SIMULATION OF AN AGGREGATE PRODUCTION PLANT USING GERTS GQ MODULES

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ABSTRACT

Materials processing through an aggregate production plant was modelled and simulated using the GERTS network approach. The modelling procedure was facilitated by modular subnetworks representing frequently recurring operations. For the aggregate industry, simulation is particularly appealing because it permits effective analysis of plant performance and improved allocation of equipment in response to such questions as:

- How can a balanced workload be maintained and adapted to changing workloads?
- How can plant operations be scheduled to produce diverse kinds of aggregates demanded by a fluctuating market?
- How can truck scheduling be planned to avoid unacceptably high transportation costs?

Profits in the industry are highly sensitive to supply and demand balance, a condition referred to as product elasticity. Guidelines are developed to achieve this objective by simulation.

A NETWORK FLOW MODEL TO SIMULATE AN AGGREGATE PRODUCTION PLANT

Introduction

Aggregates, a fundamental building material, play a vital role in the construction industry. In the unbound form, sand and gravel are used as foundation materials for all types of improved roads, for railroad beds, and airport runways. Aggregates combined with a binder, such as portland cement or asphaltic cement, support or comprise floors, foundations, walks, walls, garages, streets, bridges, dams, overpasses, patios, drive ways, and many other applications.

Although deposits of aggregate materials occur throughout the world, few locations offer commercially competitive grades. The Sacramento Valley is the source of a wide variety of aggregate production area. Representative operations examined include: Teichert Aggregates, Granite Aggregates and Nevada Aggregates and Asphalt. A representative "big" producer, Teichert Aggregates, has quarries and major plant operations in four California cities: Tracy, Woodland, Sacramento, and Truckee.

Benefits. This study develops a prototype network flow model of a crushed rock aggregate plant; this model is suitable to evaluate conventional facets of plant performance such as is entailed in production planning and forecasting. The innovative impact of the model results from:

- the promptness with which data to support decision making regarding specific problem statements is generated,
- the manager's independence of the details of systems analysis or computer programming,
- the potential utility to medium-size and small producers.

Since aggregates are the common denominator for both asphaltic and ready-mix concretes, most aggregate plants are multi-functional and thus present complex process control requirements. The profit margin is a particularly sensitive parameter which is dependent on maintaining:

- scheduled multi-product flows under seasonal demand variations,
- continual updating and awareness of operational cost of factors,
- adequate control of processing time in response to changing market projections.

User Demand. The flow model representing an aggregate process plant can give detailed information about plant operational behavior helping to answer questions as:

- How can a balanced workload be maintained?
- What factors control or inhibit the efficiency of available resources?
- What operations are critical in avoiding "Bottlenecks"?
- How should the truck scheduling be planned to maintain optimal plant utilization?
- How should plant operations be scheduled to produce diverse aggregates demanded by a fluctuating market?

GERTS GQ SIMULATION PROGRAM

A User-Oriented Network Program

GERTS GQ is an acronym for Graphical Evaluation and Review Technique Simulation including Gated Queue option, and is FORTRAN based stochastic event simulation program (1). To simulate the aggregate production plant, the aggregate production system was represented in the form of a network and then was simulated by GERTS GQ. The option GQ refers to a modification of the GERTS IIIQ Simulation package (2). GERTS GQ incorporates a "gated" queue node as one of its basic elements. The GERTS GQ package includes features which adapt it naturally to the structure of the HAD modules,* resulting in a substantial improvement in program performance and reliability.[3,4,5,6,7,8]

Modular Network Approach

Network modules are here intended to govern information flow. Networks with this function have only been developed and explored during the past ten years. The operations of each network module consist of the flow or transmission of a commodity or other entity.

Flow may have several different definitions depending upon the commodity:[9,10,11,12,13,14,15,16,17,18,19,20]

- If the commodity consists of information, flow is referred to as communications,
- If the commodity consists of materials, flow is referred to as material handling, distribution or transportation, or
- If the flow consists of information and material, it is defined as a management information system.

GERTS GQ is particularly suited to implement these kinds of network modules with the aid of about fifteen network modules. These modules may be defined as operational subsystems usually closely resembling modes of operation as they occur in practice. As a result, the modules become building blocks in a hierarchy of modelling concepts and thereby bridge the "problem to model" interface.

A Resource Library of Network Modules

A number of frequently recurring network modules have been carefully reviewed and collected to compile a resource library of modules. Each network module has been assembled from GERTS GQ network elements. Simulation of entity handling processes is facilitated by classifying modules in accordance with the input count/output count ratio. This ratio relates the number of entities entering a module to the number of entities leaving it over an appropriate period and generates four types:

Proliferative Modules generate more outgoing than entering pulses thereby acting as "sources" of entities or as "multipliers" of the entity flow.

Consolidative Modules emit fewer units than they absorb thus, the flow of transactions is "compacted."

Flow-through Modules neither increased nor attenuate entity flow but modify the flow while it is conserved within modular entering it by a single input and leaving it by a single output.

Channeled Modules similarly control the entity flow without increase or attenuation: pulses are selected and re-distributed, typically delayed or speeded up.

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* The HAD modelling technique utilizing network modules was developed by Happ, Akiba and Dabaghian.

The Activity Profile as a Tool for Performance Analysis

The activity profile is an instantaneous "snapshot" of the realization of each event in the network. These realizations result in an event-time discontinuum, which some investigators regard as a state. Propagation of an event through the constituent elements of a module constitutes a sequence of states called a trace. The activity profile is a representative sample of such traces. The GERTS GQ program can generate the activity profile by printing time coordinates vertically and the node numbers from left to right as illustrated in Table 5. The activity profile provides:

- A concise summary of information flow through the event space,
- Event sequences to draw conclusions and insights on the interconnection scheme,
- Monitoring capability for any nodes, particularly for queue nodes,
- Activities for up to fifty nodes in numerical order.

- Material remaining in the trommel passes through a revolving screen at the end of the trommel to separate cobbles (larger than 2½" dia.) from the material; these are routed by a belt (8) into a large cobble bin. The cobble bin is periodically unloaded by trucks.

- Material gradations larger than sand, yet smaller than 2½" dia. are emptied by inclined conveyor belt (9) into a set of double deck vibrating screens (10) at the wash side tower. These separate the material into two gradations stored in bins beneath the tower and return the finest residues to the sand screw via a launder flume.

- Part of the material separated by the first set of vibrating screens (3) can also be routed by a short conveyor belt (11) into the 66" Telsmith primary cone crusher (12) for discharge into an inclined conveyor belt (13) which already carries a sand product.

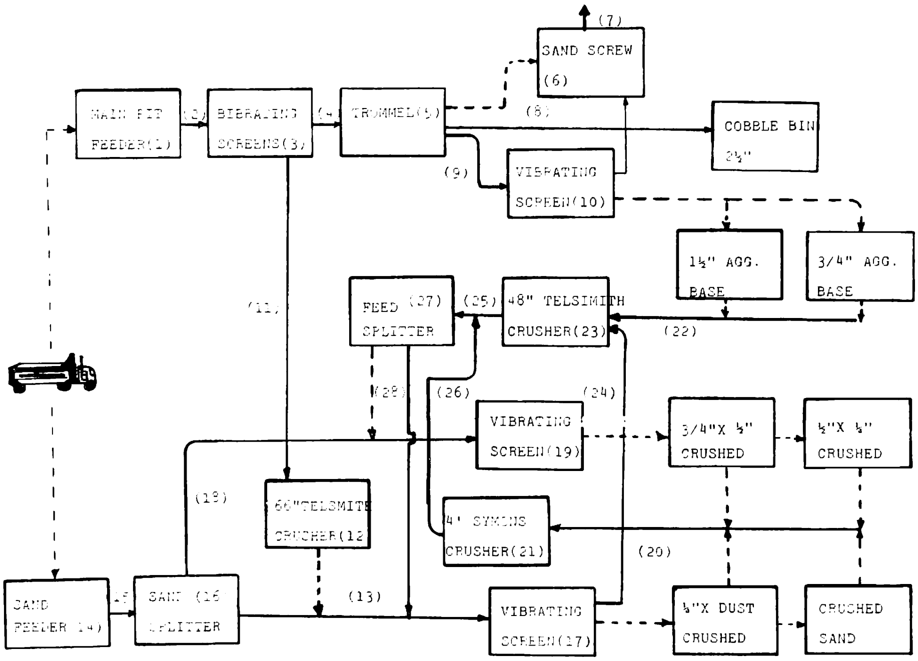

Figure 1 - State diagram of an aggregate plant

AN AGGREGATE PRODUCTION PLANT

Qualitative Description

A detailed study of three major aggregate plants in California identified elements common to major aggregate plant operations. Processing through a "typical" rock plant is illustrated by the state diagram, Figure 1:

- The pit run material, delivered to the main pit vibrating feed hopper (1) by Euclid trucks, is transported by an inclined conveyor belt (2) to a set of triple deck vibrating screens (3) which separate the material by size gradation. Depending on what product is currently being produced the output from these screens can be routed to either of two different conveyor belts.
- One conveyor belt (4) transports material to the trommel (5) which separates sand from the product. This sand is routed by a sand screw (6) to a portable radial stacking belt (7) which distributes it uniformly in a stockpile.

- A receiving hopper with a vibrating feeder (14) is also fed with sand by Euclid trucks. The feeder transports the sand to an inclined conveyor belt (15) which sends the material, through a splitter (16), to one of two belts. One of these, the inclined conveyor belt (13), passes under the primary crusher (12) emptying into a set of vibrating screens (17) in the crush side tower which separate the material into two bins beneath it.

- Conveyor (18), also fed by the splitter, carries material to another set of vibrating screens (19) in the plant tower where it is separated and discharged into the two bins beneath it. Material overflows from any of these four bins is collected by conveyor belt (20) and transported to the 3' Symons secondary short-head cone crusher (21).

- Conveyor belt (22) collects material overflows from the two bins on the wash side emptying it into the 48" Telsmith secondary crusher (23).

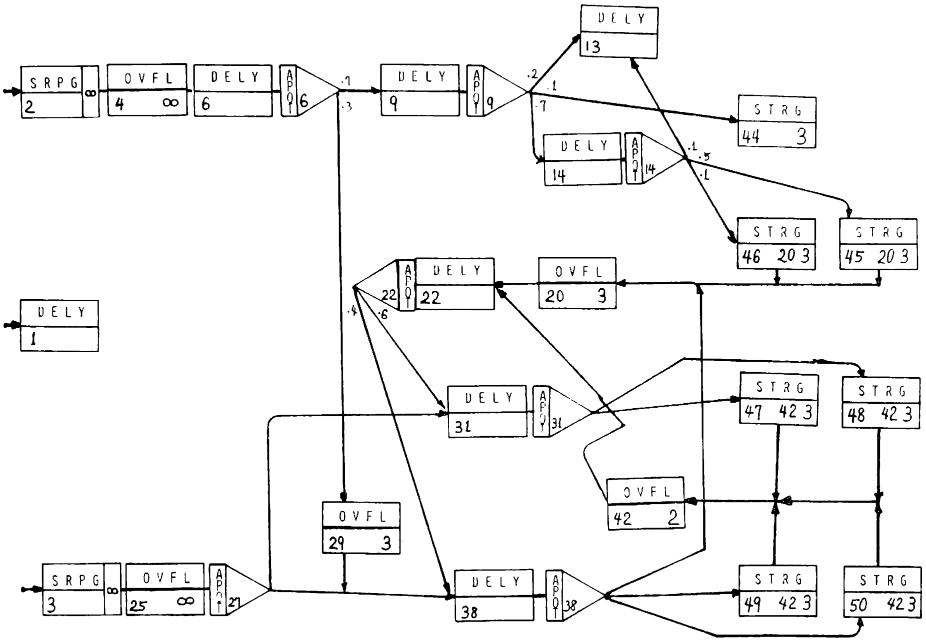

Figure 2 - Modular diagram of an aggregate plant

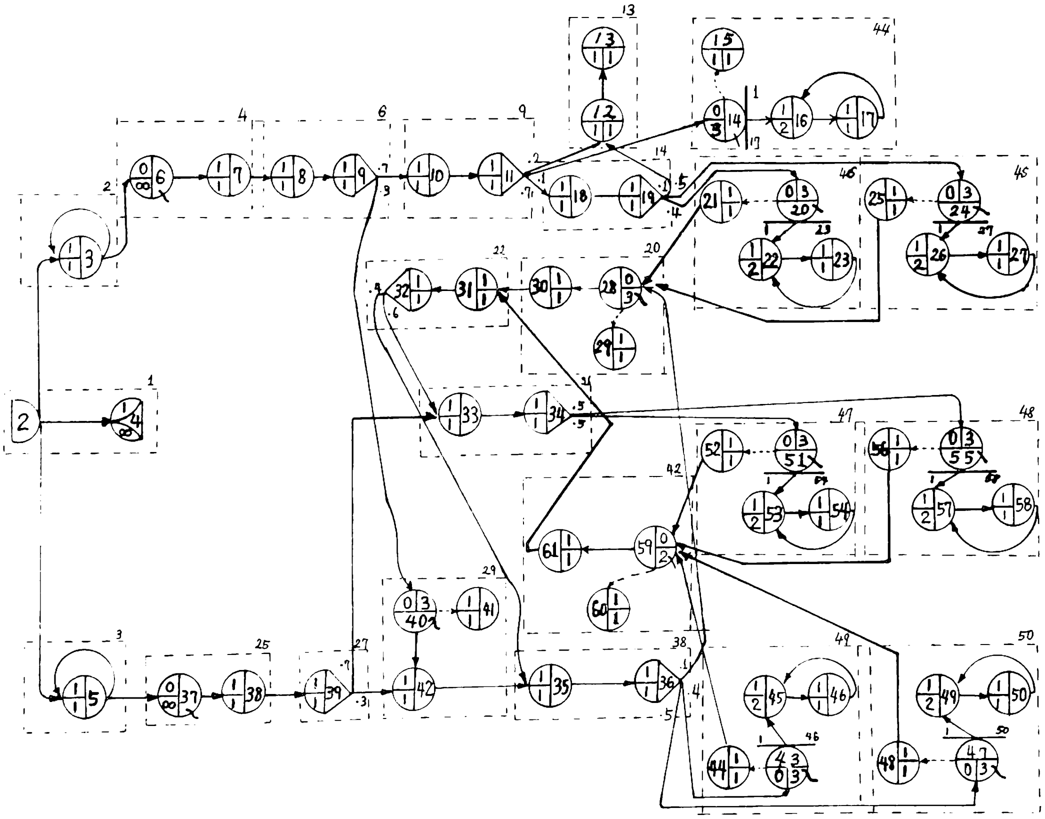

Figure 3 - Nodal diagram of an aggregate plant

Table 1 - Activity descriptions for an aggregate rock plant model

No.	Module	Branches (n-m(Prob.))	Parameter (minutes)	Description of Activity Time (n" wide x m' long)(nTons/minutes)
1	DELY	2-4	480	Eight hour clock
2	SRPG	3-3	2.5	Truck input to the main feeder (12T/m)
3	SRPG	5-5	5	Truck input to the sand feeder (6T/m)
4	OVFL	6-7	3	(1) Main pit feeder (10T/m)
5	→	7-8	4.5	(2) Main pit feed belt (36"x 160')
6	DELY-APOT	8-9	6	(3) Vibrating screen (5T/m)
7	→	9-10(.7)	3.5	(4) Trommel feed belt (30"x 60')
8	→	9-40(.3)	3	(11) 66" Telsmith crusher belt feed (36"x 5')
9	DELY-APOT	10-11	6	(5) Trommel (5T/m)
10	→	11-12(.2)	0	Sand drop through to sand screw
11	→	11-14(.1)	3	(8) Cobble bin belt (24"x 20')
12	→	11-18(.7)	3.5	(9) Inclined tower belt (24"x 90')
13	DELY	12-13	6	(6-7) Sand screw (5T/m)-radial stacker(24"x40')
14	DELY-APOT	18-19	6	(10) Vibrating screen (5T/m)
15	→	19-12(.1)	3.5	A launder flume (90')
16	→	19-24(.5)	0	Material separation to bins
17	→	19-20(.4)	0	" " " "
18	→	25-28	3.25	(22) 48" Telsmith belt feed from wash
19	→	21-28	3.25	(22) side of plant (24"x 35')
20	OVFL	28-30	3	(23) 48" Telsmith crusher (10T/m)
21	→	30-31	3.5	(25) 48" Telsmith collecting belt (24"x 70')
22	DELY-APOT	31-32	6	(27) Feed splitter
23	→	32-33(.6)	0	Material separation to vibration screen
24	→	32-35(.4)	3.25	(28) Transfer belt from 48" Telsmith collecting belt (24"x 30')
25	OVFL	37-38	6	(14) Sand feeder (5T/m)
26	→	38-39	3.25	(15) Sand feed belt (24"x 40')
27	→	39-33(.7)	4	(18) Transfer belt from sand feed belt(24"x 25')
28	→	39-42(.3)	0	(13) Inclined tower belt from sand feed belt
29	OVFL	40-42	2.5	(12) 66" Telsmith primary cone crusher
30	→	42-35	4.5	(13) Inclined tower belt (30"x 155')
31	DELY-APOT	33-34	6	(19) Vibrating screen (5T/m)
32	→	34-51(.5)	0	Material separation to bins
33	→	34-55(.5)	0	" " " "
34	→	52-59	3.5	(20) Symons 3' crusher feed belt (24"x 75')
35	→	56-59	"	" " " " " " "
36	→	44-59	"	" " " " " " "
37	→	48-59	"	" " " " " " "
38	DELY-APOT	35-36	6	(17) Vibrating screen (5T/m)
39	→	36-28(.1)	3.25	(24) Cross feed belt to 48" Telsmith crusher (24"x 20')
40	→	36-43(.4)	0	Material transfer to bins
41	→	36-47(.5)	0	" " " "
42	OVFL	59-61	6	(21) 3' Symons short head cone crusher (5T/m)
43	→	61-31	3.25	(26) Transfer belt from Symons to 48" Telsmith crusher (24"x 35')
44	STRG-PACK -DELY	14-16-17-16	2	Cobble material withdrawing period (wd. pd.)
45	"	24-26-27-26	2	3/4" aggregate base material wd. pd.
46	"	20-22-23-22	2	1 1/2" aggregate base material wd. pd.
47	"	51-53-54-53	2	3/4"x 1/2" crushed material wd. pd.
48	"	55-57-58-57	2	1/2"x 1/4" crushed material wd. pd.
49	"	43-45-46-45	2	1/4"x dust crushed material wd. pd.
50	"	47-49-50-49	2	Crushed sand material wd. pd.

- The 48" Telsmith secondary crusher is also fed by a cross-belt (24) with material from the crush side vibrating screens (17). Its product, on inclined conveyor belt (25), joins material brought from the 3' Symons by another collecting belt (26). Belt (25) empties material from the two crushers into a feed splitter (27).
- The feed splitter channels material back to the inclined conveyor belt (18) leading to the plant tower or onto conveyor belt (28) which empties into the inclined conveyor belt (13) leading to the crush side tower.

  Products remaining in the six tower bins are periodically unloaded by trucks and transferred to stockpiles.

Establishing a Modular Equivalent

The state diagram of Figure 1 corresponds in structure, that is topologically, to the modular network of Figure 2. Using the library of modules the user replaces each substate by the modular component which is its functional equivalent in relation to processing of entities. The following features are significant:

- Flow of Euclid trucks transporting pit run to the main feeder and the sand feeder are simulated by SRPG modules.
- Vibrating feeders are simulated by OVFL modules. Infinite queues are specified here since stockpiles are, for practical purposes, unlimited.
- DELY and APOT modules are combined to simulate the vibrating screens or the trommel. DELY represents the material processing time; APOT uses probability to separate the material by size.
- Decision making at each splitter is also simulated by an APOT module.
- Times for material transport by conveyor belts and the portable radial stacking belt are simulated by DELY modules.
- Since many delays are involved the symbolism is abbreviated: is often used.
- Crushers are simulated by OVFL modules with limited queue lengths using their balk nodes as bottleneck sensors.
- Storage bins are simulated by STRF modules with a balk capacity for overflows. Material transfer from a bin to a stockpile by a truck is represented by combining PACK and DELY modules. One of the elements in this combination acts as a switch for the STRG module.

The Nodal Network

Each modular element can be replaced by its "micronetwork," defined as a standard subnetwork composed of GERTS GQ elements. This micronetwork yields Figure 3 for the aggregate production plant. Details of this procedure are illustrated in several recent investigations.[4,5]

Specification of Operating Parameters. Performance in complex physical systems depends upon both design and operating parameters. Specification of particular characteristics and parameters are required to transform the generic or prototype model into the model of a specific aggregate rock plant. Parameters serve to characterize specific operations but are free to vary in the sense that once starting values have been assigned, other parameter variations permit the user to adjust plant performance as desired.

Table 1 lists definitions and starting values for activites of the network in Figure 3. For the simulation runs it was assumed that material is transported:

- to the main feeder from the pit at a rate of one truck load every 2.5 minutes,
- from the pit to the sand feeder at a rate of one truck load every 5 minutes,
- by a truck load representing 30 tons of material, used as basic unit.
- It is further assumed that time parameter values are listed in minutes,
- each computer execution simulates an eight hour shift
- shift operations in progress at the end of the shift are terminated.

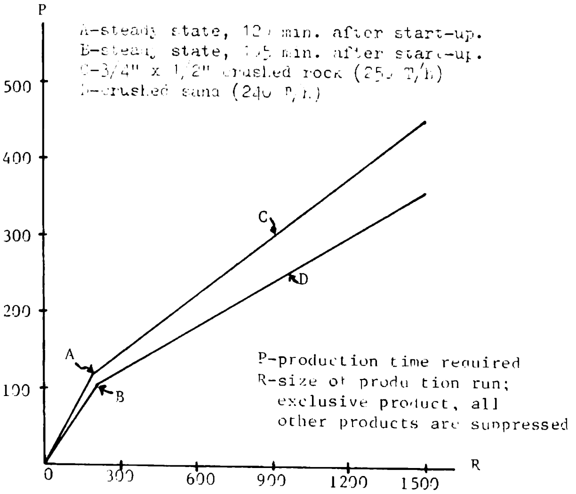

Figure 4 - Plant operation time for production of exclusive products

SIMULATION RESULTS AND INTERPRETATION

Model Validation and Runs

The model of the aggregate rock plant, Figure 3, simulated by the GERTS GQ necessitated preliminary runs to validate model structure and parameters. Close agreement with an actual prototype plant was demonstrated. This validated model served four distinct uses:

1. To determine required operational times for producing certain types of material to meet market demands,
2. To predict output volumes of aggregate when the inherent characteristics of the material deposit are altered,
3. To schedule trucks for transferring product materials to remote stockpiles, and
4. To analyze queueing phenomenon for efficient utilization of material stockpiled at the main feeder and the sand feeder.

Plant Operation Times

The market for sand and gravel products expands rapidly with increasing population densities and accompanying regional development. Extensive demands for certain types of aggregate encourage aggregate producers to meet this need. For example, in a single home over 170 tons of sand and gravel is used to build the foundation, garage floor, driveway, and similar structures. The importance of this building material makes it imperative for the aggregate plant manager to plan production capability: "How should plant operations be scheduled to produce the diverse kinds of aggregate needed to meet market demands?"

Table 2 - Probabilities of separation by size at suboperational plant stations

LOCATION	TO	LOCATION	PIT A	PIT B
SCREEN (3)		TROMMEL (5)	.6	.7
		66" CRUCHER (1)	.4	.3
SAND SPLITTER (16)		SCREEN (19)	.5	.7
		SCREEN (17)	.5	.3
FEED SPLITTER (27)		SCREEN (19)	.5	.6
		SCREEN (17)	.5	.4
TROMMEL (5)		SAND SCREW (6)	.2	.2
		COBBLE BIN	.3	.1
		SCREEN (10)	.5	.7
SCREEN (10)		SAND SCREW (6)	.1	.1
		1 1/2" AGG.	.4	.4
		3/4" AGG.	.5	.5
SCREEN (19)		3/4" X 1/2"	.5	.5
		1/2" X 1/4"	.5	.5
SCREEN (17)		48" TELSMITH	.1	.1
		1/4" X DUST	.4	.4
		CRUSH. SAND	.5	.5

Figure 4 charts the time required for production of 3/4" × ½" crushed rock and for crushed sand respectively, assuming production of a single product exclusively with all other products suppressed. In production of 3/4" × ½" crushed rock, steady-state is reached 120 minutes after start-up. At reaching a steady-state the production rate is 250 tons per hour. During production of crushed sand exclusively, 105 minutes is needed to reach steady-state, the steady-state production rate is 240 tons per hour.

This typical model permits the aggregate producer to construct production planning charts for both production of an exclusive product, and product mixes comprising different materials.

Adaptability of the Model

Aggregate characteristics differ from one deposit location to another. Sand and gravel deposits in streams are often suitable for use as commercial aggregates with minimal processing, because the abrasive action of the stream removes soft, weak particles leaving only the hard particles. The size gradation of a stream deposit is determined by water volume and velocity: heavy materials are deposited first, lighter ones being carried further downstream.

Table 3 - Plant mix output volume

	PIT A (tons)	PIT B(tons)
COBBLE	900	270
1 1/2" AGG.	450	660
3/4" AGG.	480	930
SAND	660	1170
3/4" X 1/2"	510	930
1/2" X 1/4"	660	780
1/4" X CRUSH	1357	1080
CRUSH. SAND	1800	990
TOTAL/SHIFT	6810	6810

To illustrate how to incorporate these factors into simulation studies consider a hypothetical pit/plant system:

- Two different types of raw materials are extracted from pits A and B respectively. Both pits are sited along the American River in Sacramento. Pit A is upstream of pit B. Sediment gradations are laboratory tested; on this basis probabilities of separation by size at suboperational plant stations are predicted. These results, summarized in Table 2, provided the parameters used in the simulation runs forecasting output volume and mix proportions for the plant. Plant mix output volume is shown in Table 3.
- If the total plant output volume is the same regardless of whether the raw materials are supplied from pit A or pit B, the pit location determines the mix proportions of plant output. In Figure 5, pit A shows the gradation characteristics of upstream sediments; pit B shows downstream sediment characteristics.
- Output probabilities and plant production rates can be predicted from the output volume and mix from input characteristics. Changes in input characteristics are similarly incorporated into the model.

Material Transfer from Storage Bins

Total production capability frequently depends on the truck scheduling used in transferring product materials to remote stockpiles. When trucks are scheduled to all bins (except cobble bins) at uniform time intervals, the overall production volume becomes a function of the truck interarrival times.

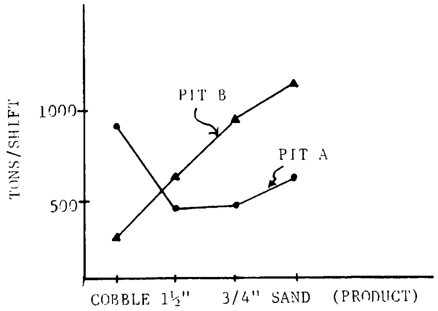

Figure 5 - Mix production of plant output

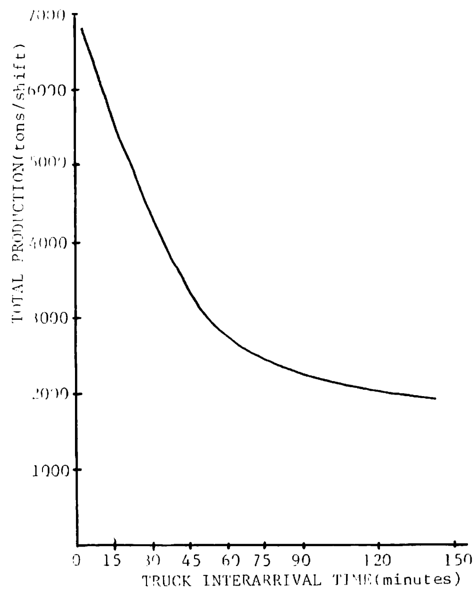

Figure 6 - Total plant production capacity: Dependence on scheduling of trucks transferring product material to remote stockpiles

System production decreases exponentially (from 6810 tons/shift) for a truck interarrival time of zero to the projected lower asymptotic value (of 1500 tons/shift) when the interarrival becomes infinite; in the latter case all material transfer is by means of the radial stackers. Plant production capacity for several truck interarrival times, Figure 6 illustrates that 15 minutes is acceptable performance; longer times lower the system production capacity because the system then becomes constrained by truck interarrival times; for shorter times other factors constrain the system.

Truck scheduling statistics, collected at each storage bin for different combinations of mean interarrival time and standard deviation, permit the scheduling optimization show in Table 4.

Material Stockpiling

Stockpiled materials awaiting processing at the input area such as idle trucks and idle loaders represent costly delays which can be eliminated if not prevented from occuring in the first place. Material backlogs at the main feeder and the sand feeder can be minimized by effective truck scheduling. Excessive material stockpiles at the main feeder increase truck operating costs without improving plant production efficiency.

Table 4 - Material interarrival time to bins

	MEAN (min.)	STAN. DEV.
COBBLE	49.00	32.14
1 1/2" AGG.	21.84	18.95
3/4" AGG.	15.21	13.07
3/4" X 1/2"	15.36	9.83
1/2" X 1/4"	18.09	14.99
1/4" X CRUSH.	12.97	12.23
CRUSH. SAND	13.74	12.59

The simulation assumed that a truck load of raw material arrives every 2.5 minutes at the main feeder and every 5 minutes at the sand feed hopper. Also, the main feed hopper requires 3 minutes to transfer a truckload of material into the plant and the sand feeder requires 6 minutes. These rates, expressed in tons/minute, are denoted by the symbols λ1, λ2, μ1, and μ2.

The accumulated material stockpiled at each feeder, in Figure 7, was obtained from the activity profile shown in Table 5, a useful output option in GERTS GQ. As this figure shows, material accumulates at the main feeder at two tons/minute and at the sand feeder at one tons/minute. Eight hours after start-up 960 tons and 480 tons, respectively, have accumulated at the main feeder and the sand feeder.

The average number of items in a queue is obtained in Table 6 from integrating the number in the queue over the time required (480 minutes) and then dividing the resulting total by this time.

$$\bar{Q} = \sum_{i}^{n} N_i t_i / \Sigma t_i$$

where

N_i = the number of units waiting in a queue during time interval t_i

Q = Average number in a queue

n = number of time intervals

t_i = time interval

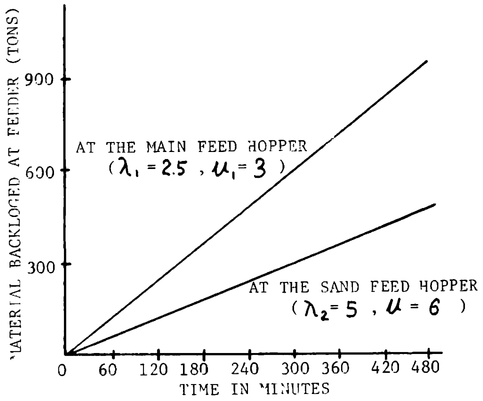

Figure 7 - Accumulated material stockpiled at each feeder

Average utilization is defined as the fraction of time that a server is busy, that is, the time the main feeder was busy (477.5 minutes) giving an effective utilization of 99.48 percent.

CONCLUSION

The modular simulation technique can model the operation of an aggregate production plant effectively and offers numerous practical advantages. Although application presented here is hypothetical it does, nevertheless, indicate the power of simulation for the study of industrial operations.

This technique permits effective analysis of performance and allows managers to model their plants, conducting simulations of complex systems for which effects of interactions cannot be directly observed or evaluated.

BIBLIOGRAPHY

1. Blom, N., Akiba, Y. and Happ, W. W., "The Gated Queue Node: Properties of a New Element for Stochastic queueing Networks," Proceedings, 1975 Winter Computer Simulation Conference, Sacramento, December 1975.

2. Akiba, Y., Blom, N., Duran, G., Dabaghian, L., "GERTS GQ Simulator for Systems Simulation," Report to NSF, Grant GY-11495, School of Engineering, California State University, Sacramento, CA, November 1974.

Table 5 - Gerts GQ output: an activity profile

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TIME      4 61314151617202122232425262728293740

474.000   .32 . . . . . 2 . . . T . . . . .15 .
                                            ↓
475.000   .31 . . . . . 2 . . . T . . . . .16 .
            ↓                              ↑
475.250   .32 . . . . . 2 . . . T . . . . .16 .
           ↑
475.500   .32 . . . . . 2 . . . T . . . . .16 .

476.000   .32 . . . . . 2 . . . T . . . . .15 .
             ↑↓
476.500   .32 . . . . . 2 . . . . . T . . .16 .
                                ↓  ↑↓↑↓
477.000   .32 . . . . . 2 . . . . . T . . .15 .

477.250   .31 . . . . . 2 . . . . . T . . .15 .
            ↓
477.500   .31 . . . . . 2 . . . . . T . . .16 .

478.500   .32 . . . . . 2 . . . . . T . . .16 .
           ↑
479.000   .32 . . . . . 2 . . . . . T . . .15 .

479.500   .32 . . . . . 2 . . . . . T . . .16 .

480.000   T32 . . . . . 2 . . . . . T . . .15 .
         ↑
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Table 6 - Queueing analysis at each input feeder

	Main Feeder	Sand Feeder
Average number in a queue	15.833	7.8333
Average utilization of a feeder	0.9948	0.9896

3. Akiba, Y., "A Modular Technique for Synthesis of Activity Networks: Development and Applications," Master's Thesis, School of Engineering, CSUS, Sacramento, CA, May 1975.

4. Akiba, Y., and Happ, W. W., "Activity Profiles: A Validation Technique for Logic Modules in Pulse Network," Proceedings, Eighth Asilomar Conference on Circuits, Systems and Computers, Monterey, CA, December 3, 1974.

5. Akiba, Y., Dabaghian, L. and Happ, W. W., "Validation of Component and System Performance in Modular Queueing Networks," Proceedings, Seventh Asilomar Conference on Circuits, Systems, and Computers, Monterey, CA, Nevember 1973.

6. Pritsker, A. A. B. and Burgess, R. R., "The GERT Simulation Programs: GERTS III, GERTS III Q, GERTS III C, and GERTS III R." NASA/ERC Contract NAS-12-2113, Departmental Report, Virginia Polytechnic Institute, Dept. of Industrial Engineering, 1970.

7. Akiba, Y., "Decision and Commodity Flow for Cargo Facilities," Proceedings, 3rd Annual Greater Los Angeles Area Transportation Symposium, Octiber 3, 1974.

8. Pritsker, A. A. B. and Happ, W. W., "GERT: Part I - Fundamentals," J. Ind. Eng., Vol. XVII, No. 5, 1966, pp. 267-274.

9. Elmaghraby, S. E., Network Models in Management Science, Springer-Verlag, Lecture Series on Operations Research, 1970.

10. Halpin, D. W., "An Investigation of the Use of Simulation Networks for Modelling Construction Operations," PhD Dissertation, Graduate College of the University of Illinois, Urbana-Champaign, IL, 1973.

11. Halpin, D. W. and Happ, W. W., "Network Simulation of Construction Operations," Proceedings, Third International Congress on Project Planning by Network Techniques, pp. 222-232, Stockholm, March 1972.

12. Whitehouse, G. E., Systems Analysis and Design Using Network Techniques, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1973.

13. Porte, H. A., Happ. W. W., Lee, C. T., and McNamee, L. P., "A Stochastic Network to Model Air Cargo Terminals," Proceedings, 1972 Army Science Conference, U.S. Military Academy, West Point, NY, June 1972.

14. Hogg, G. L., "An Analysis of Labor Limited Queueing Systems with a GERTS Simulation," PhD Dissertation, Graduate School, University of Texas, Austin, TX, December 1971.

15. Sprague, C. R., "Investigation of Hot-Mix Asphaltic Concrete Distribution Systems by Means of Computer Simulation," PhD Dissertation, Graduate College, Texas A & M University, College Station, TX, 1972.

16. Porte, H. A. and Happ, W. W., "Activity Networks to Model Transportation Systems Subject to Facility Constraints," Proceedings, Ninth Annual Allertion Conference on Circuit and System Theory, pp. 1151-1160, October 1971.

17. Burgess, R. R., "GERTS Models of a University," Master's Thesis, Virginia Polytechnic Institute, Blackburg, VA, 1970.

18. Elmaghraby, S. E., "Theory of Networks and Management Science I and II," Management Science, Vol. 17, Nos. 1 & 2, September and October 1970.

19. Dabaghian, L., Melnicoe, W. B., and Dabaghian, J., "Decision Flow Structure to Simulate Alternatives for Resource Allocation in Crime Control Systems," Proceedings, 1974 Carnahan and International Crime Countermeasures Conference, Lexington, KY, April 1974.

20. Whitehouse, G. E. and Hauan, E. C., "The Application of GERT to Quality Control: A Feasibility Study," Proceedings, 21st National Meeting of AIIE, 1970.