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SCHEDULE CONTINGENCY ANALYSIS FOR TRANSIT PROJECTS USING A SIMULATION APPROACH

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Abstract. This paper presents a probabilistic method to establish schedule contingency levels based on percent completion of the project. The objective is providing a distribution for contingency for various percent completion levels which allows the project owner/manager to choose the schedule contingency at their comfort level. The proposed method is applied on real data from a number of US transit projects and actual schedule overruns for different phases of the project development (preliminary engineering, final design and construction) are analyzed. These values are used to establish the required contingency at the conclusion of each of the mentioned project phases. Additionally, using these values, the required contingency at various points during the construction phase (such as 25% and 50% completion) is calculated and reported. This approach can be used by project owners to plan realistic schedules during various phases of the project, providing better control on duration and the opportunity for being prepared to take necessary action in case the available schedule contingency falls below reasonable levels.

Keywords: contingency; simulation; schedule; transportation; transit projects; overrun; delay; risk.

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Introduction

Schedule delays and cost overruns are challenging for large-scale construction projects with long durations. Uncertainties embedded in such projects affect both schedule and cost (Tseng *et al.* 2009). Project delays are common in practice and the amount of delay vary with the nature of the project. In construction, delay could be defined as the time overrun either beyond completion date specified in a contract, or beyond the date that parties agreed upon delivery of a project (Assaf, Al-Hejji 2006). The delays are usually accompanied by cost overruns and the problem is experienced by both developed and developing countries (Kaliba *et al.* 2009). Cost overrun and time overrun generally result from factors that occur at various phases of the project life cycle (Bhargava *et al.* 2010). Delays in construction projects are a universal phenomenon and develop slowly during the course of the work (Ahmed *et al.* 2003). Causes of delay in large construction projects, average of time overrun is between 10% and 30% of original duration (Assaf, Al-Hejji 2006).

It is clear that the complex nature and immense size of the large-scale projects require effective planning (Capka 2004). Project managers should know the probability of time overrun in order to take necessary corrective actions. One obvious planning approach is to use this information to include sufficient contingency for the project schedule. Other corrective actions may include but not limited to a change of project delivery method (Design Build vs Design Bid Build, etc.), use of new equipment or technology, redrafting dispute resolution procedures and expediting construction permits. Therefore, a distinct need has emerged to develop facilitated methods for evaluating the probability of construction time overruns (Luu *et al.* 2009).

The causes of undesired growths in schedule and cost have attracted construction management researchers worldwide and many reports and research studies can be found in the literature. The issue of optimism bias in organizational dynamics in construction and concluded that it is imperative to have

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Table 1. Case study project schedule analysis (phases are expressed in "years")

		Original project duration by phase (years)				Approximate project delay by phase (years)					
A	B	C	D	E	F	G	H	I	J	K	L
Project Number	Case study projects	PE/ FEIS	FD	Construction	Original total project duration (Col.C + Col.D + Col.E)	PE/ FEIS delay	FD delay	Construction delay	Total project delay (Col.G + Col.H + Col.I)	Final duration (Col.F + Col.G + Col.H + Col.I)	Schedule overrun changes for total project % (Col.K − Col.F)/(Col.F)
1	Atlanta North Line Extension	1	3	6	10	0	0	4	4	14	40
2	Boston Old Colony Rehabilitation	1	6	2	9	1	2	0	3	12	33
3	Boston Silver Line (Phase 1)	1	1	10	12	4	0	4	8	20	67
4	Chicago Southwest Extension	2	3	3	8	0	1	2	3	11	38
5	Dallas South Oak Cliff Extension	2	1	3	6	1	2	−1	2	8	33
6	Denver Southwest Line	4	1	3	8	4	0	0	4	12	50
7	Los Angeles Red Line MOS 1		5	1	6		1	2	3	9	50
8	Los Angeles Red Line MOS 2		7	4	11		2	2	4	15	36
9	Los Angeles Red Line MOS 3		10	5	15		2	1	3	18	20
10	Minneapolis Hiawatha Line	6	1	4	11	3	1	1	5	16	45
11	New-Jersey Hudson-Bergen MOS1	3	1	5	9	1	1	2	4	13	44
12	New York 63rd Street Connector	3	2	7	12	3	1	0	4	16	33
13	Pasadena Gold Line	3	4	3	10	2	4	0	6	16	60
14	Pittsburgh Airport Busway (Phase 1)	2	1	7	10	4	3	0	7	17	70
15	Portland Airport MAX Extension		2	4	6		0	0	0	6	0
16	PortlandBanfield Corridor		3	1	4		2	0	2	6	50

Table 1 (*Continued*)

		Original project duration by phase (years)				Approximate project delay by phase (years)					
A	B	C	D	E	F	G	H	I	J	K	L
Project Number	Case study projects	PE/ FEIS	FD	Construction	Original total project duration (Col.C + Col.D + Col.E)	PE/ FEIS delay	FD delay	Construction delay	Total project delay (Col.G + Col.H + Col.I)	Final duration (Col.F + Col.G + Col.H + Col.I)	Schedule overrun changes for total project % (Col.K − Col.F)/(Col.F)
17	Portland Interstate MAX	1	2	2	5	0	0	0	0	5	0
18	Portland Westside/ Hillsboro MAX	1	3	4	8	1	3	0	4	12	50
19	Salt Lake North-South Line	1	3	1	5	2	0	−1	1	6	20
20	San Fransisco SFO Airport Exten.	4	1	6	11	2	0	2	4	15	36
21	San Juan Tren Urbano	3	1	8	12	2	1	4	7	19	58
22	Santa Clara Capitol Line		1	4	5		0	0	0	5	0
23	Santa Clara Tasman East Line	3	4	2	9	2	1	0	3	12	33
24	Santa Clara Tasman West Line	1	3	3	7	2	0	−1	1	8	14
25	Santa Clara Vasona Line		1	5	6		0	0	0	6	0
26	Seattle Busway Tunnel	1	3	3	7	1	3	0	7	11	57
27	St Louis Saint Clair Corridor	3	1	2	6	0	0	0	0	6	0
28	Washington Largo Extension	3	1	4	8	2	−1	0	1	9	13
Mean: 34											
Standard deviation 22											

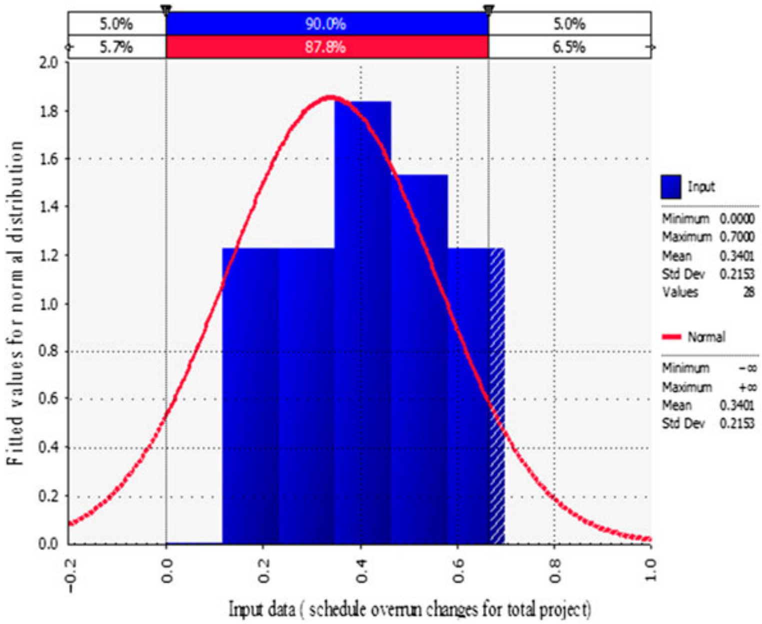

Fig. 1. Histogram of schedule growth at the completion of the project

explicit and systematic evaluation methods to achieve large-scale projects' objectives (Son, Rojas 2011).

Transportation projects are typical candidates that deserve thorough investigations for possible reasons of both schedule and cost growths. This twofold issue has been investigated at some depth (Bakshi, Touran 2009). It has been shown that there are many reasons for schedule delays and cost overruns including optimistic original estimates, lack of scope definition at the start of the project, increase in scope during project development phase due to pressure from project stakeholders, errors in estimation and lack of appropriate contingency budget (Booz Allen Hamilton Inc. 2005). In many construction projects, the owner plans for unexpected events that may affect project cost by adding a contingency to the estimated cost (Touran 2003). If the contingency is overestimated and allocated, the use of capital may be deemed inefficient and if it is underestimated, it contributes to increase the probability that the project may fail (Tseng *et al.* 2009). There are many factors affecting a project performance; disturbances in the supply of materials and equipment, irregular financing, design errors, inclement weather, equipment failures, inefficient contractors, administrative and legal disturbances, etc. (Rogalska, Hejducki 2007), and the risks in several infrastructural projects including road and railroad projects (Lam 1999). Construction delay and overrun is a critical function in construction of public projects and the time required to complete these projects is frequently greater than the time specified in the contract (Al-Momani 2000). It is clear that contingency is critical in scheduling and it can be developed for project schedule as a time buffer that is set aside to cope with uncertainties during project design and construction.

Several quantitative studies have been made to determine the project duration, schedule contingencies and time overruns; Bayesian belief networks to quantify the probability of construction delays (Luu *et al.* 2009), real options approach for contingency estimation (Tseng *et al.* 2009), and three-stage least-squares technique to identify the factors that significantly affect cost and time overruns (Bhargava *et al.* 2010). Monte Carlo simulation has been used to estimate project contingency and allocate among project activities (Barraza 2011).

The estimation of highway project duration can be made on the basis of past experience or using historical data from similar projects in similar contractual circumstances (Irfan *et al.* 2011). They investigated the project duration on the basis of variables known at the planning phase such as planned cost, project and contract type, and then developed a model using data from the State of Indiana, spanning the years 1996–2001.

In this study, a probabilistic approach is proposed to calculate schedule contingency in transit projects. The objective is to estimate schedule contingencies for the different level of completion of a project and to achieve the project completion without delay. For this purpose, Joint Confidence Level-Probabilistic Calculator (JCL-PC) approach proposed by Butts and Linton (2009) is adopted as the probabilistic method. The method is modified and used for transportation projects and applied on a set of data obtained from Booz Allen Hamilton Inc. (2005) report.

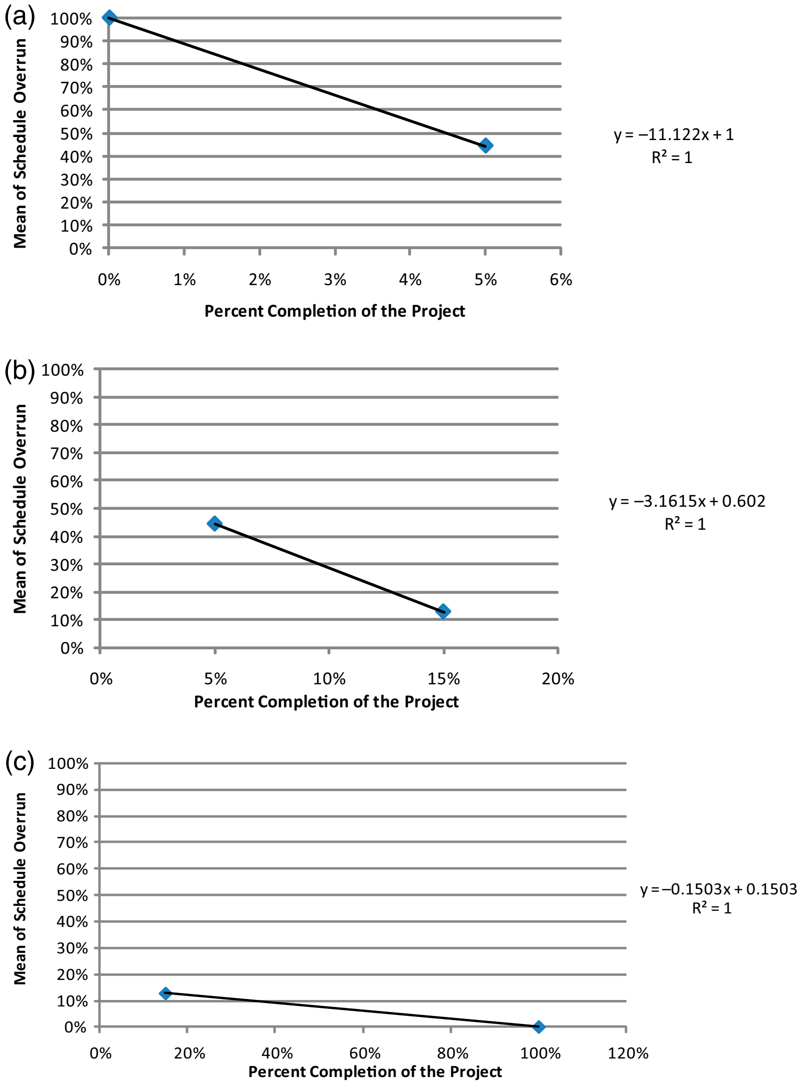

Fig. 2. Overview of contingency available in PE/FEIS phase (a); Overview of contingency remaining in FD phase (b); Overview of contingency remaining in Construction phase (c)

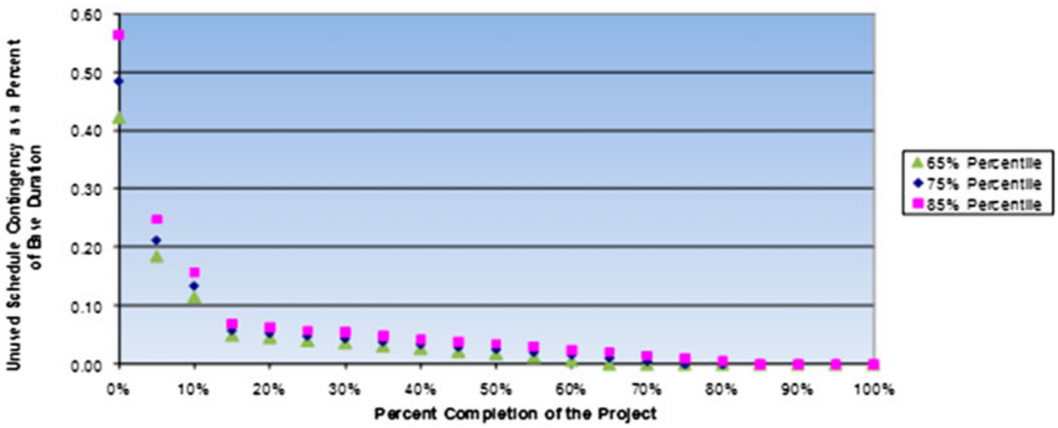

Fig. 3. Unused schedule contingency as a percent of base duration vs. project percent completion

Table 2. Schedule contingencies at the end of each phase

	Delays in phases (years)				Cumulative phase delay/total project delay			Schedule contingency at the end of phases		
A	B	C	D	E	F	G	H	I	J	K
Project Number	PE/FEIS	FD	Construction	Total project delay	PE/FEIS (Col.B/Col.E) %	FD ([Col.B + Col.C]/Col.E) %	Construction ([Col.B + Col.C + Col.D]/Col.E) %	PE/FEIS (1 − Col.F) %	FD (1 − Col.G) %	Construction (1 − Col.H) %
1	0	0	4	4	0	0	100	100	100	0
2	1	2	0	3	33	100	100	67	0	0
3	4	0	4	8	50	50	100	50	50	0
4	0	1	2	3	0	33	100	100	67	0
5	1	2	−1	2	50	150	100	50	−50	0
6	4	0	0	4	100	100	100	0	0	0
7		1	2	3	0	33	100	100	67	0
8		2	2	4	0	50	100	100	50	0
9		2	1	3	0	67	100	100	33	0
10	3	1	1	5	60	80	100	40	20	0
11	1	1	2	4	25	50	100	75	50	0
12	3	1	0	4	75	100	100	25	0	0
13	2	4	0	6	33	100	100	67	0	0
14	4	3	0	7	57	100	100	43	0	0
15		0	0	0						
16		2	0	2	0	100	100	100	0	0
17	0	0	0	0						
18	1	3	0	4	25	100	100	75	0	0
19	2	0	−1	1	200	200	100	−100	−100	0
20	2	0	2	4	50	50	100	50	50	0
21	2	1	4	7	29	43	100	71	57	0
22		0	0	0						
23	2	1	0	3	67	100	100	33	0	0
24	2	0	−1	1	200	200	100	−100	−100	0
25		0	0	0						
26	1	3	0	4	25	100	100	75	0	0
27	0	0	0	0						
28	2	−1	0	1	200	100	100	−100	0	0

Notes: Mean 44, 13 and 0.

Table 3. JCL-PC notations used for simulation

A	B	C	D	E	F	G	H	I
% completion	Schedule contingency remaining	Assume no risks occur	Normal risk dist.	% project complete	% project remaining	JCL-PC Mult.	Schedule contingency	Schedule contingency × contingency remaining
0	Values obtained by using Eq. 3, 4 and 5	1	RiskNormal (mean;SD) + 1	0	1 − Col.E	RiskDiscrete (Col.C:Col.D;Col.E;Col.F)	Col.G-1	Col.H × Col.B

Notes: Col. A: a given percent complete; Col. B: cumulative schedule contingency at the end of given percent completion from real data calculated by fitted lines in Figures 2 (a–c) using Eqns (3–5); Col. C: constant assuming that no unknown risk would occur at the given percent completion; Col. D: simulated values using a simulation software (e.g. @Risk) with schedule growth mean and standard deviation values from real data, which are 34% and 0.22, respectively; Col. E: a given percent complete; Col. F:% project remaining at that stage; Col. G: simulated values for *M* (JCL-PC multiplier); Col. H: total schedule contingency at the end of a given percent completion; Col. I: the amount of schedule contingency for the rest of the project.

1. JCL-PC approach

In a NASA Cost Estimating Symposium, Butts and Linton (2009) presented an approach, which aims to provide guidelines for developing more accurate cost estimates for NASA projects. The objective is mathematically compensating the optimism bias inherent in NASA cost estimating activity. The optimism bias is handled by looking at the historical performance of projects completed in the past and assume that the effectiveness of the owner agency will be the same as was in previous projects and hence, the same level of cost overruns and schedule delays will happen in future projects. The method is called Joint Confidence Level-Probabilistic Calculator approach (JCL-PC) and is based on the hypothesis that, in the beginning phases of a project, there are many unknown risks and over time the project will have a high probability of exceeding estimated costs and scheduled duration (Butts, Linton 2009).

The JCL-PC equation developed through this holistic algorithm is used to correct the overly optimistic cost and schedule estimates in NASA projects. The aim is to define the probability that the actual cost and schedule will be equal or less than the targeted cost and schedule date. The lessons learned and the benefits obtained by using the proposed method have also been collected (NASA 2010). It basically helps to improve project planning by strengthening risk management through quantification of risks in terms of cost and schedule impacts. Enforcing scheduling best practices, JCL-PC provides the picture of the project ability to achieve cost and schedule goals, and to help the determination of schedule and cost reserves. At any confidence level, the project can be baselined or rebaselined for schedule analysis and rebudgeted for cost analysis.

In this approach, a histogram of cost or schedule overruns is used. A ratio is selected using a simulation approach such that it ensures that the established budget or schedule will not be exceeded with a specified confidence level (Touran, Zhang 2011). It is assumed that as the project progresses, optimism biases will fade and quantifiable risks become clearer.

In order to make the appropriate correction of the estimate at a specified confidence level, a multiplier is calculated in JCL-PC method from Eqn (1). Afterwards, the base estimate is multiplied by this multiplier M and the required budget or schedule is estimated at a specified confidence level:

$$M = (1 + z) \times 1 \times (Percent\ complete); \tag{1}$$

$$projects\ required\ budget\ or\ duration = M \times projectbaseestimate. \tag{2}$$

In Eqn (1), the percent cost or schedule growth in previously completed similar projects is represented by z value from distribution Z. The sum of *percent*

Table 4. JCL-PC notations used for simulation in the application

A	B	C	D	E	F	G	H	I
% completion	Schedule contingency remaining	Assume no unknown risks occur	Normal risk dist. (mean: 0.34, SD: 0.22)	% project completed	% project remaining	JCL-PC Mult.	Schedule contingency	Schedule contingency × contingency remaining
	−11.12 × Col.A + 1 (for PE/FEIS) − 3.1615 × Col.A + 0.602 (for FD) − 0.1503 × Col.A + 0.1503 (for construction)		=RiskNormal (0.34;0.22) + 1		1 − ColE	=RiskDiscrete (Col.C: Col.D;Col.E;Col.F)	=Col.G − 1	=Col.H × Col.B
0	1.00	1	1.3401	0	100	1.3401	0.3401	0.3401
5	0.44	1	1.3401	5	95	1.3401	0.3401	0.1510
10	0.29	1	1.3401	10	90	1.3401	0.3401	0.0972
15	0.13	1	1.3401	15	85	1.3401	0.3401	0.0435
20	0.12	1	1.3401	20	80	1.3401	0.3401	0.0409
25	0.11	1	1.3401	25	75	1.3401	0.3401	0.0383
30	0.11	1	1.3401	30	70	1.3401	0.3401	0.0358
35	0.10	1	1.3401	35	65	1.3401	0.3401	0.0332
40	0.09	1	1.3401	40	60	1.3401	0.3401	0.0307
45	0.08	1	1.3401	45	55	1.3401	0.3401	0.0281
50	0.08	1	1.3401	50	50	1	0	0
55	0.07	1	1.3401	55	45	1	0	0
60	0.06	1	1.3401	60	40	1	0	0
65	0.05	1	1.3401	65	35	1	0	0
70	0.05	1	1.3401	70	30	1	0	0
75	0.04	1	1.3401	75	25	1	0	0
80	0.03	1	1.3401	80	20	1	0	0
85	0.02	1	1.3401	85	15	1	0	0
90	0.02	1	1.3401	90	10	1	0	0
95	0.01	1	1.3401	95	5	1	0	0
100	0	1	1.3401	100	0	1	0	0

Table 5. Simulated unused contingency values as a percent of base duration using normal distribution

Project completion %	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
0	−1.5	6.4	11.6	15.9	19.4	22.7	25.7	28.6	31.3	34.0	36.7	39.5	42.3	45.3	48.5	52.1	56.3	61.6	69.3
5	−0.6	0.0	3.0	5.5	7.5	9.1	10.7	12.0	13.3	14.5	15.8	17.1	**18.5**	19.8	**21.3**	22.9	**24.8**	27.1	30.5
10	−0.3	0.0	0.0	2.2	3.7	4.9	6.0	7.0	8.0	8.9	9.7	10.6	11.5	12.4	13.5	14.5	15.7	17.1	19.8
15	0.0	0.0	0.0	0.1	1.2	1.8	2.3	2.8	3.2	3.7	4.1	4.6	4.9	5.4	5.9	6.3	6.9	7.7	8.6
20	0.0	0.0	0.0	0.0	0.1	1.2	1.8	2.4	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.8	6.3	7.0	8.1
25	0.0	0.0	0.0	0.0	0.0	0.1	1.0	1.7	2.3	2.7	3.2	3.6	4.0	4.4	4.9	5.3	5.8	6.5	7.5
30	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.2	1.8	2.3	2.8	3.2	3.6	4.0	4.4	4.9	5.4	6.0	7.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	1.8	2.3	2.7	3.1	3.5	3.9	4.3	4.9	5.5	6.3
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	1.8	2.2	2.7	3.1	3.4	3.8	4.3	4.9	5.8
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.2	1.7	2.2	2.6	3.0	3.4	3.8	4.3	5.2
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.2	**1.8**	2.3	**2.6**	3.0	**3.5**	4.0	4.6
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.2	1.7	2.1	2.5	3.0	3.4	4.2
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.6	2.0	2.4	2.9	3.6
65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.1	1.5	2.1	2.5	2.9
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.4	1.9	2.5
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.5	1.9
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.4
85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

remaining and *percent complete* is always 100% and refer to the project under consideration. Base estimate is project schedule (or cost) after all contingencies have been removed. These definitions indicate that as more of the project is completed, the required contingency becomes smaller for the remaining portion. One major issue with the JCL-PC approach is that for various levels of project completion, the delay distribution for z remains the same. It is reasonable to assume that as project approaches completion, the delay distribution should represent smaller values because the magnitude of delays should become smaller. The authors of this paper have modified the JCL-PC approach to account for this important shortcoming of the NASA approach.

2. The proposed approach in the context of transit projects

In this study, 28 transit projects' historical data is used to show the proposed approach for establishing the project's schedule contingency. The data is obtained from Booz Allen Hamilton Inc. report (2005). The following phases of the project lifecycle are reported with their duration and delay data as listed in Table 1. The average duration of all projects for total, preliminary engineering, final design and construction phases are 8.4 years, 2.3 years, 2.7 years and 4.0 years respectively. These are completed transit projects in the United States characterized by three different mode types; heavy rail, light rail and bus way.

Project development phases can be defined as:

- Preliminary Engineering (PE)/Final Environmental Impact Statement (FEIS);
- Final Design (FD), which is at the end of design effort in traditional design-bid-build contracts and before going to bid;
- Construction.

Since the schedule growth is available for this set of projects, it is possible to construct the histogram of the distribution of schedule growth at the end of construction phase which actually reflects the real project completion times with delays (Fig. 1). It shows that the average schedule growth is 34% of the original duration and the standard deviation of the schedule growth is 22% (Fig. 1). Using Chi-square test of goodness of fit, a Normal Distribution is fitted to this data set.

The means of cumulative schedule growths are then calculated and the schedule contingency amount at the end of each phase is determined. Afterwards, these values are mapped against percent completions for all phases. It is assumed for the purpose of this study that PE/FEIS, FD and Construction phases refer to 5%, 15% and 100% completions respectively and the mapping is conducted for each phase independently (Touran, Zhang 2011). The average schedule contingencies at the end of PE/FEIS, FD and Construction phases are determined as 44%, 13% and 0% respectively as shown in Table 2. Three fitted sets of data against percent completions (0%, 5%, 15% and 100%) are shown in Figures 2 (a–c).

The other percent completion levels can be estimated by using the mean lines of schedule growth at the end of each phase (μ) which are fitted according to the data points expressed above and calculated depending on the corresponding phase interval.

The separate equations for determining the mean values for the PE/FEIS, FD and Construction phases are expressed below in Eqns (3–5):

$$\mu_{PE/FEIS} = -11.122x + 1; \quad (3)$$

$$\mu_{FD} = -3.1615x + 0.602; \quad (4)$$

$$\mu_{Construction} = -1503x + 0.1503, \quad (5)$$

where x is percent completion for the project, expressed in decimal format.

Eqns (3), (4) and (5) can be used to calculate the means of schedule contingency remaining at a given percent completion between 0–0.05 (PE/FEIS), 0.05–0.15 (FD) and 0.15–1 (Construction) respectively, assuming linear changes in delay during each of these phases.

For different completion percentages, the appropriate normal distribution value is used to determine the values of M which is the JCL-PC multiplier (Eqn 1). A distribution for M is simulated for each percentage point and then used to calculate the value of M for the specified confidence levels as proposed by Butts and Linton (2009). The amount of the schedule growth at a given percent completion is then determined by multiplying the total schedule contingency value (obtained by using JCL-PC multiplier) and the schedule contingency remaining at that stage. A sample table is provided in Table 3 in order to show the notations that are used in the calculations.

3. Application

In order to use the lines fitted, a hypothetical transit project is considered and it is assumed that the owner wants to establish a schedule contingency at different confidence levels as a percentage of base duration. Base duration is the established project duration excluding all contingencies. If the estimate is prepared at the end of PE/FEIS phase (approximately 5% completion), the simulation results in Table 5 show that 18.5%, 21.3%, 24.8% schedule contingency is determined (as the percentage of the base estimate) with a probability of 65%, 75% and 85%, respectively. If this estimate is made for 50% completion, then the amount will be about 1.8%, 2.6% and 3.5% of the base duration, respectively. It is obvious that as the project progresses, the schedule contingency that should be added to the base estimate decreases. This pattern is observed in simulation results and it is shown as an example in Figure 3. The JCL notations used for simulation in the application and JCL multipliers determined by simulation are presented in Table 4. All of the simulation results including these values generated for different levels of project completions vs. probabilities are shown in Table 5. It should be noted that the aim of the proposed method is to establish sufficient contingency to ensure the project completion without any delay.

Summary and conclusions

In this paper, a methodology is proposed to analyze the project schedule contingency for transit projects by considering various stages of project completion for different contingency levels. It considers the usage of schedule contingency as the project progresses. It takes into account the variations of both the mean values and standard deviations of time extensions at different percent completions. Since the calculations are based on actual data set of transit projects, the schedule growth rates can be obtained more accurately for desired confidence levels. This would provide opportunity to all project parties to make more realistic estimates in their schedules and plans during various stages of the project; and be prepared to take necessary action in case the available schedule contingency falls below reasonable levels.

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