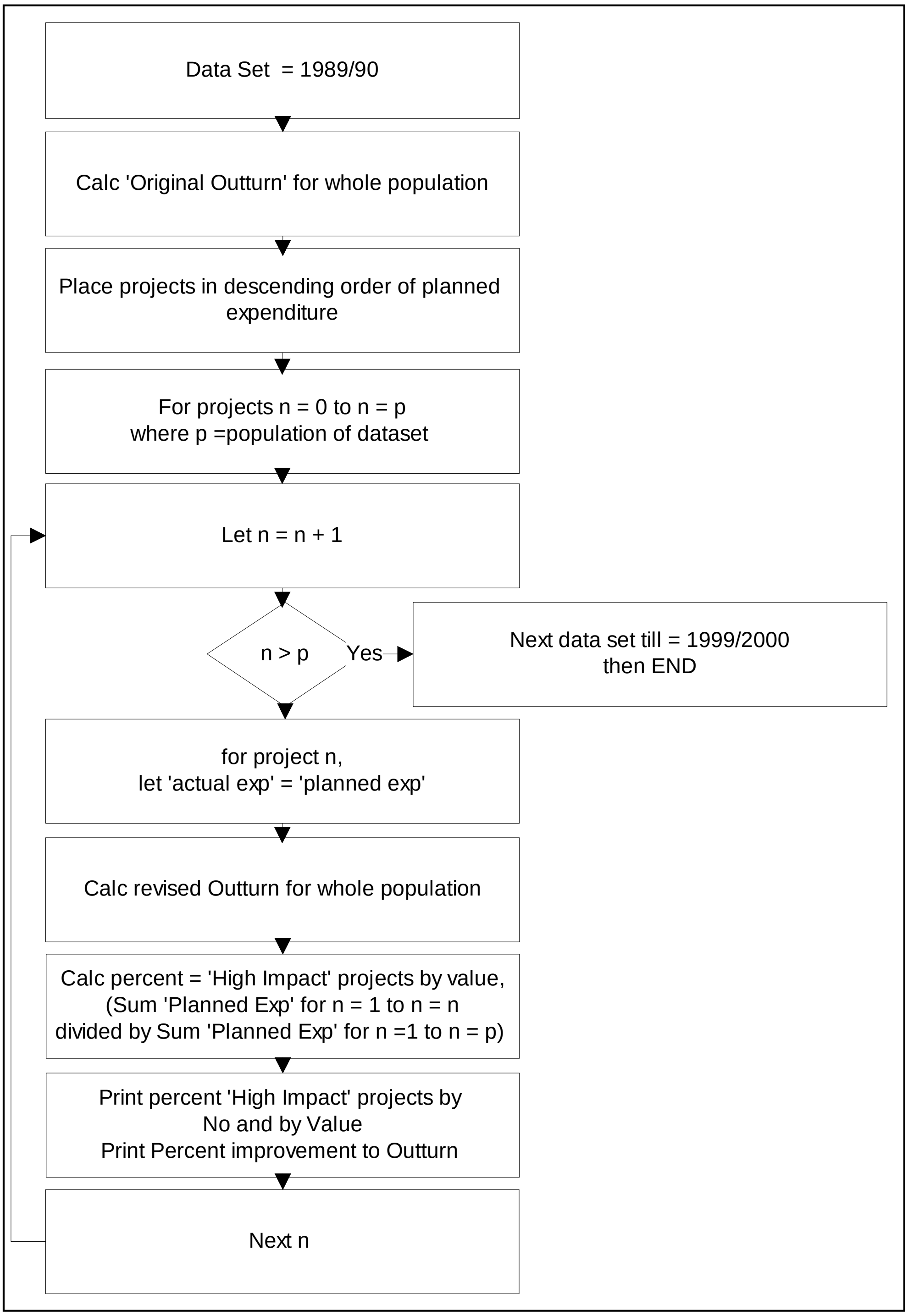

Figure 1: Flow chart of mathematical method for evaluating the impact of project significance on portfolio outturn

This method of curve fitting chooses values for the parameters of the probability distributions to better fit to the data set. The results of the distribution fitting to each of the ten standard, continuous distributions are tested using the standard goodness of fit methods shown in Table 5.

Table 4: Continuous Probability Distributions used for best fit comparison with the empirical frequency data.

Continuous Probability Curve	Typical application
Triangular	Simplistic: used if minimum, maximum and most likely values are known, assumed intermediary linear variation
Weibull	Complex: used to represent physical effects
Normal	Used to describe natural phenomena or uncertain variables
Beta	Used to represent variability over a fixed range
Logistic	Used to represent growth
Extreme Value	Used to describe the largest value of a response over a period of time i.e., flood flows.
Exponential	Used to describe events recurring at random in time
Gamma	Used to describe a wide range of physical quantities i.e., pollutant quantities
Lognormal	Used where values are positively skewed
Uniform	Simplistic: all values between the minimum and the maximum occur with equal likelihood.

Table 5: Tests for degree of fit of empirical data to probability distributions

Goodness of fit test	Typical application (ref Sargent and Wainwright, 1998)
Chi square	Gauges the general accuracy of the fit. Generally, a *p-value* greater than 0.5 indicates a close fit
Kolmogorov Smirnov	Is essentially the largest vertical distance between the two cumulative distributions. Generally, a value less than 0.03 indicates a close fit
Anderson Darling	Resembles Kolmogrov Smirnov except that it weights the differences between the two distributions at their tails greater than at their mid ranges. This method is used when a better fit is needed at the extreme tails of the distribution. Generally, a value less than 1.5 indicates a close fit

If, the curve fitting of the empirical values of 'outturn variance' from each of the ten data sets is a close fit to one of the continuous probability distributions, particularly within the range of zero to twenty percent 'outturn variance', then this part of the probability distribution is used in the Monte Carlo analyses. If not, the curve fitting exercise is repeated for the empirical values of 'outturn variance' within the 'zero to twenty percent outturn variance' range of higher performance. The best fit probability distribution derived from this calculation is used in the Monte Carlo analysis to assign a stochastic value of high performance 'outturn variance' in the case of the significant projects in the portfolio. The curve fitting and the Monte Carlo analysis is performed by using Crystal Ball® Version 4.0 software by Decisioneering (www.decisioneering.com). Figure 2 shows some of the probability distributions available within the software for curve fitting. Figure 3 is an example of a probability distribution derived from curve fitting for the 1989-1990 empirical dataset and used in the Monte Carlo analysis in this research.

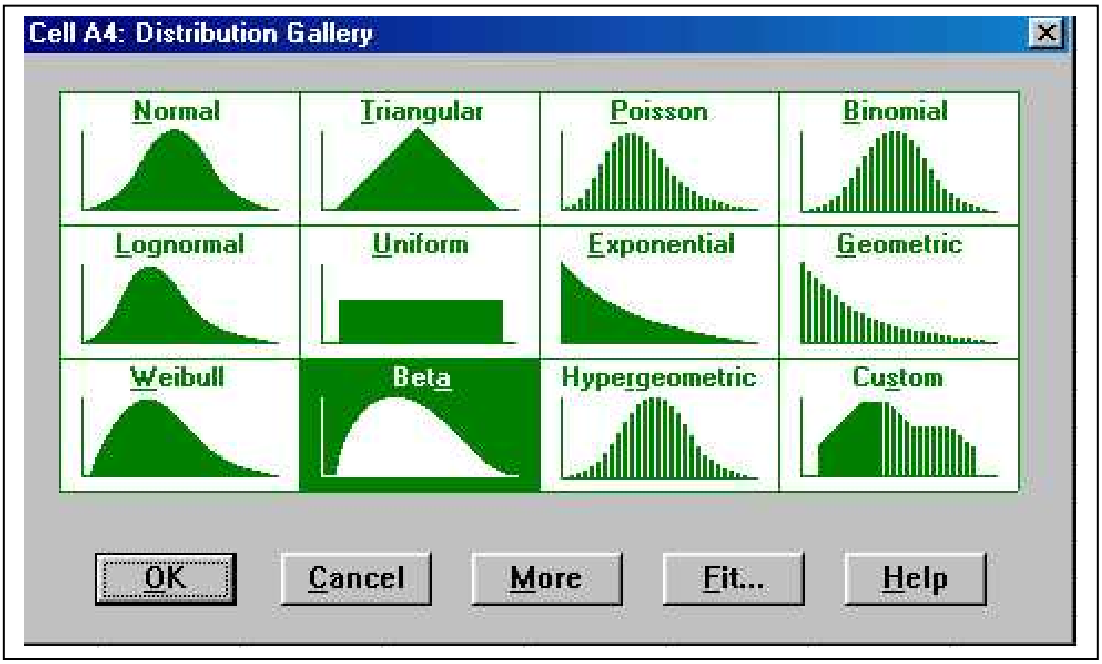

Figure 2: Example the range of standard probability distributions within Crystal Ball software

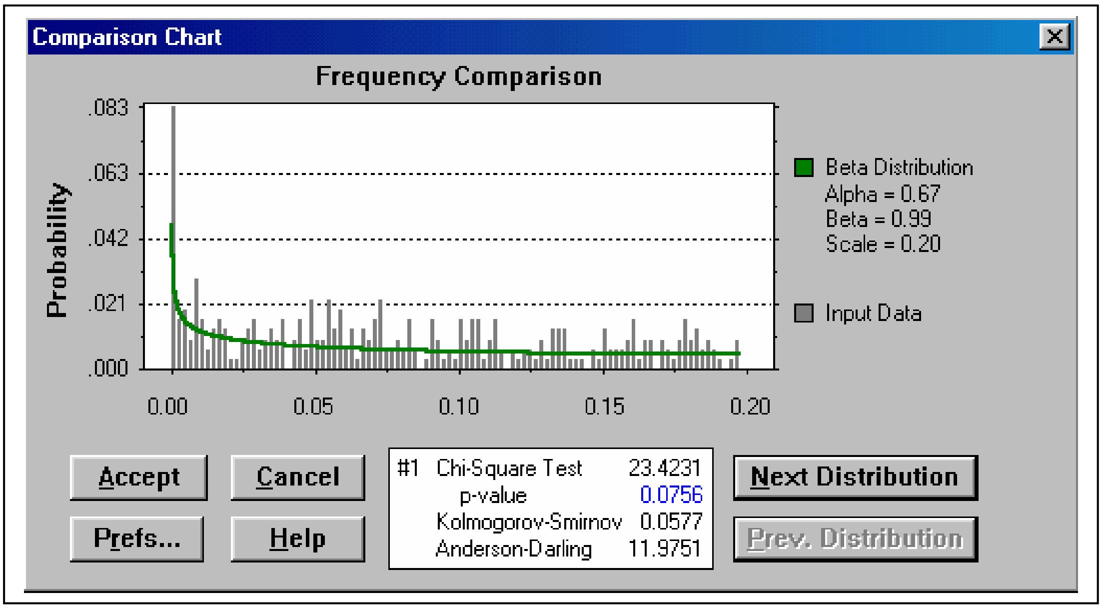

Figure 3: Probability distribution of the best 20% performance achieved in the 1989-90 empirical data from the HKG SAR.

Crystal Ball® allows selected variables in an Excel spreadsheet to be assigned a stochastic value according to a user selected probability distribution. In this case, the values of the outturn variance for each of the significant projects are randomly assigned a stochastic value from within the Beta distribution to represent the achievable range of higher performance found within the portfolio: other projects are unchanged. This random selection occurs for each significant project and for each 'trial' carried out by the software, in this case – one thousand trials. A frequency distribution of portfolio outturn is derived from these trials. Figure shows an example of the output from this research.

The methodology for a stochastic validation of the significance approach is shown in Figure 5. For the purposes of this research it is assumed that the significant projects can achieve the best ten percent of the two-hundred percent range of outturn variance found within the empirical data. The effect is calculated, of an increasing percentage of the highest value projects achieving an actual expenditure that represents this better performance whilst the outturn variance for the remainder of the projects is unchanged. The relationship between greater success for high impact projects compared to the achievement for the portfolio as a whole is then considered.

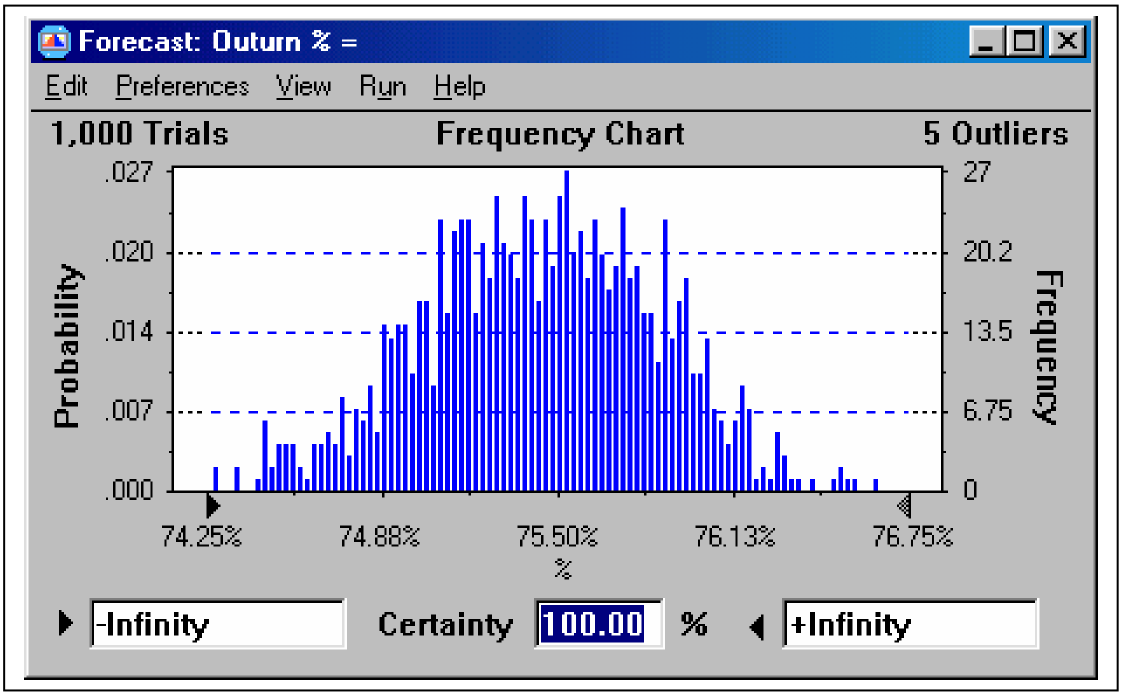

Figure 4: Monte Carlo generated output of the outturn variance of expenditure for the 1989-90 HKG SAR PWP empirical data for 1% of significant projects.

Table 6 is an example of the results derived by this method of analysis for the 1989-90 PWP portfolio of projects of the HKG SAR. It contains the ‘actual’ results achieved by the empirical data, compared to the ‘mathematical modelled’ results, and compared to the 95%, 90%, 75% and 50% percentile outcome derived from the Monte Carlo analyses. The ‘Ave mean’ is the average of the mean values derived from each of the one thousand Monte Carlo trials for each significant project in the analysis. In this case, the ‘Ave-mean’ outturn variance in the significant projects is 8.93% compared the 0.0% assumed for the mathematical modelling.

CONCLUSIONS

The management approach of the HKG SAR is to achieve a perfect outcome for all the projects in the PWP. The empirical data from the HKG SAR showed that in 1989-90 they achieved an under spend of twenty five percent of budgeted expenditure. Theoretically this outturn variance could have been reduced by 10%, 12%, or 21% percent, if it were possible for correspondingly 5%, 10%, or 20% of the high spend projects to achieve a perfect outcome. However, it is unrealistic to expect an ideal outcome to be achieved by a large number of high spend projects.

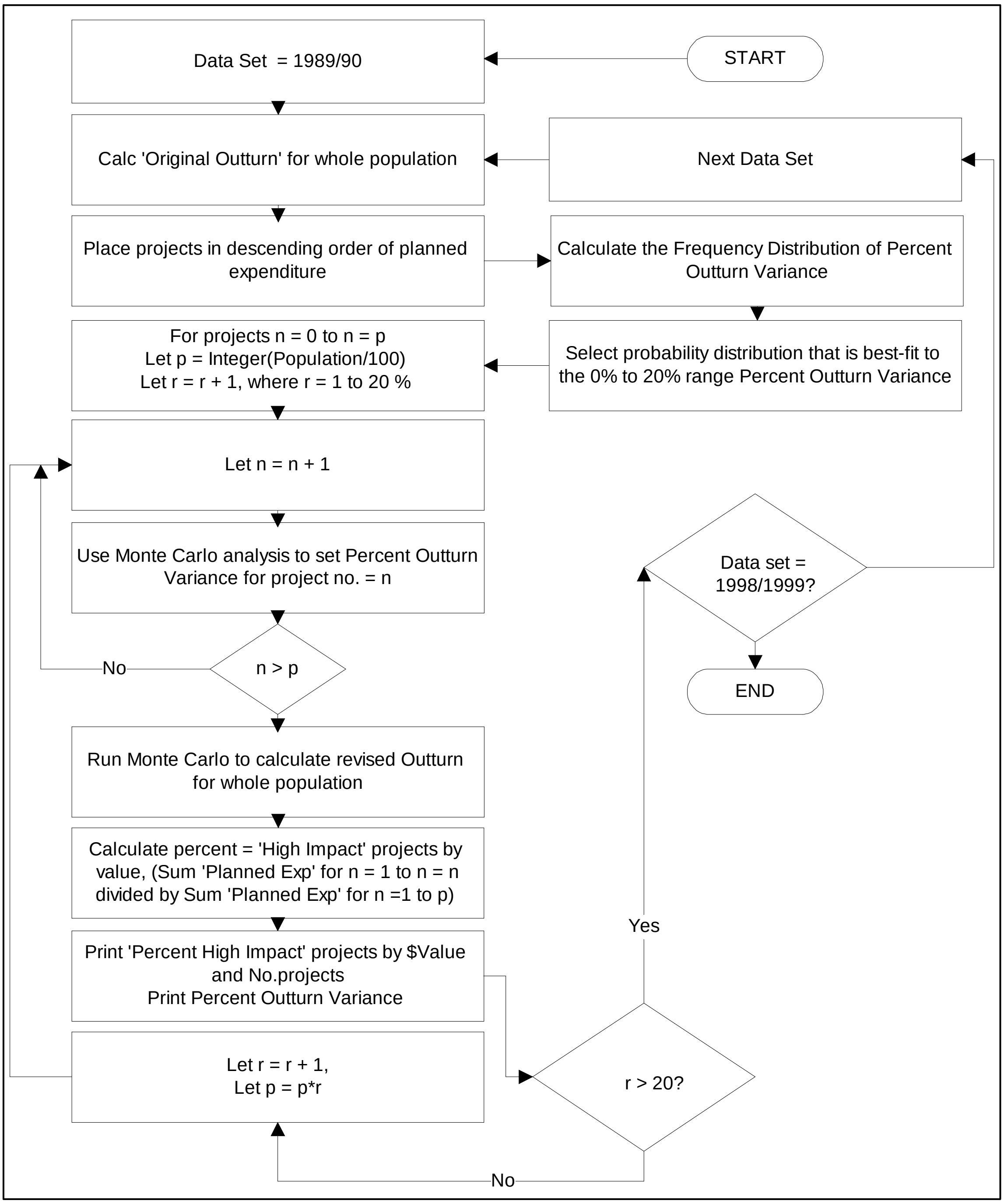

Figure 5: Flow chart of stochastic method for evaluating the impact of project significance on portfolio outturn

The combination of Pareto and Monte Carlo methodology described here sets more realistic aspirations for the same portfolio of projects. Using this approach, there is an ‘evens’ probability that the outturn variance of the portfolio will be improved by 5%, 6%, or 10%. If, the corresponding 5%, 10%, or 20% of the high spend projects achieve an outcome that falls within the best 10% of the range of empirical performance achieved by the projects within the portfolio. On the basis of results of using this methodology over ten sets of empirical data, heuristics are proposed for the application of this significant project approach to the management of portfolios of projects in the manner of Cleland and King.

Table 6: Comparison of the improved outtrun for the 1989-90 portfolio due to the impact of the outturn variance for 1% to 20% significant projects according to 'actual', 'ideal' and 'stochastic' scenarios

% No projects modified outturn	% Value	Outturn percent of target expenditure achieved						
		Actual %	Ideal %	Monte Carlo Percentiles				
				Ave-Mean variance per project	95%	90%	75%	50%
1%	25%	75.4	80.6	8.84	79.51	79.36	79.86	78.92
2%	38%	75.4	82.5	8.94	80.21	80.04	79.76	79.52
3%	45%	75.4	83.4	8.91	80.29	80.20	79.97	79.71
4%	51%	75.4	84.0	8.98	80.44	80.29	80.01	79.78
5%	55%	75.4	84.9	8.92	80.98	80.83	80.59	80.35
6%	59%	75.4	85.6	8.94	81.33	81.18	80.96	80.74
7%	62%	75.4	86.2	8.97	81.68	81.53	81.23	81.00
8%	65%	75.4	86.5	8.90	81.73	81.57	81.33	81.07
9%	67%	75.4	87.2	8.92	82.28	82.14	81.39	81.67
10%	69%	75.4	88.0	8.92	82.79	82.63	82.39	82.14
11%	71%	75.4	88.7	8.91	81.13	83.02	82.82	82.59
12%	72%	75.4	89.0	8.95	83.60	83.42	83.18	82.93
13%	74%	75.4	89.4	8.92	83.95	83.71	83.49	83.22
14%	76%	75.4	89.7	8.91	84.09	83.37	83.57	83.32
15%	77%	75.4	90.1	8.94	84.37	84.17	83.88	83.50
16%	78%	75.4	90.5	8.94	84.51	84.37	84.14	83.29
17%	79%	75.4	90.9	8.93	84.84	84.70	84.46	84.15
18%	81%	75.4	91.3	8.92	85.13	84.96	84.69	84.95
19%	82%	75.4	91.6	8.92	85.16	85.05	84.82	84.28
20%	83%	75.4	97.1	8.93	85.41	85.24	84.99	84.71

REFERENCES

Cleland, D. and King, W. (1983) *Systems Analysis and Project Management*. Singapore: McGraw-Hill International. 435-437.

Futcher, K.G. and Rowlinson, S. (1998) Information technology used by Hong Kong contractors. *The life-cycle of construction IT innovations ~ Technology transfer from research to practice, CIB proceedings CIB/W78 1998 (ed. Bork, B and Jagbeck, C).* Sweden: Royal Institute of Technology. 245-256.

Futcher, K.G. and Rowlinson, S. (1999) Strategic use of IT by the Contractors and Consultants in the Hong Kong construction industry. *Proceedings CIB/W78 (June, 1999).* Vancouver.

Hong Kong Government (1990) *Annual Report of the Director of Accounting Services and the Accounts of Hong Kong for the year ended 31 March 1990*. Hong Kong: Government Printer.

Horner, R.M.W. (1991) *Iterative estimating can double Estimator's output*. Construction Management Research Unit, University of Dundee.

Horner, R.M.W. (1992) *Measurement, valuation and control, of civil engineering works* SERC Research Grant No GR/F/91186.

Sargent, R., and Wainwright, E. (1998) *Crystal Ball Version 4.0 User Manual*. Denver: Decisioneering