ANALYSIS OF EARTH-MOVING SYSTEMS USING DISCRETE-EVENT SIMULATION[a]

Discussion by C. J. Schexnayder,[4] Fellow, ASCE

This paper joins a long list of similar investigations (AbouRizk et al. 1994; AbouRizk and Shi 1994; AbouRizk and Halpin 1992; AbouRizk et al. 1990; Ashley 1980; Bernold 1989; Clemmins and Willenbrock 1978; Farid and Koning 1994; Gonzalez-Quevedo et al. 1993; Kavanagh 1985; McCahill and Bernold 1993; Paulson et al. 1987; Riggs 1980; Willenbrock 1972; Vanegas et al. 1993) reporting on the development and possible use of simulation models for the construction industry. It begins with the very valid argument for the use of such models in planning and estimating construction productivity: physical experimentation in the field is not practical due to the cost and time constraints. However, the authors fail, as have many others, to provide the practicing engineer with a better analysis model than the typically employed deterministic model.

The paper dismisses the use of deterministic analysis of construction production problems because "the [construction process] system is too complex." Yet the authors proceed to create a simulation model that is even more simplified than most deterministic models. They state, "To consider all the factors, first- and second-order, in one simulation model would be an extremely complex procedure. . . ." The first-order factors listed in Table 1 of the paper would be carefully considered in almost all deterministic analyses of the type of problems discussed here. Nevertheless, the simulation model developed in this research considers only what are classified as second-order factors.

After some 20 years of research efforts, such as the one described in this paper, deterministic models are still the method of choice for studying and estimating production in the construction industry. This choice of models is not because of some exceptional accuracy inherent in deterministic methods, but because of the more mundane reason that the parameters that define productivity are stated in physical terms; whereas with a simulation model, critical judgments about statistical inputs would be necessary.

Practicing engineers find it easy to understand and relate to physical features, defined as first-order factors in the paper. Through field experience, engineers are provided with a set of internal verification points for understanding and applying the effect of physical features in deterministic models. However, statistical models are a "black box." The engineer understands the mechanics of statistical model input, but has difficulty establishing reference points with which to check the model's results against the physical world.

The discusser believes this paper serves to emphasize this disconnectedness between the model and its utilization. Development of the model is not the barrier to industry acceptance; the barrier is knowledge about appropriate statistical inputs. The model drivers, input statistical distributions, must be defined based on a clear understanding of how those distributions impact model results. It is very difficult to acquire a good, intuitive understanding of the effects of these statistical choices. To continue to publish about simplified simulation models is not what the industry needs. Practicing engineers know, without even using a rudimentary deterministic model, that production is sensitive to the number of trucks, haul distance, etc. If simulation is to be accepted in the construction industry there is a critical need for reliable information on which statistical distributions should be used in the models. The authors state, "Time-component means and variabilities are determined prior to simulation runs using a database of observed times. . . ." They further state that the mean and variability were entered as parameters for the Erlang distribution. What was not stated is exactly what the profession needs if simulation models are to be accepted.

How and why were certain statistic choices made? Of interest to practitioners attempting to use simulation models would be definitive statements about such things as the ratio of class intervals to data points, the distributions that were considered, and why certain distributions were selected or not selected for use in the model. Was a goodness-of-fit statistic used in selecting the distribution? Was the distribution selected simply because it was easy to handle mathematically in the model?

The idea of a simulation model to study a stochastic process is obvious. The authors have proposed a valid simulation model framework, as have many others. But the critical questions are about defining appropriate statistics for use in such models. Until there is a better understanding of those issues, simulation modeling of construction operations will remain a curiosity to the university.

APPENDIX. REFERENCES

AbouRizk, S. M., and Halpin, D. W. (1992). "Statistical properties of construction duration data." *J. Constr. Engrg. and Mgmt.*, ASCE, 118(3), 525–544.

AbouRizk, S. M., and Shi, J. (1994). "Automated construction-simulation optimization." *J. Constr. Engrg. and Mgmt.*, ASCE, 120(2), 374–385.

AbouRizk, S. M., Gonzalez-Quevedo, A. A., and Halpin, D. W. (1990). "Application of variance reduction techniques in construction-simulation." *Microcomputers in Civ. Engrg.*, 5(Sep.), 299–306.

AbouRizk, S. M., Halpin, D. W., and Wilson, J. (1994). "Fitting beta distributions based on sample data." *J. Constr. Engrg. and Mgmt.*, ASCE, 120(2), 288–305.

Ashley, D. B. (1980). "Simulation of repetitive unit construction." *J. Constr. Div.*, ASCE, 106(2), 185–194.

Bernold, L. (1989). "Simulation of nonsteady construction processes." *J. Constr. Engrg. and Mgmt.*, ASCE, 115(2), 163–178.

Clemmins, J. P., and Willenbrock, J. H. (1978). "The SCRAPESIM computer simulation." *J. Constr. Div.*, ASCE, 104(4), 419–435.

Farid, F., and Koning, T. L. (1994). "Simulation verifies queuing program for selecting loader-truck fleets." *J. Constr. Engrg. and Mgmt.*, ASCE, 120(2), 386–403.

Gonzalez-Quevedo, A. A., AbouRizk, S. M., Iseley, D. T., and Halpin, D. W. (1993). "Comparison of two simulation methodologies in construction." *J. Constr. Engrg. and Mgmt.*, ASCE, 119(3), 573–589.

Kavanagh, D. P. (1985). "SIREN: a repetitive construction simulation model." *J. Constr. Engrg. and Mgmt.*, ASCE, 111(3), 308–323.

McCahill, D. F., and Bernold, L. E. (1993). "Resource-oriented modeling and simulation in construction." *J. Constr. Engrg. and Mgmt.*, ASCE, 119(3), 590–606.

Paulson, B. C. Jr., Chan, W. T., and Koo, C. C. (1987). "Construction operations simulation by microcomputer." *J. Constr. Engrg. and Mgmt.*, ASCE, 113(2), 302–320.

Riggs, L. S. (1980). "Simulation of construction operations." *J. Constr. Div.*, ASCE, 106(3), 145–163.

Vanegas, J. A., Bravo, E. B., and Halpin, D. W. (1993). "Simulation technologies for planning heavy construction processes." *J. Constr. Engrg. and Mgmt.*, ASCE, 119(2), 336–354.

Willenbrock, J. H. (1972). "Estimating costs of earthwork via simulation." *J. Constr. Div.*, ASCE, 98(1), 49–60.

[a]December 1995, Vol. 121, No. 4, by S. D. Smith, J. R. Osborne, and M. C. Forde (Paper 8162).

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TABLE 10. Summary of Risk Importance: Author Sample versus Discusser Sample

Risk description (1)	Difference in averages (2)	Author Sample		Discusser Sample				
		Average (3)	Standard deviation (4)	Average (5)	Standard deviation (6)	Low (1–3) (%) (7)	Medium (4–7) (%) (8)	High (8–10) (%) (9)
Permits and ordinances	−0.7	4.7	3.0	4.0	3.0	50	38	12
Delayed site access/right of way	−0.9	5.6	3.0	4.8	3.6	62	—	38
Labor, equipment, and material availability	—	6.4	2.6	6.4	2.3	13	62	25
Labor and equipment productivity	−0.7	7.6	2.6	6.9	2.3	13	25	62
Defective design	−2.3	8.0	2.2	5.8	3.4	25	37	38
Changes in work	−0.4	6.9	2.4	6.5	1.7	—	87	13
Differing site conditions (lump-sum contract)	−0.9	6.9	2.5	6.0	2.4	13	62	25
Acts of God	−0.5	4.4	2.5	3.9	2.9	62	25	13
Defective materials	−0.4	5.1	2.7	4.8	2.1	12	75	13
Changes in government regulations (lump sum)	−0.5	4.1	2.7	3.6	2.0	50	50	—
Labor disputes	−0.8	5.5	2.5	4.8	1.7	12	88	—
Safety	−2.7	8.3	2.1	5.6	1.3	—	87	13
Inflation (lump sum)	−1.1	4.7	1.9	3.6	1.7	62	38	—
Contractor competence	−3.3	7.5	2.5	4.3	3.4	50	25	25
Change-order negotiations	0.1	6.4	3.3	6.5	2.9	12	38	50
Third-party delays	0.7	6.2	2.2	6.9	2.0	—	50	50
Contract-delay resolution	−2.3	6.8	2.3	4.5	1.7	25	75	—
Delayed payment on contract	−1.8	7.5	2.5	5.8	1.2	—	87	13
Quality of work	−2.5	8.2	2.2	5.8	2.3	13	62	25
Indemnification and hold harmless	0.1	6.5	2.4	6.6	2.7	12	38	50
Financial failure: either party	−4.1	7.3	2.6	3.3	3.0	75	12	13
Actual quantities of work	−0.8	5.8	2.5	5.0	2.0	12	75	13
Defensive engineering	−0.1	4.6	1.8	4.5	1.8	25	62	13

TABLE 11. Summary of Risk Allocation: Author Sample versus Discusser Sample

Risk description (1)	Author Risk Allocation (Sample = 49)			Discusser Risk Allocation (Sample = 8)		
	Owner (%) (2)	Shared (%) (3)	Contractor (%) (4)	Owner (%) (5)	Shared (%) (6)	Contractor (%) (7)
Permits and ordinances	81	13	6	75	25	—
Delayed site access/right of way	83	15	2	87	—	13
Labor, equipment, and material availability	2	10	88	—	—	100
Labor and equipment productivity	2		98	—	—	100
Defective design	83	9	8	75	12	13
Changes in work	77	21	2	50	50	
Differing site conditions (lump-sum contract)	94	6		100	—	—
Acts of God	58	40	2	38	62	
Defective materials	2	20	78		13	87
Changes in government regulations (lump sum)	79	19	2	87	13	—
Labor disputes	2	28	70	—	13	87
Safety		19	81	—	50	50
Inflation (lump sum)	6	24	70	—		100
Contractor competence	15	14	71	38		62
Change-order negotiations	9	87	4		75	25
Third-party delays	40	53	7	38	37	25
Contract-delay resolution	23	73	4	37	50	13
Delayed payment on contract	79	15	6	100	—	—
Quality of work		10	90	—	—	100
Indemnification and hold harmless	8	79	13	12	75	13
Financial failure: either party	4	89	7	—	75	25
Actual quantities of work	19	11	70	—	25	75
Defensive engineering	35	54	11	12	13	75

RISK MANAGEMENT PERCEPTIONS AND TRENDS OF U.S. CONSTRUCTION[a]

Discussion by Joseph P. Connolly,[2] Member, ASCE

The author's paper considers a topic that is important to the construction industry. Both contractors and owners can benefit from understanding how each perceives risk. As the author notes, determining the cost of risk is a critical activity for contractors. Traditionally, risk allocation is proposed in the contract documents, and the contractor must then cost the risks or negotiate changes in their allocation.

In 23 years with a top 100 contractor, the discusser has found that different construction sectors (infrastructure, petrochemical/oil and gas, power, etc.) view risk management in different ways. And this partisan risk management philosophy influences a sector's contracting strategies.

Some of the literature seems to have recognized these differences, and several papers [see Gordon, (1994)] have provided frameworks for viewing their respective sector approach to contracting strategies.

The author's sample of top 100 contractors of 1993 would

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