

PROJECT ADMINISTRATION DATA SHEET

ORIGINAL

Project No. E-20-644 GTR/GIT: _____ DATE 1/15/83
 Project Director: Dr. Daniel W. Halpin School XXX City Lawrenceville
 Sponsor: National Science Foundation

Type Agreement: Grant No. CEE-8208271

Award Period From 1/15/83 To 5/31/84 (Performance) 8/31/84 (Report)

Sponsor Amount: Total Estimated: \$ 57,255 Funded: \$ 57,255

Cost Sharing Amount: \$ 4,500 Cost Sharing No: E-20-323

Title: Resource Analysis Using Microcomputers (Construction Engineering)

ADMINISTRATIVE DATA OCA Contact Faith G. Costello

1) Sponsor Technical Contact:	2) Sponsor Admin/Contractual Matters:
<u>Arthur A. Ezra</u>	<u>Lois A. Shapiro</u>
<u>Water Resources & Environmental Eng'g</u>	<u>AAED/ENG Branch, Section I</u>
<u>Program General Civil Engineering Section</u>	<u>Division of Grants & Contacts</u>
<u>Division of Civil & Environmental Engineering</u>	<u>Directorate for Administration</u>
<u>Directorate for Engineering</u>	<u>NSF</u>
<u>NSF</u>	<u>Washington, DC 20550</u>
<u>Washington, D. C. 20550</u>	<u>(202) 357-9626</u>
<u>(202) 357-7737</u>	

Defense Priority Rating: N/A Military Security Classification: N/A
 (or) Company/Industrial Proprietary: _____

RESTRICTIONS

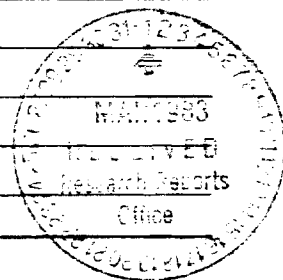
See Attached NSF Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of \$500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT

COMMENTS:

*Includes a 6 month unfunded flexibility period.



COPIES TO:

Research Administrative Network	Research Security Services	Research Communications (2)
Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	GTRI	Other <u>Project Director</u>
Procurement/EES Supply Services	Library	Other _____

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 11/15/85

Project No. E-20-644

School/MMX CE

Includes Subproject No.(s) N/A

Project Director(s) D. W. Halpin

GTRC /MMX

Sponsor National Science Foundation

Title Resource Analysis Using Microcomputers (Construction Engineering)

Effective Completion Date: 5/31/85 (Performance) 5/31/85 (Reports)

Grant/Contract Closeout Actions Remaining:

- ☐ None
- ☐ Final Invoice or Final Fiscal Report
- ☐ Closing Documents
- ☒ Final Report of Inventions - Questionnaire sent to Dr. Halpin for file.
- ☐ Govt. Property Inventory & Related Certificate
- ☐ Classified Material Certificate
- ☐ Other _____

Continues Project No. None Indicated

Continued by Project No. None Indicated

COPIES TO:

Project Director
Research Administrative Network
Research Property Management
Accounting
Procurement/GTRI Supply Services
Research Security Services
Report Coordinator (OCA)
Legal Services

Library
GTRC
Research Communications (2)
Project File
Other A. Jones; M. Heyser; R. Embry

INTERIM PROGRESS REPORT
FOR
NATIONAL SCIENCE FOUNDATION
GRANT NO. CEE -8208271

RESOURCE ANALYSIS USING MICROCOMPUTERS

SUBMITTED BY

DANIEL W. HALPIN

SCHOOL OF CIVIL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY

DECEMBER 1983

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
CIVIL ENGINEERING

TELEPHONE:
(404) 894.

20 December 1983

Subject: Interim Progress Report

To: Gifford Albright
Civil Engineering Division
National Science Foundation

1. Name of Institution: Georgia Institute of Technology
2. Name of Principal Investigator: Daniel W. Halpin
3. Grant No.: CEE-8208271
4. Starting Date: 15 January 1983
5. Completion Date (Anticipated): 15 January 1985
6. Grant Title: Resource Analysis Using Microcomputers
7. Summary of Progress to Date:

The original project schedule as submitted with the proposal is given in Appendix A to this report and contains 28 activities. The activities can be understood in the context of the conceptual diagram shown in Figure 1 and included in the original proposal.

All work on the QUANTITY module has been completed and the module is presently being tested on Apple and Radio Shack computers. It will in the near future be running under IBM PC computer and under the CP/M operating system.

Work on the resource definition module is essentially complete. This work is based on the standard networks which are described in detail in Appendix B. The library of standard networks is presently being implemented in a graphics mode so that the user can make the required input to the networks while being prompted by the diagram on the monitor screen. A typical network screen is shown in Figure 2.

A user's manual describing the integration of the Quantity, Resource, and production analysis (CYCLONE) modules as they operate in the present prototype version is given in Appendix C.

In effect, all items scheduled for work during the first year have been commenced and satisfactory progress has been achieved.

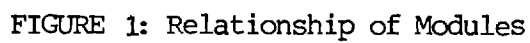


FIGURE 1: Relationship of Modules

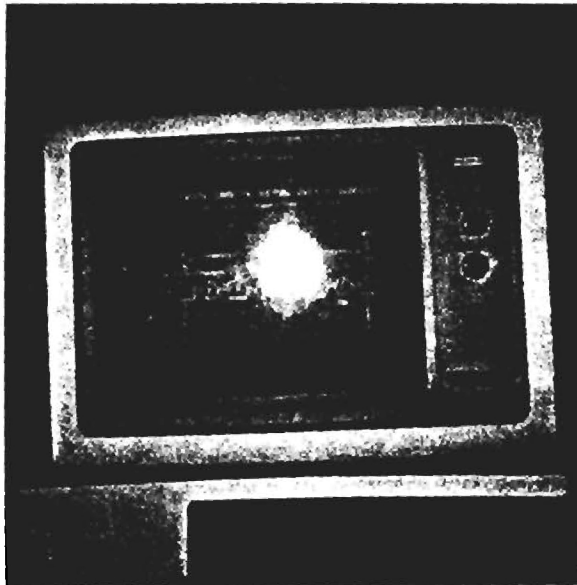


Figure 2: Graphics for Simulation Input

8. Current Problems and Favorable Developments

The major area requiring greater attention relates to the time data relationships as noted in activities 8, 9, 10. Work on this activity has been hampered due to difficulty in standardizing observations of processes in progress. This work will be undertaken in the coming year with the assistance of a Video Cassette Recorder (VCR) unit and Camera. This equipment should enhance the collection and study of data for time analysis purposes.

The use of the screen graphics as a user friendly method of linking the user to the computer analysis system during input is a significant development and its exploitation should make the system much more attractive to potential users. This approach is possible since the basic process networks are prefabricated and stored in the process library (thus relieving the user of inputting the network logic associated with the process).

9. Summary of Work to be Accomplished in the subsequent Budget Period

Work to be accomplished in the coming (last) year of the grant will be consistent with the activities described in the original schedule. The context of the integration and optimization activities as shown in Figure 1 is described in detail in Appendix D.

10. Other Pertinent Information:

Due to the need to enhance the time gathering activity, the budget for the second year of the grant has been revised slightly to provide for the purchase of a video tape unit to aid in the study and analysis of field operations.

In summary, excellent progress is being made and the the system proposed should be thoroughly tested and debugged by the end of the second year of the grant. The budget for the second year of the project is included as Appendix E.

No funds will be unobligated as of the end of the first year of the project (i.e. 15 January 1984).

Appendix A
ORIGINAL PROJECT SCHEDULE

Project Schedule (Cont'd)

ACTIVITIES	I	82	I		83		I	84					
	I		I				I						
	I	O	N	D	J	F	M	A	M	J	J	A	S
17. Design PA* Module Interface w/Cost & Time Modules	I						X	X	X	X	X	X	I
	I						*						I
18. Design Cost Output Formats & Graphics	I						*	X	X	X	X	X	I
	I						*						I
19. Develop Processing Routines for Cost Module	I						*	X	X	X	X	X	I
	I						*						I
	I						*						I
(a) Macro Flow Charts	I						*	X	X	X	X	X	I
(b) Detailed Flow Charts	I						*	X	X	X	X	X	I
(c) Code Development	I						*	X	X	X	X	X	I
20. Study Existing Time Scheduling Systems	I		X	X	X	X	X	X	X	X	X	X	I
	I						*						I
21. Review Resource Allocation and Leveling Algorithms	I			X	X	X	X	X	X	X	X	X	I
	I						*						I
	I						*						I
22. Design Time Output Formats & Graphics	I						X	X	X	X	X	X	I
	I						*						I
23. Develop Processing Routines for Time Module	I						*						I
	I						*						I
	I						*						I
(a) Macro Flow Charts	I						X	X	X	X	X	X	I
(b) Detailed Flow Charts	I						X	X	X	X	X	X	I
(c) Code Development	I						X	X	X	X	X	X	I
24. Develop System Test Problems	I		X	X	X	X	X	X	X	X	X	X	I
	I						*						I
25. Debug System as Required	I						*	X	X	X	X	X	I
26. Develop User's Documentation	I						*	X	X	X	X	X	I
	I						*						I
(a) Draft Manual	I						*	X	X	X	X	X	I
(b) Final Manual	I						*			X	X	X	I
27. Test at Selected Sites	I						*	X	X	X	X	X	I
28. Dissemination of Results via Publications	I						*						I
	I						*						I

Project Schedule

ACTIVITIES	I	82	I					83							I																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
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* Q = Quantity
RD = Resource Definition
PA = Productivity Analysis

APPENDIX B
CYCLONE STANDARD NETWORKS

STANDARD CYCLONE MODELS

In a study conducted at the Army Construction Engineering Research Laboratory [37], Rood has developed an "Equipment Selection Card" which provides construction activity estimates, a table for balancing fleet sizes and a nomograph for use in computing fleet productivity. Productivity estimates in the activity tables are developed from computer-assisted simulation studies and the tables are based on queueing theory. Estimates are provided for twelve "standard" heavy construction activities as follows :

1. Construction clearing
2. Stripping
3. Crane excavation
4. Excavating and hauling

Table 2. Job Description - Types of Equipment

A. Lifting

- .Crawler mounted crane
- .Truck mounted crane
- .Self-propelled mobile crane
- .Tower crane
- .Forklift
- .Derrick

B. Excavating

- .Face Shovel
- .Dragline
- .Grab
- .Hydraulic excavator
- .Excavator-loader
- .Front end loader
- .Trenching machine

C. Excavating/Transporting

- .Tractor drawn scraper
- .Rubber tired scraper
- .Bulldozer and angledozer
- .Grader

D. Transporting

- .Dump truck
- .Dumper
- .Belt conveyor
- .Monorail, cable way and so on

E. Compaction

- .Smooth wheel roller
- .Pneumatic tired roller
- .Grid roller
- .Sheepfoot and tamping rollers
- .Vibrating roller
- .Small compaction machines

F. Tunneling

- .Shield
- .Tunneling machine in soft ground
- .Tunneling machine in rock
- .Bentonite machine

5. Excavating and hauling (cont.)
6. Spreading fill
7. Compacting fill
8. Controlling soil moisture
9. Spreading base course
10. Watering
11. Ditching
12. Ancillary activities.

The standard activities in road construction are identified as follows:

1. Clearing, grubbing and stripping
2. Road and drainage excavation
3. Placing, spreading, compaction and final grading of the subgrade
4. Placing, spreading, compaction and grading the subbase
5. Placing, spreading, compaction and grading of the base
6. Paving.

The CYCLONE models for the standard activities in road construction are developed in conjunction with Jahangard [20] and several practicing construction professionals. These models are not the ultimate standard models but they are adequate and realistic representation of the actual work done in the field. These models will be used in structuring

the input to the resource definition module and the processing of the productivity and cost analysis module.

Standard Clearing and Grubbing CYCLONE Model #1

The only equipment used is a clearing/grubbing unit (e.g. dozer). The work tasks are pushing forward, stockpiling, backing up and burning. The standard clearing and grubbing CYCLONE model #1 is shown in Figure 7. Table 3 illustrates the typical CYCLONE problem oriented language specification for the standard model.

Standard Clearing and Grubbing CYCLONE Model #2

The equipments used are clearing/grubbing unit (e.g. dozer), loading unit (e.g. front end loader) and hauling unit (e.g. truck). The work tasks are pushing forward, stockpiling, backing up, loading, hauling, dumping and returning. Figure 8 illustrates the standard clearing and grubbing CYCLONE model #2. The typical CYCLONE problem oriented language specification for the standard model is shown in Table 4.

Standard Stripping CYCLONE Model

The only equipment used is an excavating/loading/hauling/dumping/spreading unit (e.g. scraper). The work tasks are excavating/loading, hauling, dumping/spreading and returning. The standard stripping CYCLONE model is shown in Figure 9. Table 5 illustrates the typical CYCLONE problem oriented language specification for the standard model.

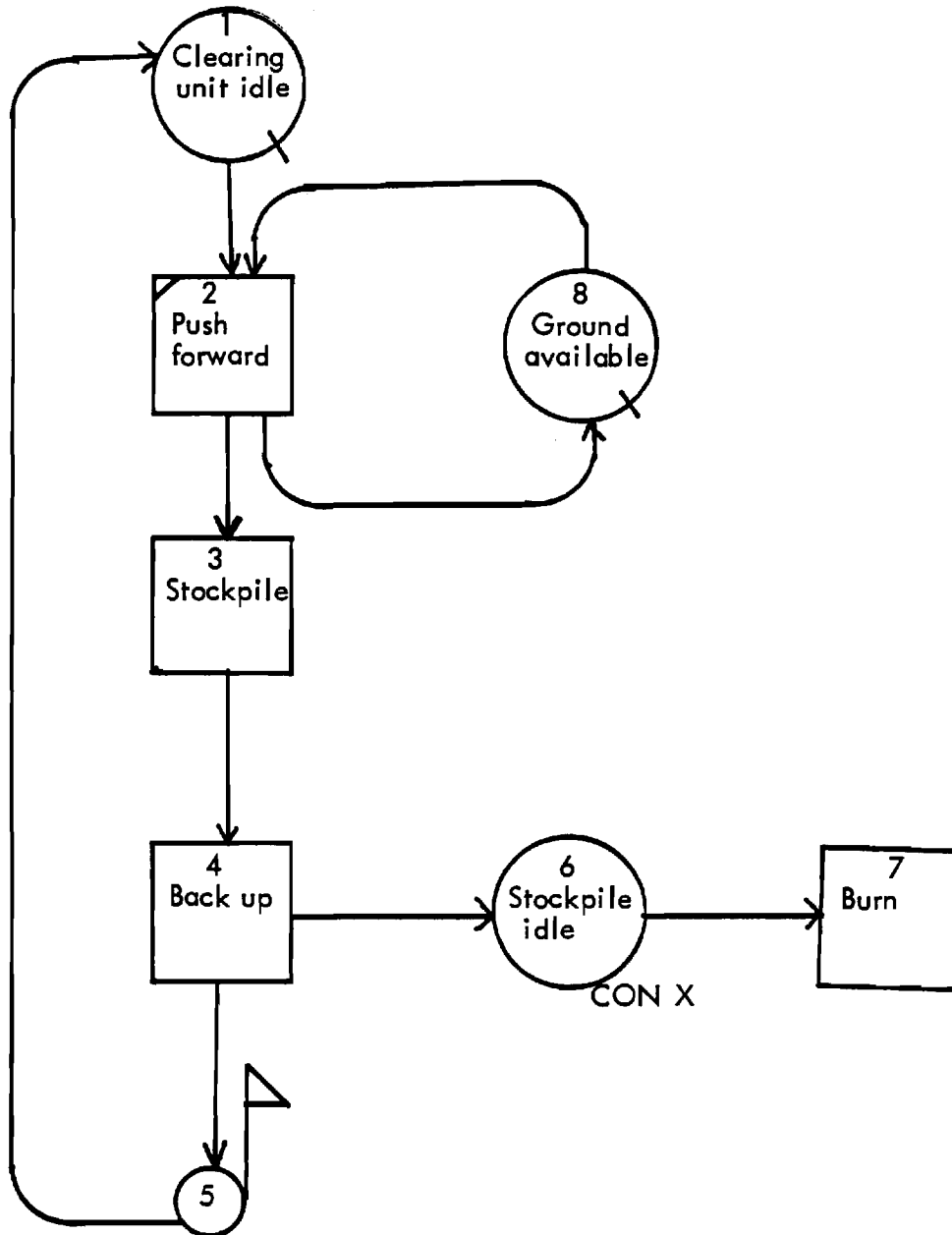


Figure 7. Standard Clearing and Grubbing CYCLONE Model #1

Table 3. Typical CYCLONE Problem Oriented Language
Specification for Standard Clearing and
Grubbing CYCLONE Model #1

```
CONTROL INPUT
NAME CLEARING CYCLES 872 LENGTH 1E+38
NETWORK INPUT
ACT 1 QUE 'CLEARING/GRUBBING UNIT IDLE'
ACT 2 COMBI 'PUSH FORWARD' PRE 1 8 FOL 3 8 SET 2
ACT 3 NOR 'STOCKPILE' FOL 4 6 SET 3
ACT 4 NOR 'BACK UP' FOL 5 SET 4
ACT 5 FUN 'COUNT' FOL 1 QUANTITY 5.7392102846648D-03
ACT 6 FUN 'STOCKPILE IDLE' FOL 7 CON 100
ACT 7 SINK 'BURN'
ACT 8 QUE 'GROUND AVAILABLE'
EQUIPMENT INPUT
1 AT 1 FI 0 VA 50
10 AT 8
DURATION INPUT
SET 2 2
SET 3 2
SET 4 2
END DATA
```

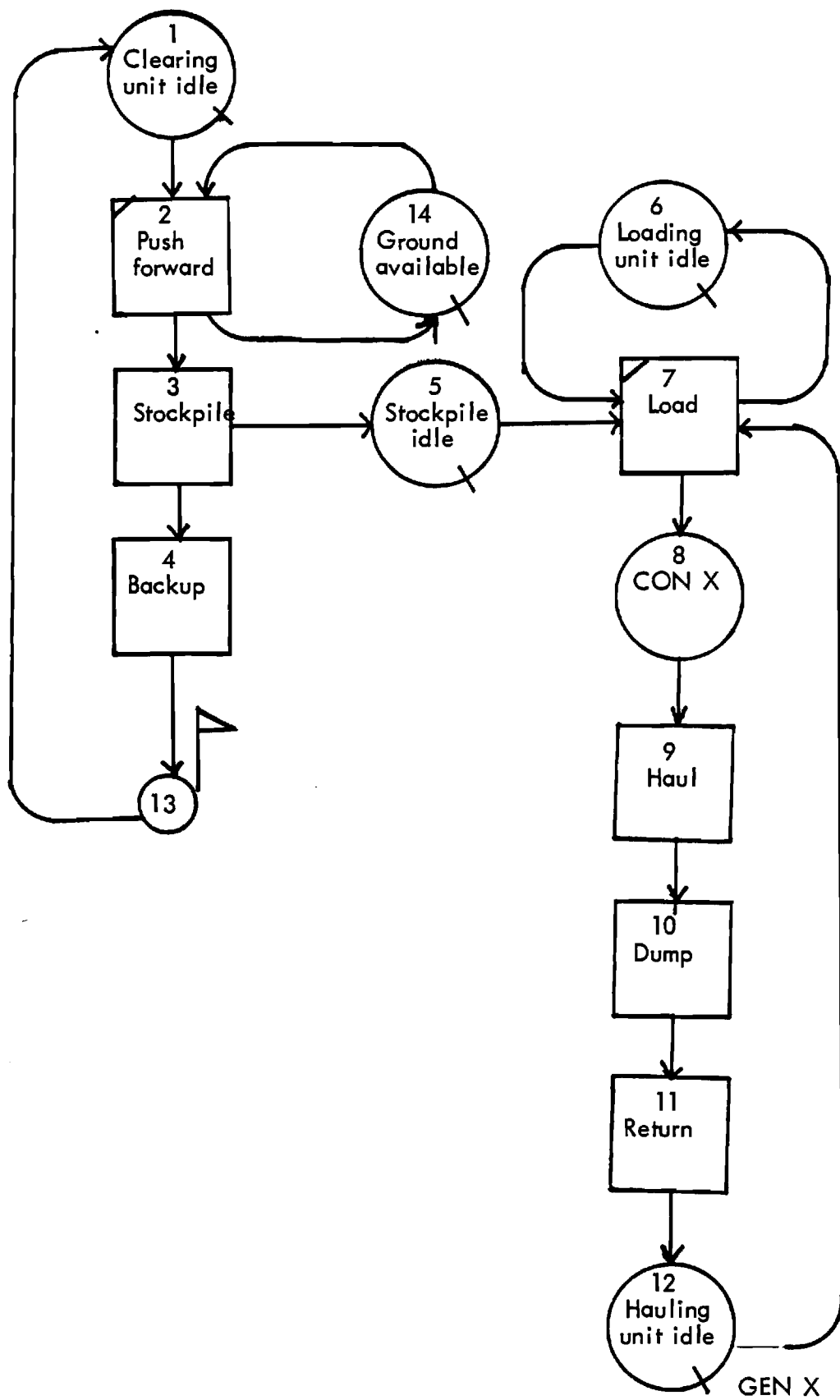


Figure 8. Standard Clearing and Grubbing CYCLONE Model #2

Table 4. Typical CYCLONE Problem Oriented Language
Specification for Standard Clearing and
Grubbing CYCLONE Model #2

CONTROL INPUT

NAME GRUBBING CYCLES 872 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'CLEARING/GRUBBING UNIT IDLE'

ACT 2 COMBI 'PUSH FORWARD' PRE 1 14 FOL 3 14 SET 2

ACT 3 NOR 'STOCKPILE' FOL 4 5 SET 3

ACT 4 NOR 'BACK UP' FOL 13 SET 4

ACT 5 QUE 'STOCKPILE IDLE'

ACT 6 QUE 'LOADING UNIT IDLE'

ACT 7 COMBI 'LOAD' PRE 5 6 12 FOL 6 8 SET 7

ACT 8 FUN FOL 9 CON 4

ACT 9 NOR 'HAUL' FOL 10 SET 9

ACT 10 NOR 'DUMP' FOL 11 SET 10

ACT 11 NOR 'RETURN' FOL 12 SET 11

ACT 12 QUE 'HAULING UNIT IDLE' GEN 4

ACT 13 FUN 'COUNT' FOL 1 QUANTITY 5.73921028466483D-03

ACT 14 QUE 'GROUND AVAILABLE'

EQUIPMENT INPUT

1 AT 1

1 AT 6

1 AT 12

10 AT 14

DURATION INPUT

SET 2 2

SET 3 2

SET 4 2

SET 7 2

SET 9 5

SET 10 1

SET 11 4

END DATA

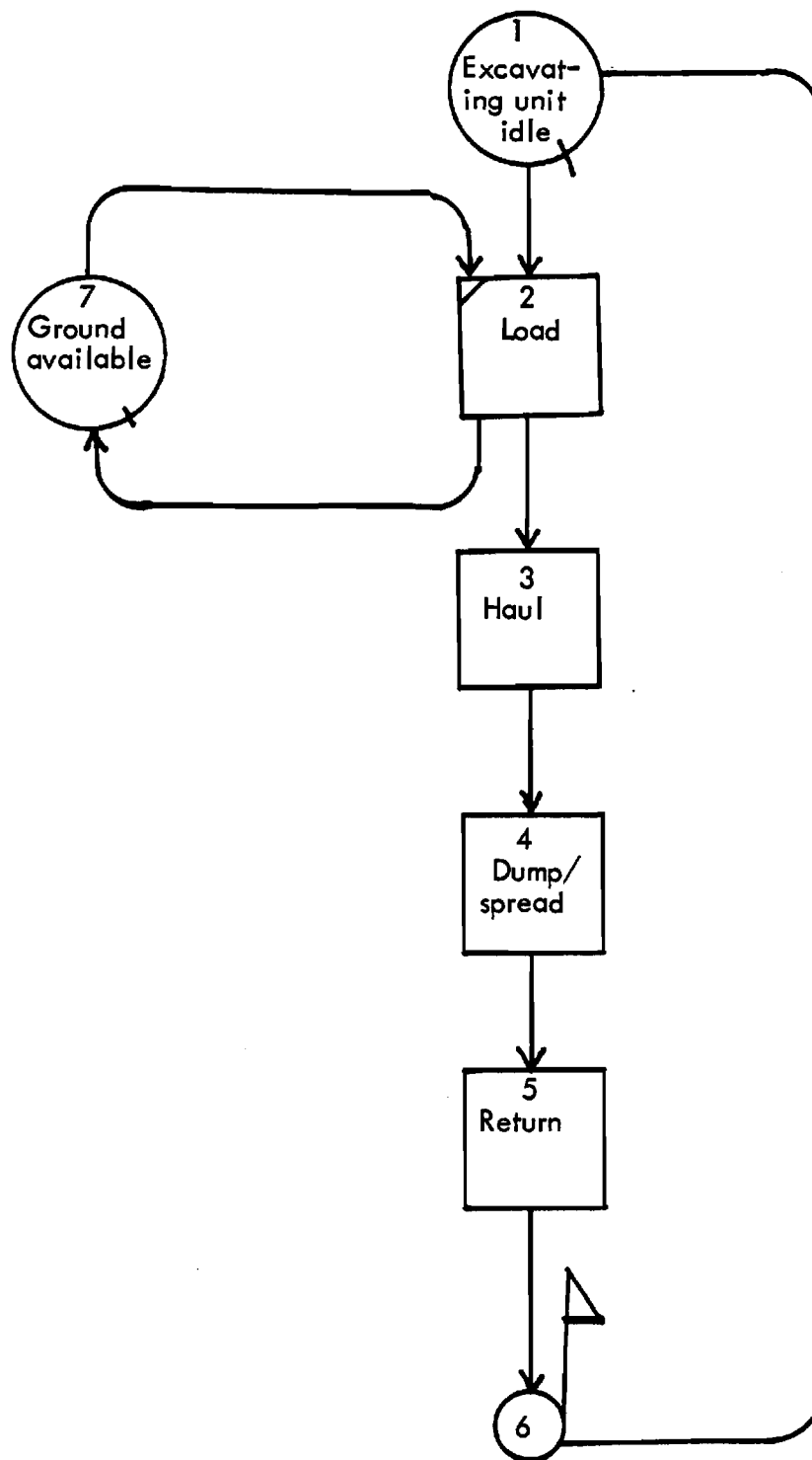


Figure 9. Standard Stripping CYCLONE Model

Table 5. Typical CYCLONE Problem Oriented Language
Specification for Standard Stripping CYCLONE
Model

```

CONTROL INPUT
NAME STRIPPING CYCLES 807
NETWORK INPUT
ACT 1 QUE 'EXCAVATING/LOADING UNIT IDLE'
ACT 2 COMBI 'LOAD' PRE 1 7 FOL 3 7 SET 2
ACT 3 NOR 'HAUL' FOL 4 SET 3
ACT 4 NOR 'DUMP/SPREAD' FOL 5 SET 4
ACT 5 NOR 'RETURN' FOL 6 SET 5
ACT 6 FUN 'COUNT' FOL 1 QUANTITY 5
ACT 7 QUE 'GROUND AVAILABLE'
EQUIPMENT INPUT
DURATION INPUT
SET 2 2
SET 3 5
SET 4 2
SET 5 4
END DATA

```

Standard Excavation CYCLONE Model #1

The equipments used are excavating unit (e.g. face shovel), loading unit (e.g. front end loader), hauling unit (e.g. truck) and spreading unit (e.g. dozer). The work tasks are excavating, stockpiling soil, loading, hauling, dumping, returning and spreading. Figure 10 is a graphical representation of the model and Figure 11 shows the standard excavation CYCLONE model #1. The typical CYCLONE problem oriented language specification for the standard model is illustrated in Table 6.

Standard Excavation CYCLONE Model #2

The equipments used are excavating/loading/hauling/spreading unit (e.g. scraper) and pushing unit (e.g. pusher). The work tasks are pushing/loading, hauling, dumping/spreading and returning. Figure 12 shows the graphical representation of this model and Figure 13 illustrates the standard excavation CYCLONE model #2. The typical CYCLONE problem oriented language specification for the standard model is shown in Table 7.

Standard Excavation CYCLONE Model #3

The equipments used are excavating/loading unit (e.g. crane), hauling unit (e.g. truck) and spreading unit (e.g. dozer). The work tasks are excavating, loading, hauling, dumping, returning and spreading. Figure 14 illustrates the graphical representation of this model and Figure 15 shows

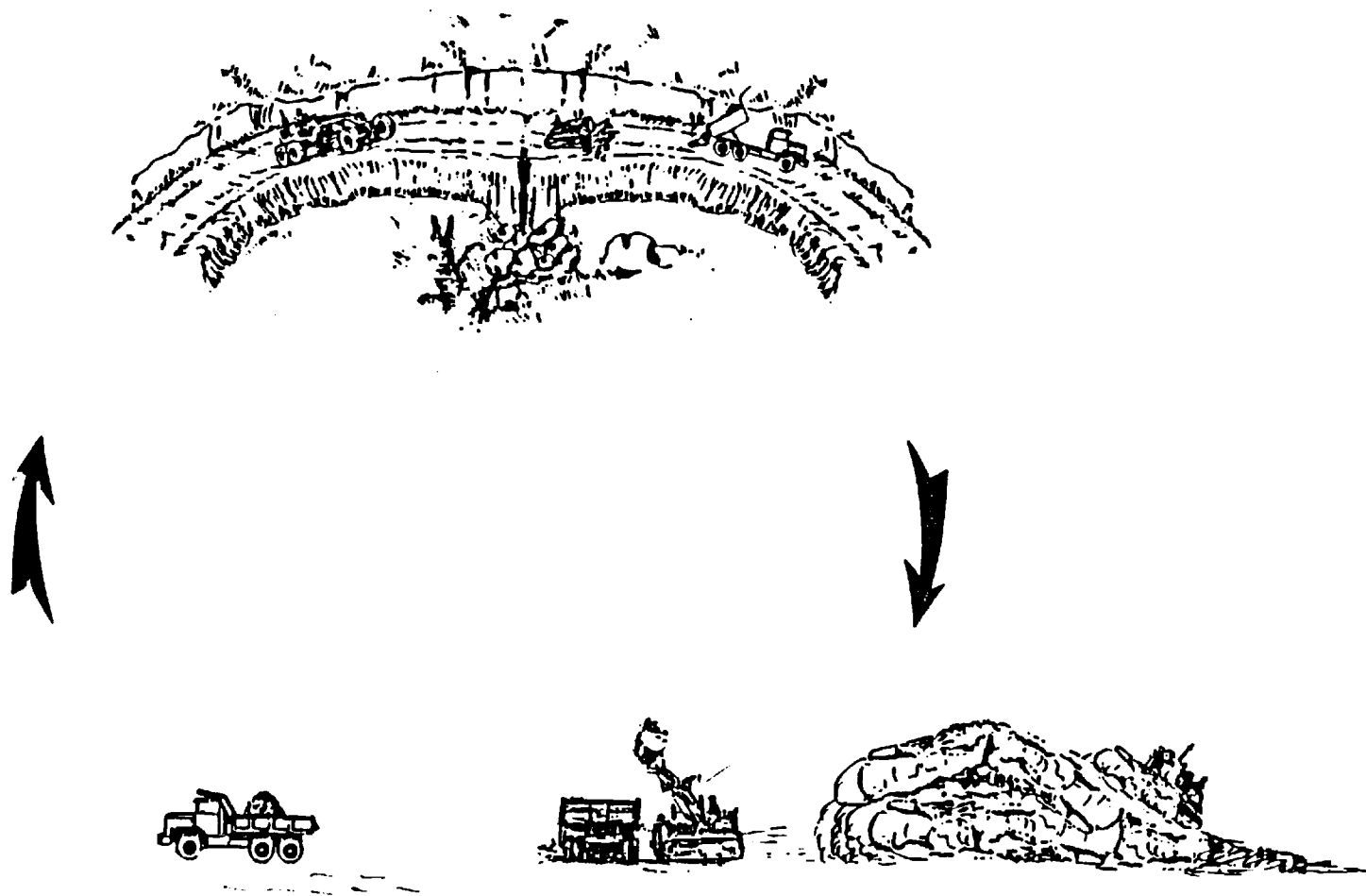


Figure 10. Graphical Representation of Standard Excavation CYCLONE Model #1

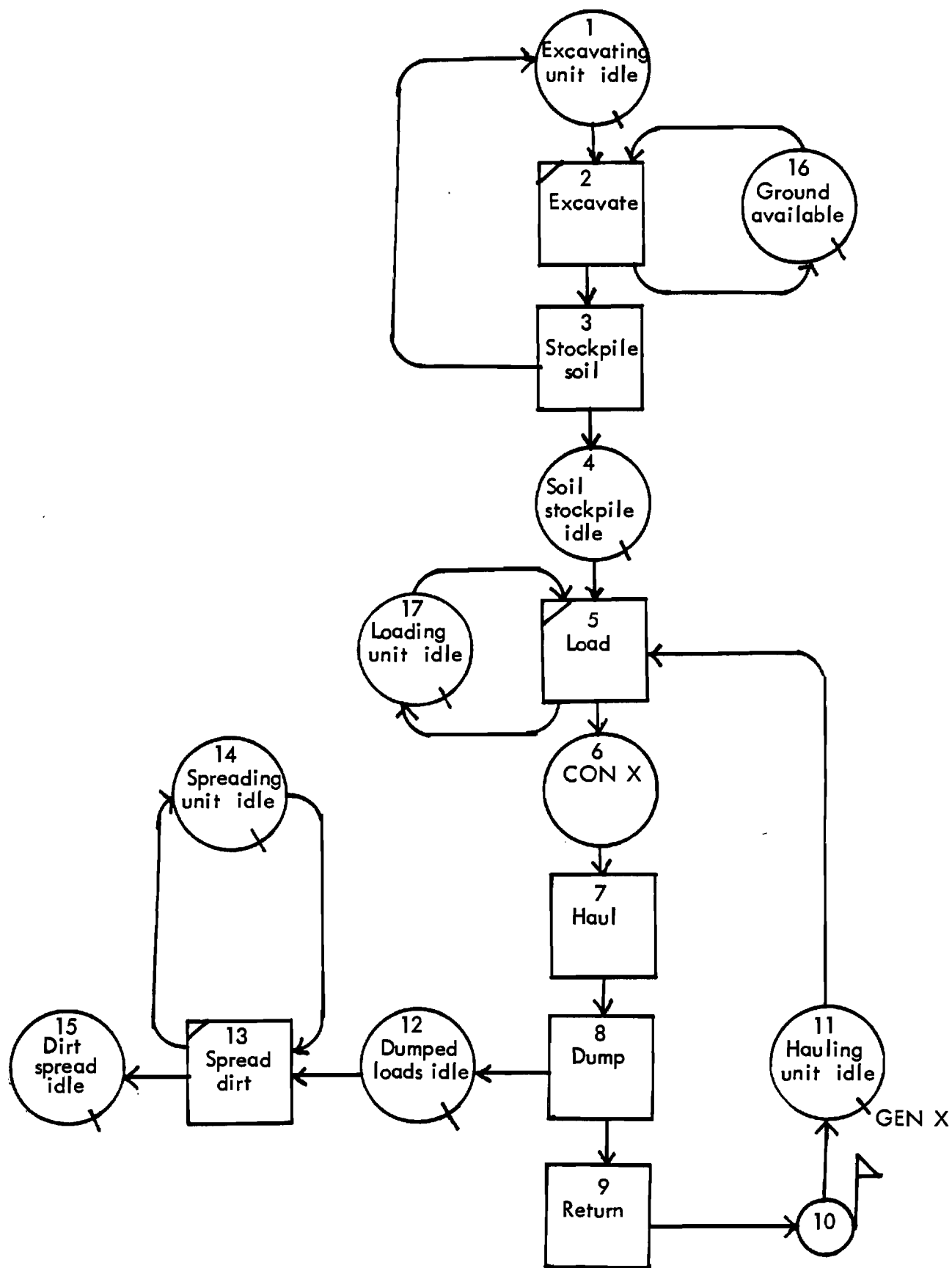


Figure 11. Standard Excavation CYCLONE Model #1

Table 6. Typical CYCLONE Problem Oriented Language
Specification for Standard Excavation
CYCLONE Model #1

CONTROL INPUT

NAME EXCAVATION CYCLES 200 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'EXCAVATING UNIT IDLE'
ACT 2 COMBI 'EXCAVATE' PRE 1 16 FOL 3 16 SET 2
ACT 3 NOR 'STOCKPILE SOIL' FOL 1 4 SET 3
ACT 4 QUE 'SOIL STOCKPILE IDLE'
ACT 5 COMBI 'LOAD' PRE 4 11 17 FOL 6 17 SET 5
ACT 6 FUN FOL 7 CON 10
ACT 7 NOR 'HAUL' FOL 8 SET 7
ACT 8 NOR 'DUMP' FOL 9 12 SET 8
ACT 9 NOR 'RETURN' FOL 10 SET 9
ACT 10 FUN 'COUNT' FOL 11 QUANTITY 20
ACT 11 QUE 'HAULING UNIT IDLE' GEN 10
ACT 12 QUE 'DUMPED LOADS IDLE'
ACT 13 COMBI 'SPREAD DIRT' PRE 12 14 FOL 14 15 SET 13
ACT 14 QUE 'SPREADING UNIT IDLE'
ACT 15 SINK 'DIRT SPREAD'
ACT 16 QUE 'GROUND AVAILABLE'
ACT 17 QUE 'LOADING UNIT IDLE'

EQUIPMENT INPUT

1 AT 1 FI 0 VA 50
1 AT 11 FI 0 VA 50
10 AT 16
1 AT 14 FI 0 VA 50
1 AT 17 FI 0 VA 50

DURATION INPUT

SET 2 2
SET 3 1
SET 5 2
SET 7 5
SET 8 1
SET 9 4
SET 13 2
END DATA

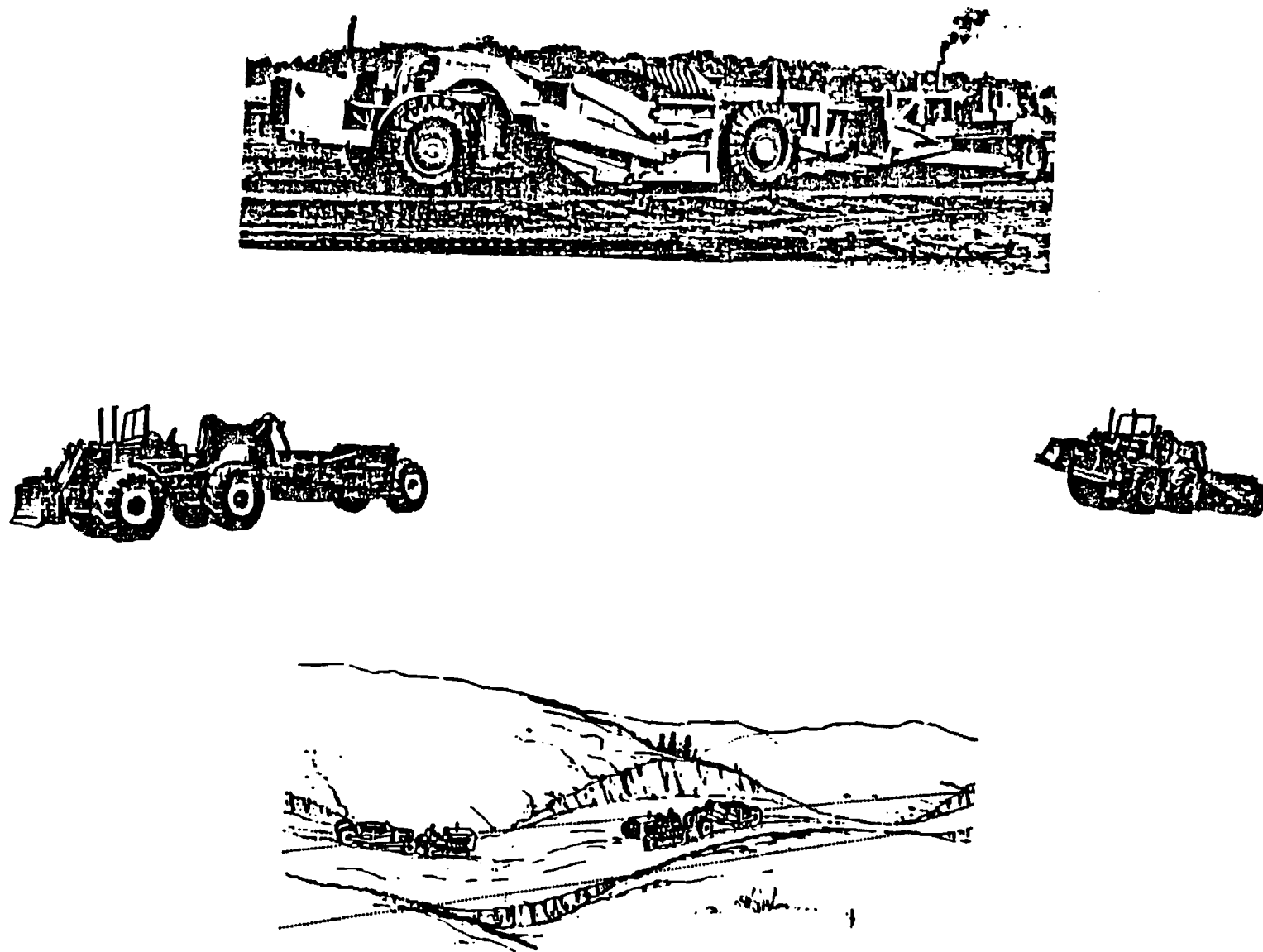


Figure 12. Graphical Representation of Standard Excavation CYCLONE Model #2

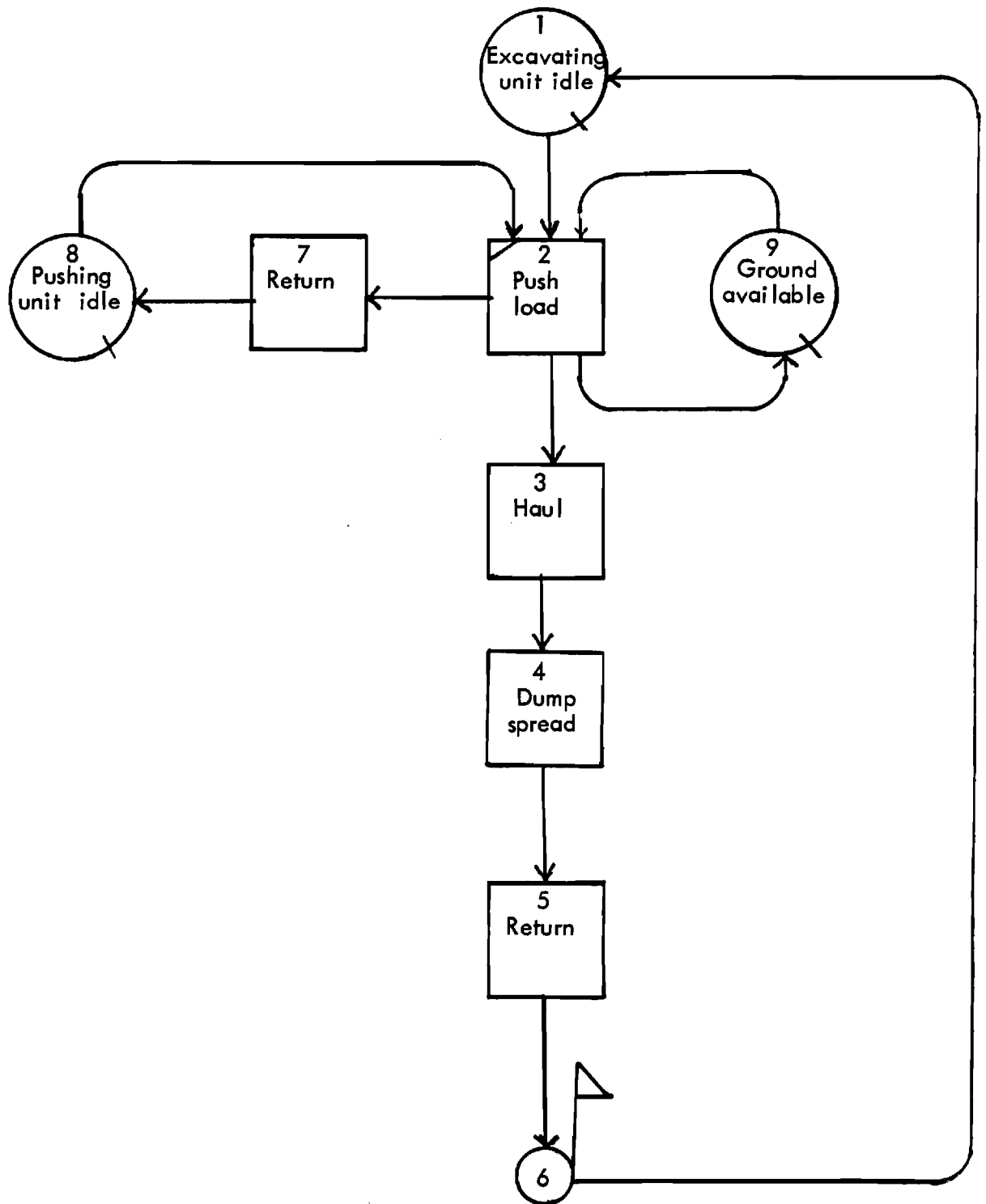


Figure 13. Standard Excavation CYCLONE Model #2

Table 7. Typical CYCLONE Problem Oriented Language
Specification for Standard Excavation
CYCLONE Model #2

CONTROL INPUT

NAME EXCAVATION CYCLES 400 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'EXCAVATING/LOADING UNIT IDLE'

ACT 2 COMBI 'PUSH/LOAD' PRE 1 8 9 FOL 3 7 9 SET 2

ACT 3 NOR 'HAUL' FOL 4 SET 3

ACT 4 NOR 'DUMP/SPREAD' FOL 5 SET 4

ACT 5 NOR 'RETURN' FOL 6 SET 5

ACT 6 FUN 'COUNT' FOL 1 QUANTITY 10

ACT 7 NOR 'RETURN' FOL 8 SET 7

ACT 8 QUE 'PUSHING UNIT IDLE'

ACT 9 QUE 'GROUND AVAILABLE'

EQUIPMENT INPUT

1 AT 1 FI 0 VA 50

1 AT 8 FI 0 VA 50

10 AT 9

DURATION INPUT

SET 2 2

SET 3 5

SET 4 2

SET 5 4

SET 7 1

END DATA

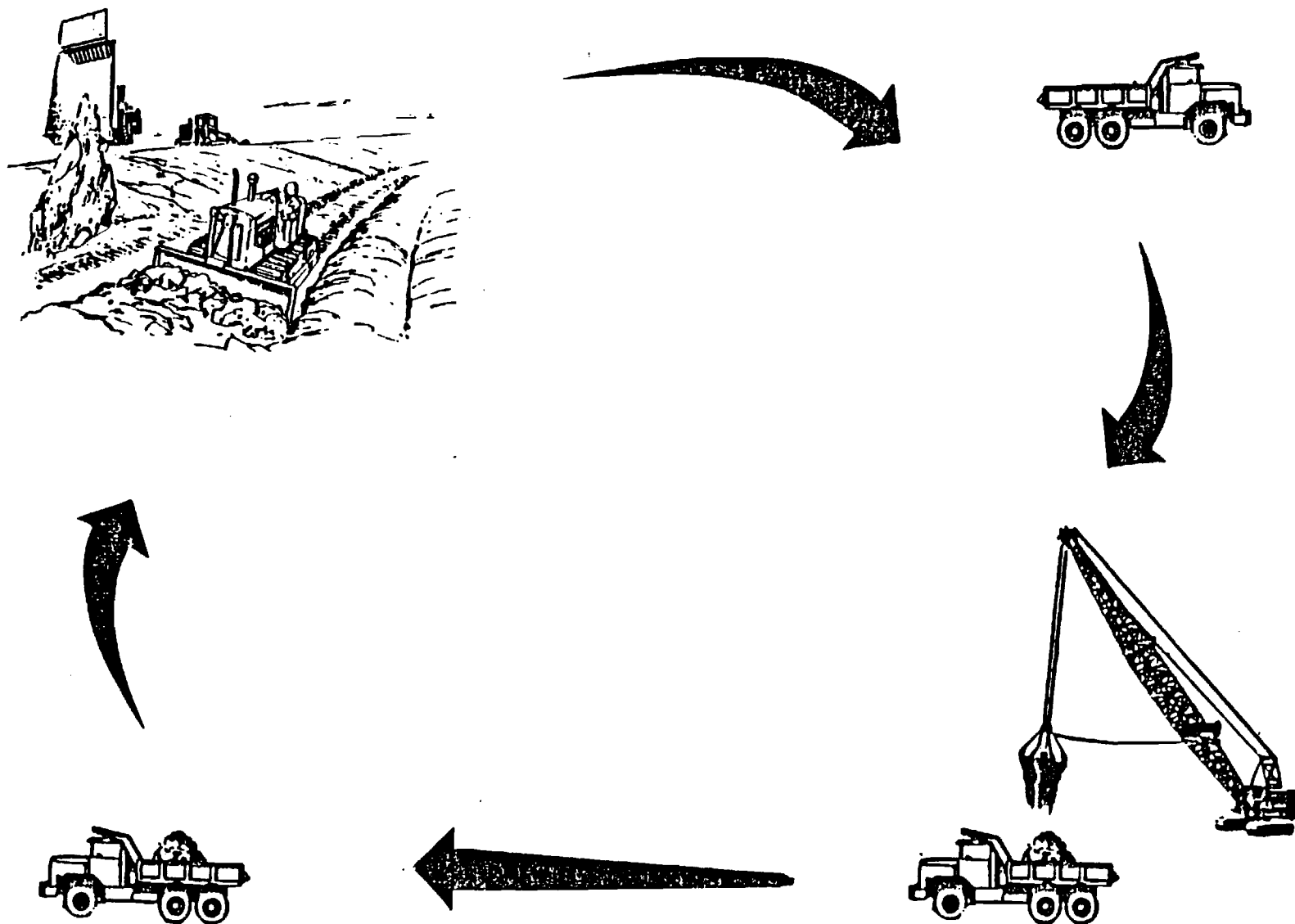


Figure 14. Graphical Representation of Standard Excavation CYCLONE Model #3

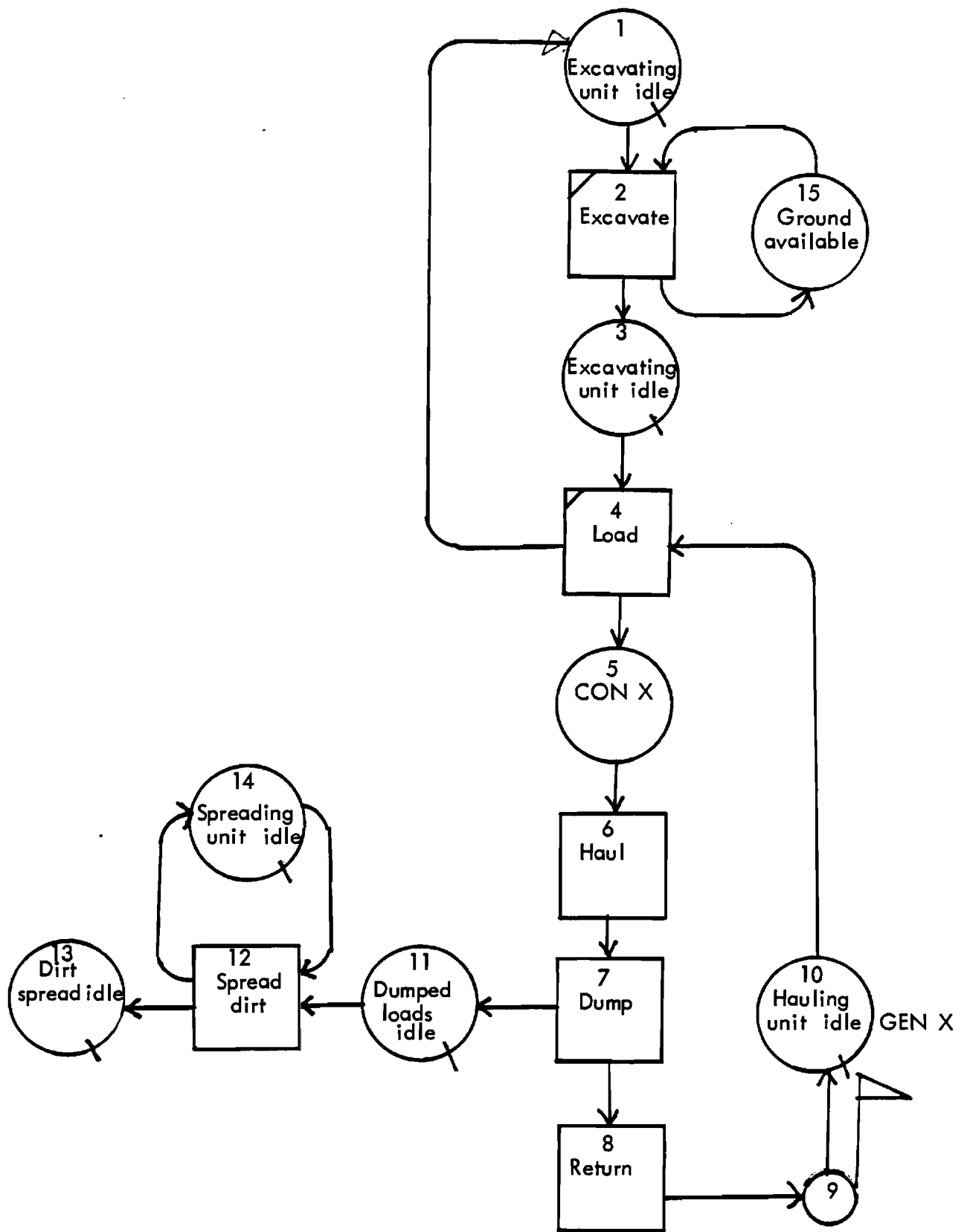


Figure 15. Standard Excavation CYCLONE Model #3

the standard excavation CYCLONE model #3. Table 8 illustrates the typical CYCLONE problem oriented language specification for the standard model.

Standard Ditching CYCLONE Model #1

The equipments used are ditching unit (e.g. ditcher), loading unit (e.g. front end loader), hauling unit (e.g. truck) and spreading unit (e.g. dozer). The work tasks are ditching, loading, hauling, dumping, returning and spreading. Figure 16 illustrates the standard ditching CYCLONE model #1. The typical CYCLONE problem oriented language specification for the standard model is shown in Table 9.

Standard Ditching CYCLONE Model #2

The equipments used are ditching/loading unit (e.g. ditcher), hauling unit (e.g. truck) and spreading unit (e.g. dozer). The work tasks are ditching, loading, hauling, dumping, returning and spreading. Figure 17 illustrates the standard ditching CYCLONE model #2. The typical CYCLONE problem oriented language specification for the standard model is shown in Table 10.

Standard Placing, Spreading, Compaction and Final Grading of Subgrade CYCLONE Model

The equipments used are loading unit (e.g. front end loader), hauling unit (e.g. truck), water spraying unit (e.g. water truck), spreading/compacting unit (e.g. dozer)

Table 8. Typical CYCLONE Problem Oriented Language
Specification for Standard Excavation
CYCLONE Model #3

```

CONTROL INPUT
NAME EXCAVATION CYCLES 200 LENGTH 1E+38
NETWORK INPUT
ACT 1 QUE 'EXCAVATING/LOADING UNIT IDLE'
ACT 2 COMBI 'EXCAVATE' PRE 1 15 FOL 3 15 SET 2
ACT 3 QUE 'EXCAVATING/LOADING UNIT IDLE'
ACT 4 COMBI 'LOAD' PRE 3 10 FOL 1 5 SET 4
ACT 5 FUN FOL 6 CON 4
ACT 6 NOR 'HAUL' FOL 7 SET 6
ACT 7 NOR 'DUMP' FOL 8 11 SET 7
ACT 8 NOR 'RETURN' FOL 9 SET 8
ACT 9 FUN 'COUNT' FOL 10 QUANTITY 20
ACT 10 QUE 'HAULING UNIT IDLE' GEN 4
ACT 11 QUE 'DUMPED LOADS IDLE'
ACT 12 COMBI 'SPREAD DIRT' PRE 11 14 FOL 13 14 SET 12
ACT 13 SINK 'DIRT SPREAD IDLE'
ACT 14 QUE 'SPREADING UNIT IDLE'
ACT 15 QUE 'GROUND AVAILABLE'
EQUIPMENT INPUT
1 AT 1 FI 0 VA 50
1 AT 10 FI 0 VA 50
1 AT 14 FI 0 VA 50
10 AT 15
DURATION INPUT
SET 2 2
SET 4 1
SET 6 5
SET 7 1
SET 8 4
SET 12 2
END DATA

```

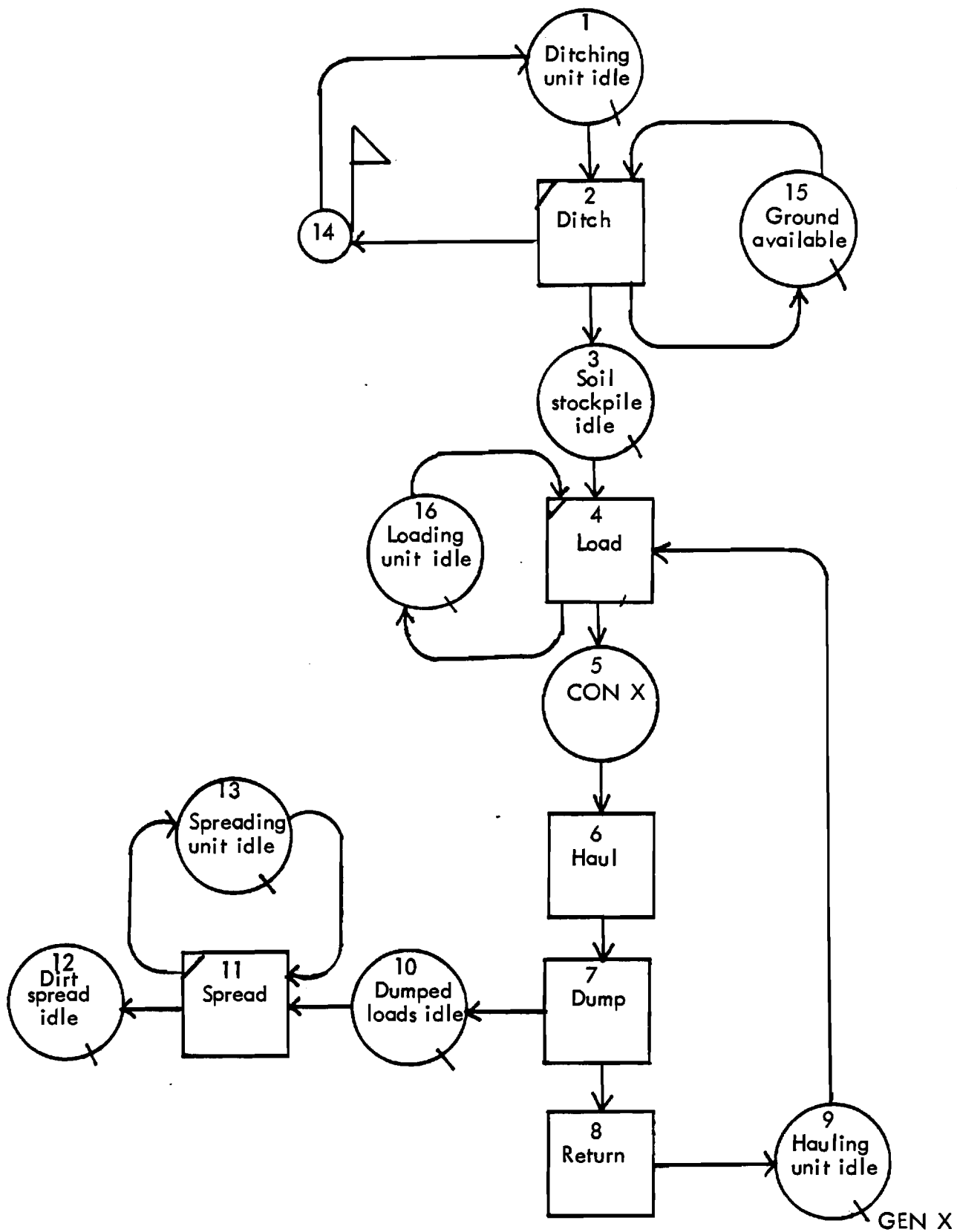



Figure 16. Standard Ditching CYCLONE Model #1

Table 9. Typical CYCLONE Problem Oriented Language
Specification for Standard Ditching CYCLONE
Model #1

CONTROL INPUT

NAME DITCHING CYCLES 1000 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'DITCHING UNIT IDLE'

ACT 2 COMBI 'DITCH' PRE 1 15 FOL 3 14 15 SET 2

ACT 3 QUE 'STOCKPILE'

ACT 4 COMBI 'LOAD' PRE 3 9 16 FOL 5 16 SET 4

ACT 5 FUN FOL 6 CON 20

ACT 6 NOR 'HAUL' FOL 7 SET 6

ACT 7 NOR 'DUMP' FOL 8 10 SET 7

ACT 8 NOR 'RETURN' FOL 9 SET 8

ACT 9 QUE 'HAULING UNIT IDLE' GEN 20

ACT 10 QUE 'DUMPED LOADS IDLE'

ACT 11 COMBI 'SPREAD' PRE 10 13 FOL 12 13 SET 11

ACT 12 SINK 'DIRT SPREAD IDLE'

ACT 13 QUE 'SPREADING UNIT IDLE'

ACT 14 FUN 'COUNT' FOL 1 QUANTITY 1

ACT 15 QUE 'GROUND AVAILABLE'

ACT 16 'LOADING UNIT IDLE'

EQUIPMENT INPUT

1 AT 1 FI 0 VA 50

1 AT 9 FI 0 VA 50

1 AT 13 FI 0 VA 50

10 AT 15

1 AT 16 FI 0 VA 50

DURATION INPUT

SET 2 2

SET 4 1

SET 6 5

SET 7 1

SET 8 4

SET 11 2

END DATA

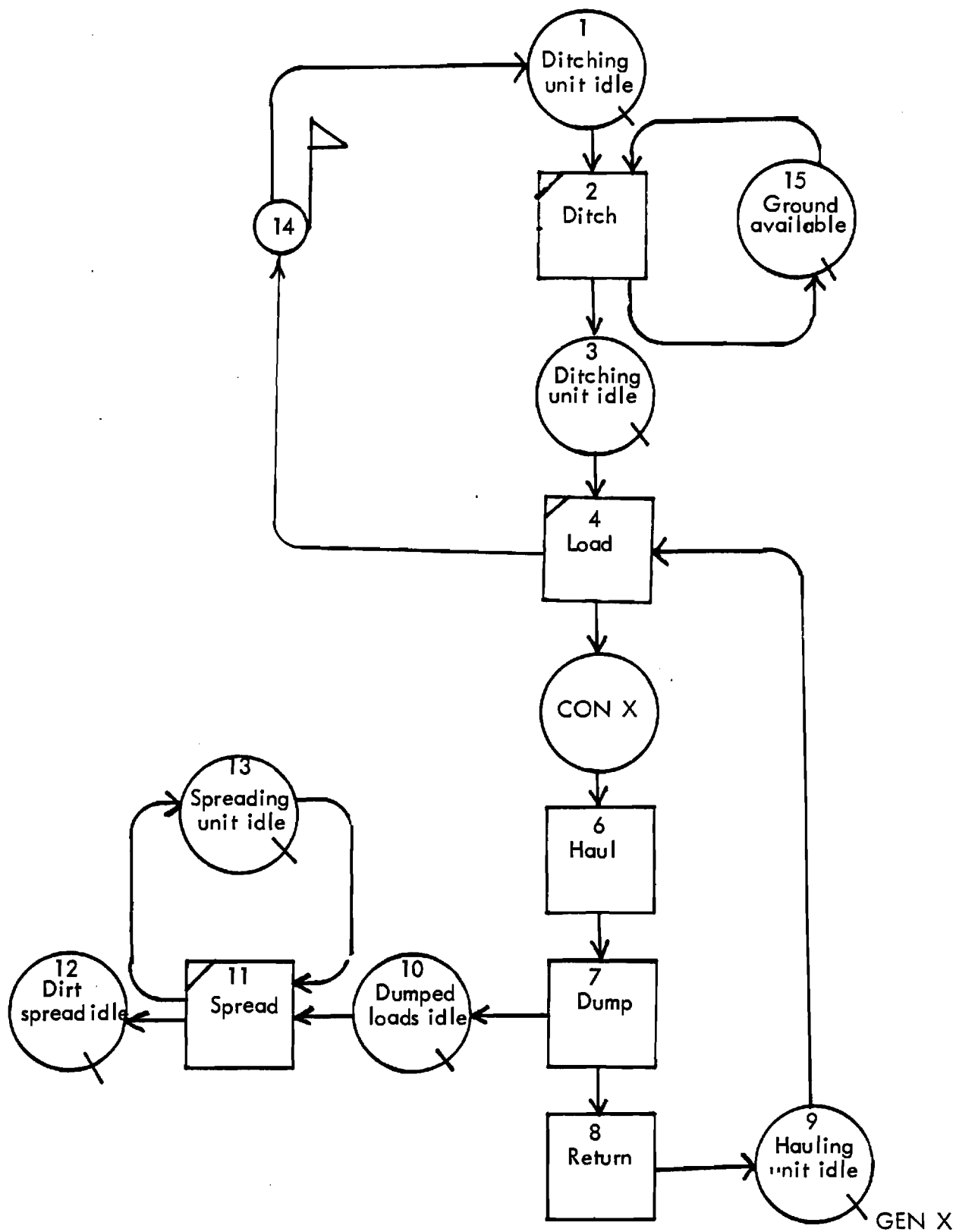


Figure 17. Standard Ditching CYCLONE Model #2

Table 10. Typical CYCLONE Problem Oriented Language
Specification for Standard Ditching CYCLONE
Model #2

CONTROL INPUT

NAME DITCHING CYCLES 1000 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'DITCHING/LOADING UNIT IDLE'

ACT 2 COMBI 'DITCH' PRE 1 15 FOL 3 15 SET 2

ACT 3 QUE 'DITCHING/LOADING UNIT IDLE'

ACT 4 COMBI 'LOAD' PRE 3 9 FOL 5 14 SET 4

ACT 5 FUN FOL 6 CON 20

ACT 6 NOR 'HAUL' FOL 7 SET 6

ACT 7 NOR 'DUMP' FOL 8 SET 7

ACT 8 NOR 'RETURN' FOL 9 10 SET 8

ACT 9 QUE 'HAULING UNIT IDLE' GEN 20

ACT 10 QUE 'DUMPED LOADS IDLE'

ACT 11 COMBI 'SPREAD' PRE 10 13 FOL 12 13 SET 11

ACT 12 SINK 'DIRT SPREAD IDLE'

ACT 13 QUE 'SPREADING UNIT IDLE'

ACT 14 FUN 'COUNT' FOL 1 QUANTITY 1

ACT 15 QUE 'GROUND AVAILABLE'

EQUIPMENT INPUT

1 AT 1 FI 0 VA 50

1 AT 9 FI 0 VA 50

1 AT 13 FI 0 VA 50

10 AT 15

DURATION INPUT

SET 2 2

SET 4 1

SET 6 5

SET 7 1

SET 8 4

SET 11 2

END DATA

and grading unit (e.g. motor grader). The work tasks are loading, hauling, dumping, returning, water spraying, spreading/compacting and final grading. Figure 18 shows the standard CYCLONE model and Table 11 illustrates the typical CYCLONE problem oriented language specification for the standard model.

Standard Placing, Spreading, Compaction and Grading
of Nonstabilized Base or Subbase CYCLONE Model

The equipments used are spreading unit (e.g. dozer), water spraying unit (e.g. water truck) and compacting unit (e.g. dozer). The work tasks are spreading, spraying water and compaction. The standard CYCLONE model is shown in Figure 19 and Table 12 illustrates the typical CYCLONE problem oriented language specification for the standard model.

Standard Placing, Spreading, Compaction and Grading
of Stabilized Base or Subbase CYCLONE Model #1

The equipments used are scarifying unit (e.g. scarifier), stabilizer application unit (e.g. mechanical spreader), water spraying unit (e.g. water truck), pulverizing/mixing unit (e.g. mixer) and compacting unit (e.g. roller). The work tasks are soil preparation, stabilizer application, spraying water, pulverizing/mixing and compaction. The standard CYCLONE model (mixed in place) is illustrated in Figure 20 and Table 13 shows the typical

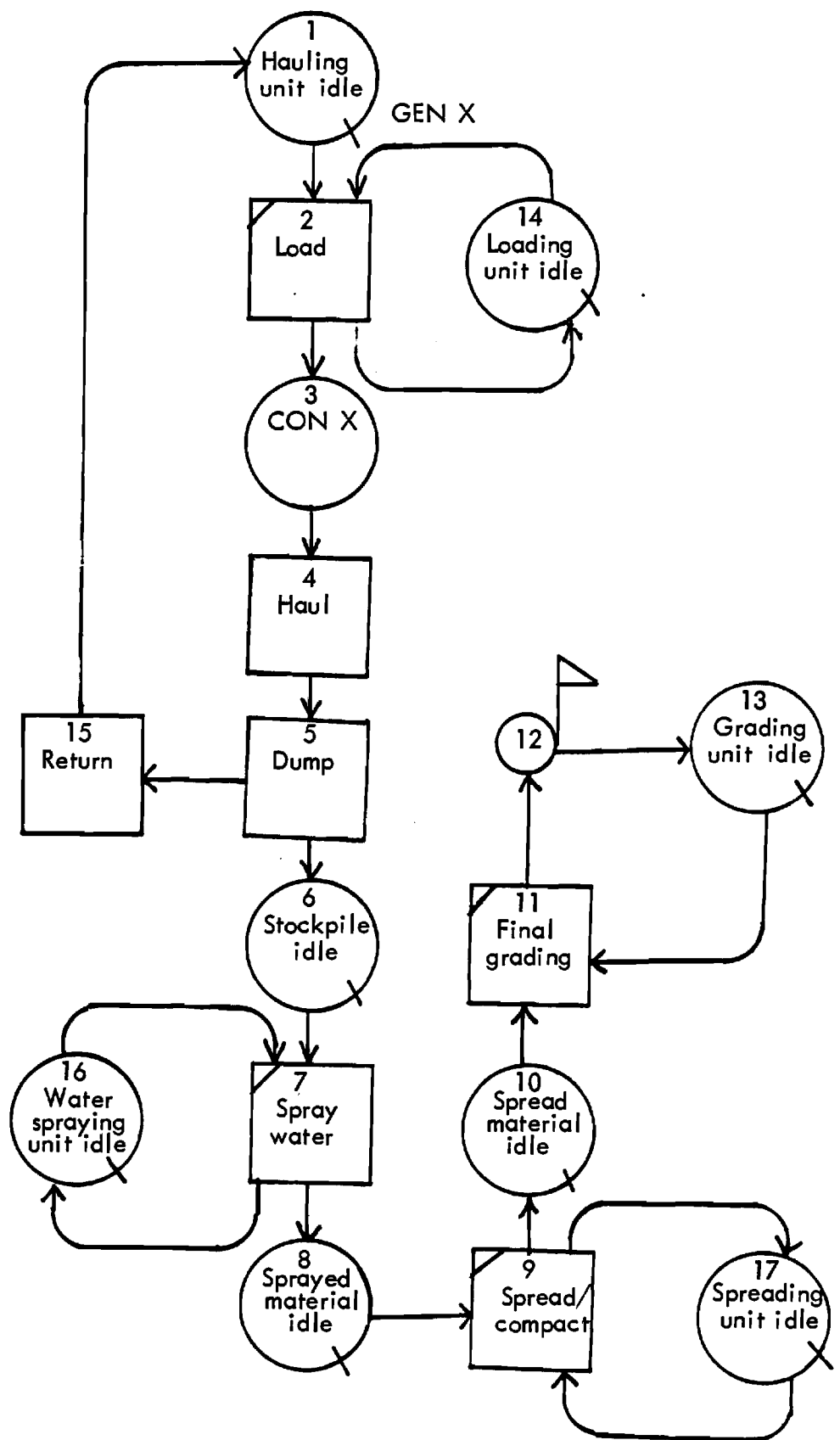


Figure 18. Standard Placing, Spreading Compaction and Final Grading of Subgrade CYCLONE Model

Table 11. Typical CYCLONE Problem Oriented Language
Specification for Standard Placing, Spreading
, Compaction and Final Grading of Subgrade
CYCLONE Model

CONTROL INPUT

NAME SUBGRADE CYCLES 50 LENGTH 1E+38

NETWORK INPUT

ACT 1 QUE 'HAULING UNIT IDLE' GEN 4
ACT 2 COMBI 'LOAD' PRE 1 14 FOL 3 14 SET 2
ACT 3 FUN FOL 4 CON 4
ACT 4 NORMAL 'HAUL' FOL 5 SET 4
ACT 5 NOR 'DUMP' FOL 6 15 SET 5
ACT 6 QUE 'DUMPED LOADS IDLE'
ACT 7 COMBI 'WATER SPRAY' PRE 6 16 FOL 8 16 SET 7
ACT 8 QUE 'SPRAYED LOADS IDLE'
ACT 9 COMBI 'SPREAD/COMPACT' PRE 8 17 FOL 10 17 SET 9
ACT 10 QUE 'COMPACTED SUBGRADE IDLE'
ACT 11 COMBI 'FINAL GRADING' PRE 10 13 FOL 12 13 SET 11
ACT 12 FUN 'COUNT' FOL 13 QUANTITY 20
ACT 13 'FINAL GRADING UNIT IDLE'
ACT 14 QUE 'LOADING UNIT IDLE'
ACT 15 NOR 'RETURN' FOL 1 SET 15
ACT 16 QUE 'WATER SPRAYING UNIT IDLE'
ACT 17 QUE 'SPREADING/COMPACTING UNIT IDLE'

EQUIPMENT INPUT

1 AT 1 FI 0 VA 50
1 AT 13 FI 0 VA 50
1 AT 14 FI 0 VA 50
1 AT 16 FI 0 VA 50
1 AT 17 FI 0 VA 50

DURATION INPUT

SET 2 2
SET 4 5
SET 5 1
SET 7 2
SET 9 5
SET 11 5
SET 15 4
END DATA

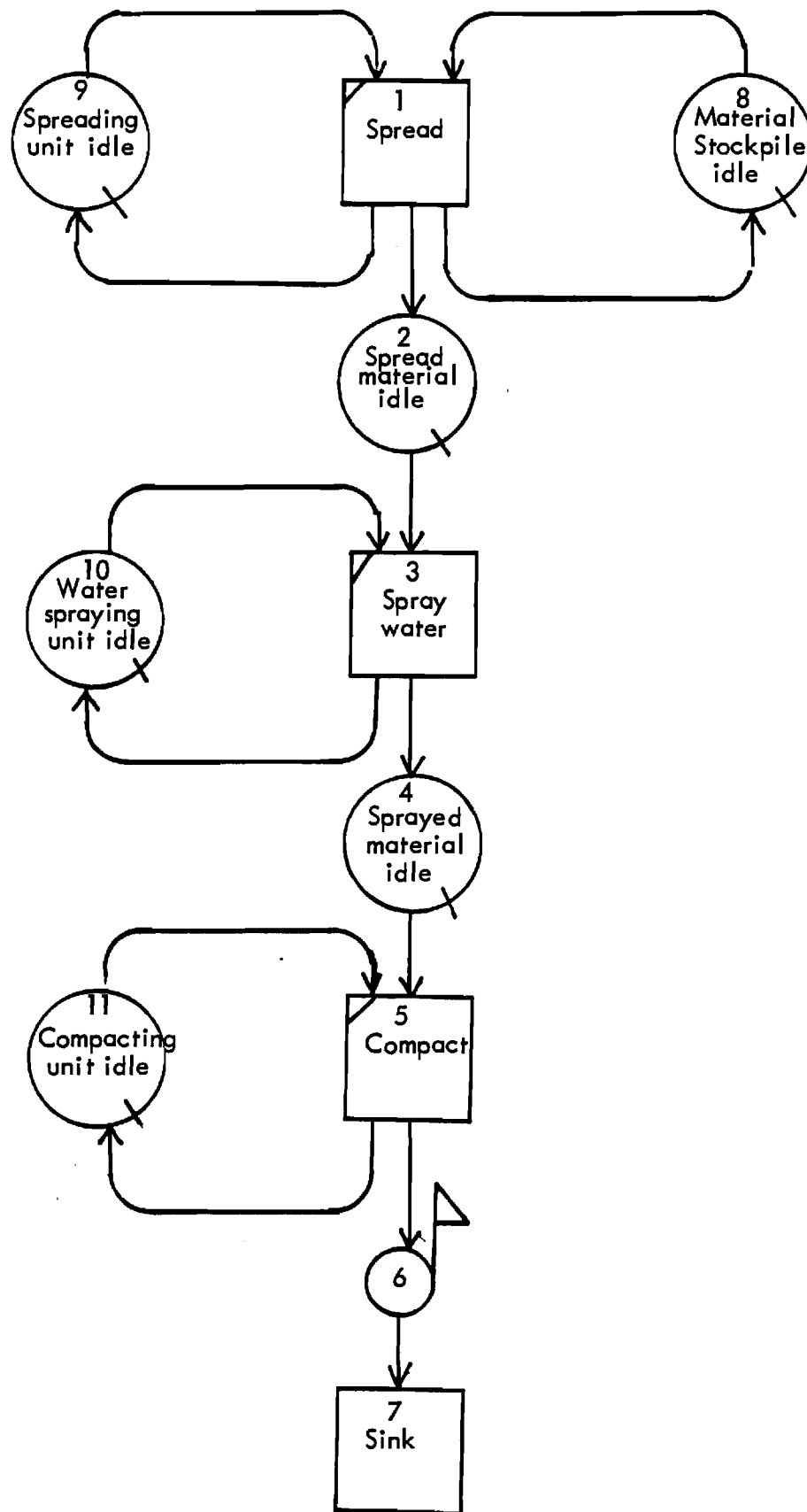


Figure 19. Standard Placing, Spreading, Compaction and Grading of Nonstabilized Base or Subbase CYCLONE Model

Table 12. Typical CYCLONE Problem Oriented Language
Specification for Standard Placing, Spreading
, Compaction and Grading of Nonstabilized
Base or Subbase CYCLONE Model

CONTROL INPUT

NAME SUBBASE CYCLES 25 LENGTH 1E+38

NETWORK INPUT

ACT 1 COMBI 'SPREAD' PRE 8 9 FOL 2 8 9 SET 1

ACT 2 QUE 'SPREAD LOADS IDLE'

ACT 3 COMBI 'WATER SPRAY' PRE 2 10 FOL 4 10 SET 3

ACT 4 QUE 'COMPACTED LOADS IDLE'

ACT 5 COMBI 'COMPACT' PRE 4 11 FOL 6 11 SET 5

ACT 6 FUN 'COUNT' FOL 7 QUANTITY 40

ACT 7 SINK 'SINK'

ACT 8 QUE 'STOCKPILE READY'

ACT 9 QUE 'SPREADING UNIT IDLE'

ACT 10 QUE 'WATER SPRAYING UNIT IDLE'

ACT 11 QUE 'COMPACTING UNIT IDLE'

EQUIPMENT INPUT

10 AT 8

1 AT 9 FI 0 VA 50

1 AT 10 FI 0 VA 50

1 AT 11 FI 0 VA 50

DURATION INPUT

SET 1 10

SET 3 5

SET 5 20

END DATA

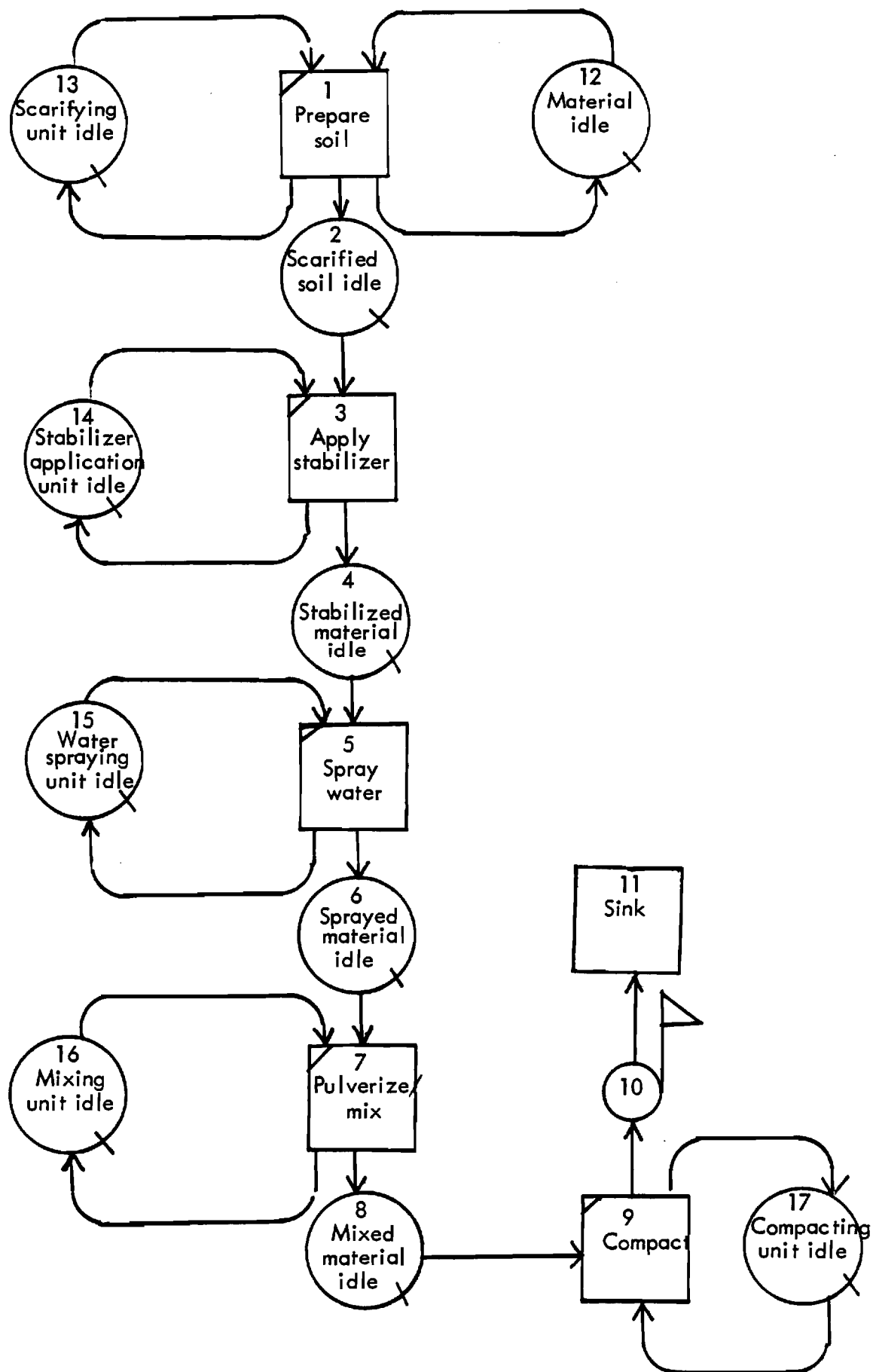


Figure 20. Standard Placing, Spreading, Compaction and Grading of Stabilized Base or Subbase
CYCLONE Model #1

Table 13. Typical CYCLONE Problem Oriented Language
Specification for Standard Placing, Spreading
, Compaction and Grading of Stabilized Base
or Subbase CYCLONE Model #1

CONTROL INPUT

NAME BASE CYCLES 10 LENGTH 1E+38

NETWORK INPUT

ACT 1 COMBI 'PREPARE SOIL' PRE 12 13 FOL 2 13 SET 1
ACT 2 QUE 'SCARIFIED SOIL IDLE'
ACT 3 COMBI 'APPLY STABILIZER' PRE 2 14 FOL 4 14 SET 3
ACT 4 QUE 'STABILIZED MATERIAL IDLE'
ACT 5 COMBI 'SPRAY WATER' PRE 4 15 FOL 6 15 SET 5
ACT 6 QUE 'SPRAYED MATERIAL IDLE'
ACT 7 COMBI 'PULVERIZE/MIX' PRE 6 16 FOL 8 16 SET 7
ACT 8 QUE 'MIXED MATERIAL IDLE'
ACT 9 COMBI 'COMPACT' PRE 8 17 FOL 10 17 SET 9
ACT 10 FUN 'COUNT' FOL 11 QUANTITY 100
ACT 11 SINK 'SINK'
ACT 12 QUE 'MATERIAL IDLE'
ACT 13 QUE 'SCARIFYING UNIT IDLE'
ACT 14 QUE 'STABILIZER APPLICATION UNIT IDLE'
ACT 15 QUE 'WATER SPRAYING UNIT IDLE'
ACT 16 QUE 'PULVERIZING/MIXING UNIT IDLE'
ACT 17 QUE 'COMPACTING UNIT IDLE'

EQUIPMENT INPUT

10 AT 12

1 AT 13 FI 0 VA 50

1 AT 14 FI 0 VA 50

1 AT 15 FI 0 VA 50

1 AT 16 FI 0 VA 50

1 AT 17 FI 0 VA 50

DURATION INPUT

SET 1 10

SET 3 5

SET 5 5

SET 7 5

SET 9 20

END DATA

CYCLONE problem oriented language specification for the standard model.

Standard Placing, Spreading, Compaction and Grading
of Stabilized Base or Subbase CYCLONE Model #2

The equipments used are hauling unit (e.g. truck), spreading unit (e.g. dozer), water spraying unit (e.g. water truck) and compacting unit (e.g. roller). The work tasks are stabilizer batch preparation, loading, hauling, dumping, spreading, spraying water and compaction. The standard CYCLONE model (central plant) is illustrated in Figure 21 and Table 14 shows the typical CYCLONE problem oriented language specification for the standard model.

Standard Asphalt Paving CYCLONE Model

The equipments used are hauling unit (e.g. truck), paving unit (e.g. paver) and compacting unit (e.g. roller). The work tasks are asphalt batch preparation, loading, hauling, dumping, returning, placing and compacting. Figure 22 illustrates the standard asphalt paving CYCLONE model and Table 15 shows the typical CYCLONE problem oriented language specification for the standard model.

Standard Concrete Paving CYCLONE Model

The equipments used are hauling unit (e.g. truck), paving unit (e.g. paver) and finishing unit (e.g. finisher). The work tasks are concrete batch preparation, loading, dumping, returning, placing and finishing. Figure 23



Table 14. Typical CYCLONE Problem Oriented Language
Specification for Standard Placing, Spreading
, Compaction and Grading of Stabilized Base
or Subbase CYCLONE Model #2

```

CONTROL INPUT
NAME BASE CYCLES 50 LENGTH 1E+38
NETWORK INPUT
ACT 1 COMBI 'PREPARE STABILIZER BATCH' PRE 14 15 FOL 2
14 SET 1
ACT 2 QUE 'STABILIZER BATCH IDLE'
ACT 3 COMBI 'LOAD' PRE 2 16 FOL 4 15 SET 3
ACT 4 NOR 'HAUL' FOL 5 SET 4
ACT 5 NOR 'DUMP' FOL 6 17 SET 5
ACT 6 QUE 'DUMPED LOADS IDLE'
ACT 7 COMBI 'SPREAD' PRE 6 18 FOL 8 18 SET 7
ACT 8 QUE 'SPREADING UNIT IDLE'
ACT 9 COMBI 'SPRAY WATER' PRE 8 19 FOL 10 19 SET 9
ACT 10 QUE 'SPRAYED MATERIAL IDLE'
ACT 11 COMBI 'COMPACT' PRE 10 20 FOL 12 20 SET 11
ACT 12 FUN 'COUNT' FOL 13 QUANTITY 20
ACT 13 SINK 'SINK'
ACT 14 QUE 'MATERIAL IDLE'
ACT 15 QUE 'CENTRAL PLANT IDLE'
ACT 16 QUE 'HAULING UNIT IDLE'
ACT 17 NOR 'RETURN' FOL 16 SET 17
ACT 18 QUE 'SPREADING UNIT IDLE'
ACT 19 QUE 'WATER SPRAYING UNIT IDLE'
ACT 20 QUE 'COMPACTING UNIT IDLE'
EQUIPMENT INPUT
1 AT 14
1 AT 15
1 AT 16 FI 0 VA 50
1 AT 18 FI 0 VA 50
1 AT 19 FI 0 VA 50
1 AT 20 FI 0 VA 50
DURATION INPUT
SET 1 20
SET 3 2
SET 4 5
SET 5 1
SET 7 5
SET 9 2
SET 11 15
SET 17 4
END DATA

```

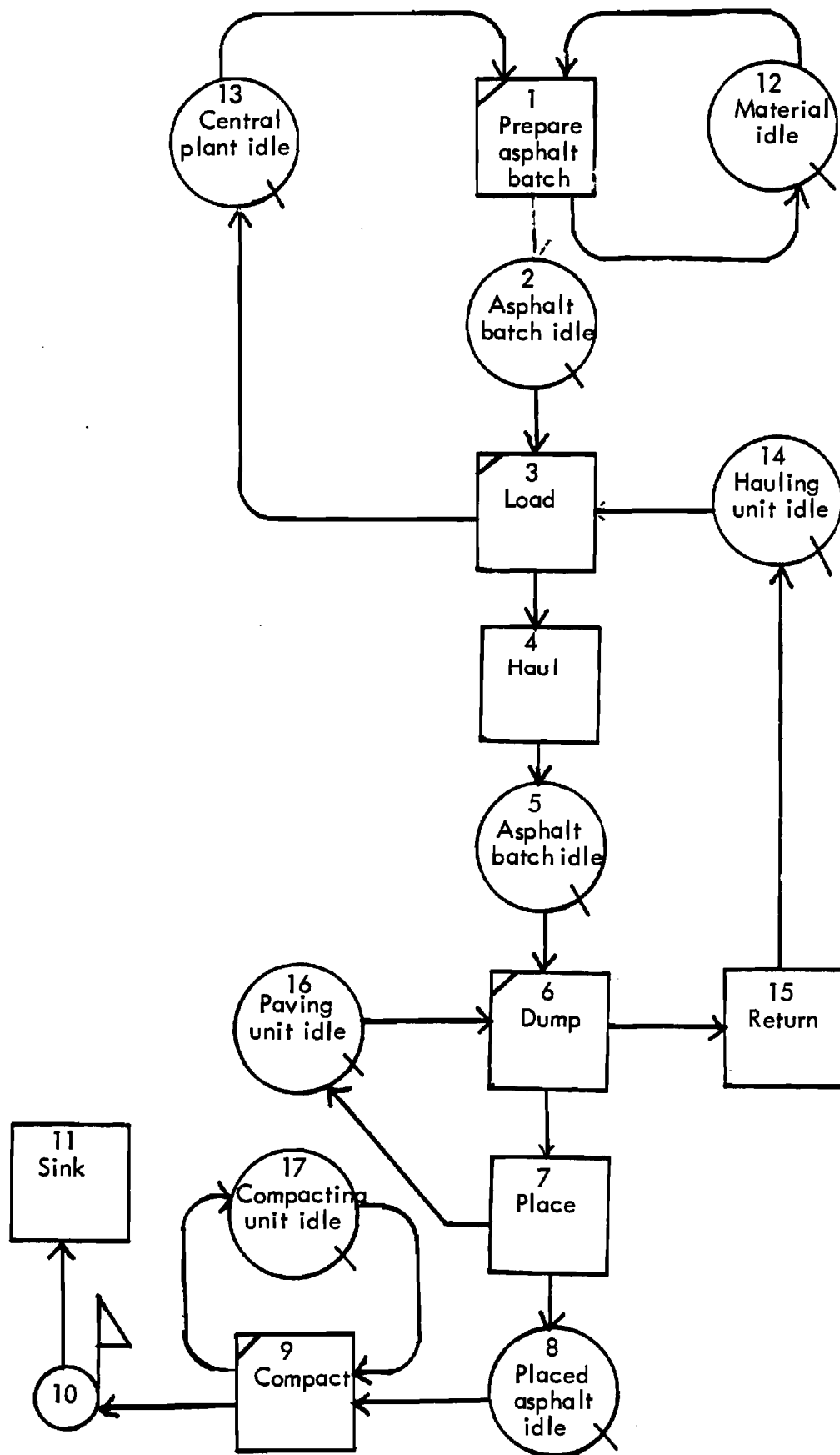


Figure 22. Standard Asphalt Paving CYCLONE Model

Table 15. Typical CYCLONE Problem Oriented Language
Specification for Standard Asphalt Paving
CYCLONE Model

CONTROL INPUT

NAME ASPHALT CYCLES 50 LENGTH 1E+38

NETWORK INPUT

ACT 1 COMBI 'PREPARE ASPHALT BATCH' PRE 12 13 FOL 2 12
SET 1
ACT 2 QUE 'ASPHALT BATCH IDLE'
ACT 3 COMBI 'LOAD' PRE 2 14 FOL 4 13 SET 3
ACT 4 NOR 'HAUL' FOL 5 SET 4
ACT 5 QUE 'ASPHALT BATCH IDLE'
ACT 6 COMBI 'DUMP' PRE 5 16 FOL 7 15 SET 6
ACT 7 NOR 'PLACE' FOL 8 16 SET 7
ACT 8 QUE 'PLACED ASPHALT IDLE'
ACT 9 COMBI 'COMPACT' PRE 8 17 FOL 10 17 SET 9
ACT 10 FUN 'COUNT' FOL 11 QUANTITY 20
ACT 11 SINK 'SINK'
ACT 12 QUE 'MATERIAL IDLE'
ACT 13 QUE 'CENTRAL PLANT IDLE'
ACT 14 QUE 'HAULING UNIT IDLE'
ACT 15 NOR 'RETURN' FOL 14 SET 15
ACT 16 QUE 'PAVING UNIT IDLE'
ACT 17 QUE 'COMPACTING UNIT IDLE'

EQUIPMENT INPUT

1 AT 12
1 AT 13
1 AT 14 FI 0 VA 50
1 AT 16 FI 0 VA 50
1 AT 17 FI 0 VA 50

DURATION INPUT

SET 1 10
SET 3 2
SET 4 15
SET 6 5
SET 7 10
SET 9 20
SET 15 4
END DATA

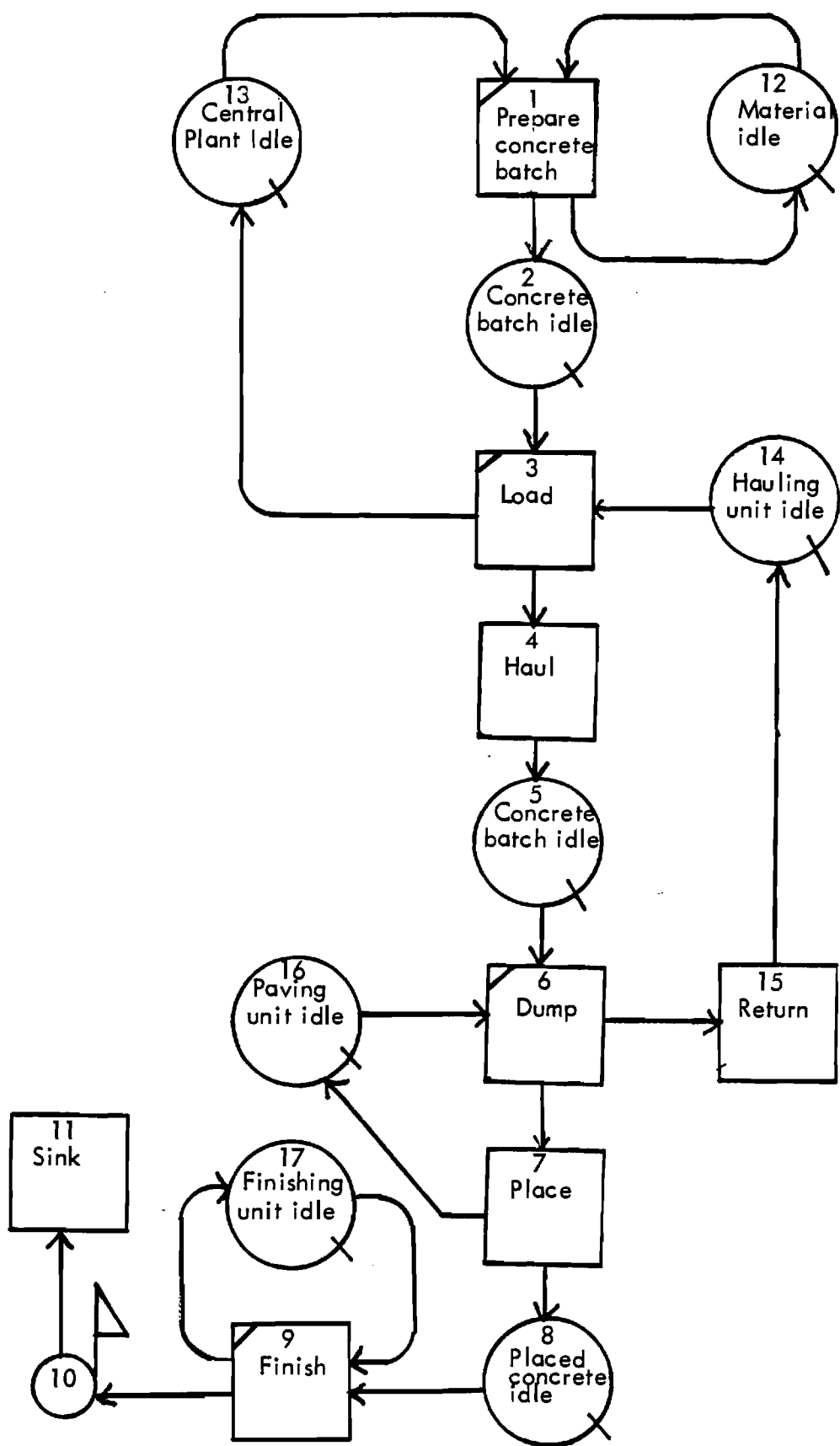


Figure 23. Standard Concrete Paving CYCLONE Model

illustrates the standard concrete paving CYCLONE model and Table 16 shows the typical CYCLONE problem oriented language specification for the standard model.

Table 16. Typical CYCLONE Problem Oriented Language
Specification for Standard Concrete Paving
CYCLONE Model

```

CONTROL INPUT
NAME CONCRETE CYCLES 50 LENGTH 1E+38
NETWORK INPUT
ACT 1 COMBI 'PREPARE CONCRETE BATCH' PRE 12 13 FOL 2 12
SET 1
ACT 2 QUE 'CONCRETE BATCH IDLE'
ACT 3 COMBI 'LOAD' PRE 2 14 FOL 4 13 SET 3
ACT 4 NOR 'HAUL' FOL 5 SET 4
ACT 5 QUE 'CONCRETE BATCH IDLE'
ACT 6 COMBI 'DUMP' PRE 5 16 FOL 7 15 SET 6
ACT 7 NOR 'PLACE' FOL 8 16 SET 7
ACT 8 QUE 'PLACED CONCRETE IDLE'
ACT 9 COMBI 'FINISH' PRE 8 17 FOL 10 17 SET 9
ACT 10 FUN 'COUNT' FOL 11 QUANTITY 20
ACT 11 SINK 'SINK'
ACT 12 QUE 'MATERIAL IDLE'
ACT 13 QUE 'CENTRAL PLANT IDLE'
ACT 14 QUE 'HAULING UNIT IDLE'
ACT 15 NOR 'RETURN' FOL 14 SET 15
ACT 16 QUE 'PAVING UNIT IDLE'
ACT 17 QUE 'FINISHING UNIT IDLE'
EQUIPMENT INPUT
1 AT 12
1 AT 13
1 AT 14 FI 0 VA 50
1 AT 16 FI 0 VA 50
1 AT 17 FI 0 VA 50
DURATION INPUT
SET 1 10
SET 3 2
SET 4 5
SET 6 5
SET 7 10
SET 9 20
SET 15 4
END DATA

```

REFERENCES

1. Ashley, D. B., "Simulation of Repetitive Unit Construction," Journal of Construction Division, ASCE, vol. 106, No. CO2, June 1980, pp. 185-194.
2. Bandonado, O. C., "Interoceanic Canal Excavation Scheduling via Computer Simulation," Proceeding of the Symposium on Engineering with Nuclear Explosives, Vol. 2, January 1970, pp. 994-1013.
3. Benjamin, N. B. H. and Greenwald, T. W., "Simulating Effects of Weather on Construction," Journal of the Construction Division, ASCE, Vol. 99, No. CO1, July 1973, pp. 175-190.
4. Bjorⁿsson, H. C., "Learning Construction Management Through Computer Simulation," System Science, Vol. 2, No. 3, 1976, pp. 37-54.
5. Borcharding, J. D., "Cost Control Simulation and Decision Making," Journal of the Construction Division, ASCE, Vol. 103, No. 4, December 1977, pp. 577-591.
6. Bournazos, I. M. and Singh, G., "Material Handling Systems," Highway and Road Construction International, Vol. 44, No. 1802, October 1976, pp. 18-19, 22-23, 25.
7. Carr, R. I., "Simulation of Construction Project Duration," Journal of the Construction Division, ASCE, Vol. 105, No. CO2, June 1979, pp. 117-128.
8. Caterpillar Performance Handbook, 13th ed., Caterpillar Tractor Company, Peoria, Illinois, October 1982.
9. Clemmens, J. P., and Willenbrock, J. H., "The Scrapesim Computer Simulation," Journal of the Construction Division, ASCE, Vol. 104, No. CO4, December 1978, pp. 419-435.
10. Crandall, K. C., "Analysis of Schedule Simulations," Journal of the Construction Division, ASCE, Vol. 102, No. CO3, September 1976.
11. Dabbas, M. A. A., Computerized Decision Making in Construction, Ph.D. Dissertation, Civil Engineering Department, Georgia Institute of Technology, May 1981.

12. Dabbas, M. A. A., "Integrated Project and Process Management," Journal of the Construction Division, ASCE, Vol. 108, No. CO3, September 1982, pp. 361-374.
13. Feiler, A. M., "Project Management Through Simulation," UCLA-ENGR-76-119, UCLA School of Engineering and Applied Science, Los Angeles, California, December 1976, pp. 1-34.
14. Halpin, D. W., A Computerized Construction Management Gaming Environment, Technical Report No. SCEGIT-75-114, National Science Foundation Grant No. ENG 74-13131 A01, Georgia Tech, 1975.
15. Halpin, D. W., An Investigation of the Use of Simulation Networks for Modeling Construction Operations, Thesis presented to the University of Illinois at Urbana-Champaign in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1973.
16. Halpin, D. W., "Constructo--An Interactive Gaming Environment," Journal of the Construction Division, ASCE, Vol. 102, No. 1, March 1976, pp. 145-156.
17. Halpin, D. W., "CYCLONE--Method for Modeling Job Site Processes," Journal of the Construction Division, ASCE, Vol. 103, No. 3, September 1977, pp. 489-499.
18. Halpin, D. W. and Woodhead, R. W., Design of Construction and Process Operations, John Wiley and Sons, Inc., New York, N.Y., 1976.
19. Hebert, J. E., "Applications of Simulation in Project Management," Eleventh Winter Simulation Conference 1979, San Diego, California, Institute for Electrical and Electronic Engineers, December 1979.
20. Jahangard, H., "Study of Excavation Operations", Research Problem, Civil Engineering Department, Georgia Institute of Technology, June 1983.
21. Kalk, A., INSIGHT--Interactive Simulation of Construction Operations Using Graphical Techniques, Thesis presented to Stanford University in partial fulfillment of the requirements for the Degree of Engineer, August 1978. It was revised and published as Technical Report No. 238, The Construction Institute, Department of Civil Engineering, Stanford University, Stanford, California, July 1980.

22. Knot, J. L. and Woodhead R. w., "The CYCLONE--
Timelapse Analysis System," Construction Monographs,
School of Civil Engineering, University of New South
Wales, 1980.
23. Ledbetter, W. N. and Cox, J. F., "Are O.R. Techniques
Being Used ?" Industrial Engineering, Vol. 9,
February 1977.
24. Lluch, J., Analysis of Construction Operations Using
Microcomputers, Ph.D. Dissertation, School of Civil
Engineering, Georgia Institute of Technology, August
1981.
25. Lluch, J. and Halpin, D. W., "Construction Operations
and Microcomputers," Journal of the Construction
Division, ASCE, Vol. 108, No. CO2, March 1982, pp.
26. Moavenzadeh, F. and Markow, M. J., "Simulation Model
for Tunnel Construction Costs," Journal of the
Construction Division, ASCE, Vol. 102, No. CO1,
March 1976, pp. 51-66.
27. Morgan, W. C. and Peterson, L., "Determining Shovel -
Truck Productivity," Mining Engineering, December
1968.
28. Naylor, T. H., Computer Simulation Experiments with
Models of Economic Systems, John Wiley and Sons,
Inc., New York, N.Y., 1971.
29. Paulson, B. C. Jr., "Interactive Graphic for
Simulating Construction Operations," Journal of the
Construction Division, ASCE, Vol. 104, No. CO1,
March 1978, pp. 69-76.
30. Paulson, B. C. Jr., "Interactive Human-Computer System
for Video Data Acquisition, Statistical Analysis, and
Graphical Simulation of Construction Operations,"
Stanford University Research Proposal No. CE52-80 (n),
Presented to the National Science Foundation.
31. Peurifoy, R. L., Construction Planning, Equipment and
Methods, McGraw Hill Book Company, 1981.
32. Phillips, D. T., Applied Goodness of Fit Testing,
Publication No. 1, Monogram Series ORD, AIIE, 1972.
33. Pietrzak, L. and McJunkin, M., "Simulation as a

Tunneling Research and Project Planning Tool,
" Proceedings of the Second Rapid Excavation and
Tunneling Conference, American Institute of Mining
Engineers, Vol. 1, June 1974, pp. 165-184.

34. Pritsker, A. A. B., "Compilation of Definitions of Simulation," Simulation, August 1979, Society for Computer Simulation, Vol. 33, No. 2.
35. Riggs, L. S., Sensitivity Analysis of Construction Operations, Ph.D. Dissertation, School of Civil Engineering, Georgia Institute of Technology, August 1979.
36. Riggs, L. S., "Simulation of Construction Operations," Journal of the Technical Council of ASCE, Vol. 106, No. TCI, August 1980, pp. 145-163.
37. Rood, O. E. Jr., "Guidance for Selection of Equipment Fleet," Technical Report P-18, Construction Engineering Research Laboratory, Champaign, Illinois, October 1973.
38. Scott, D. and Cullingford, G., "Scheduling Game for Construction Industry Training," Journal of the Construction Division, ASCE, Vol. 99, No. C01, July 1973, pp. 81-92.
39. Victor, G., INTEGRATION : Interactive Graphic Simulation of Construction Operations, Thesis presented to Stanford University in partial fulfillment of the requirements for the Degree of Engineer, June 1979. Also available as Technical Report No. 239. The Construction Institute, Department of Civil Engineering, Stanford University, Stanford, California, June 1979.
40. Weston, F. C., "O.R. Techniques Relevant to Corporate Planning Function Practices, An Investigative Look," presented at 39th National Meeting, Operations Research Bulletin, Vol. 19, Suppl. 2, Spring 1971.
41. Willenbrock, J. H., "Estimating Costs of Earthwork via Simulation," Journal of the Construction Division, ASCE, Vol. 98, No. C01, March 1972, pp. 49-60.
42. Willenbrock, J. H. and Lee, T. M., "Use of Time-Lapse Photography and Computer Simulation for Loader-Truck Production Studies," Transportation Research Record, No. 535, 1975, pp. 82-95.

43. Wright, P. H. and Paquette, R. J., Highway Engineering, 4th ed., John Wiley and Sons, Inc., New York, N.Y., 1979.

APPENDIX C

USER MANUAL

C.1 INTRODUCTION

The integrated microcomputer system consists of four programs. These programs are :

1. Road design
2. Road earthwork quantity take-off
3. Site plan earthwork quantity take-off
4. CYCLONE for microcomputers.

The first program is used for horizontal and vertical curve design of a roadway. The second program is used for earthwork quantity take-off of a road construction project while the third one is mainly used for a civil engineering project in general. Finally, the last program is the CYCLONE for microcomputers originally developed by Lluch [22] and modified by the author. The system menu must be re-accessed when transferring from one program to another. To return to the system menu, press the desired option number from the menu.

When the operator is confronted with a request from the computer for a decision, choose from the selections given or if a yes, no question is implied use 'Y' for yes and 'N' for no.

C.2 SYSTEM MENU

Once the system is turned on, insert the system disk volume #1 in drive 0 and data disk in drive 1. A prompt is

printed on the monitor indicating that TRSDOS has been loaded into memory and that TRSDOS is in control. At this point, the user responds to prompts requesting the actual date and time. After the entries are made, the following menu appears on the monitor :

SYSTEM MENU

1. ROAD DESIGN
2. ROAD EARTHWORK QUANTITY TAKE-OFF
3. SITE PLAN EARTHWORK QUANTITY TAKE-OFF
4. CYCLONE FOR MICROCOMPUTERS
5. TRSDOS

ENTER YOUR SELECTION.

These selections will now be explained.

Selection 1 : Road Design -- After a 1 is entered, the screen is cleared and the following is printed on the monitor :

LOADING ROAD DESIGN PROGRAM

The road design program is loaded next.

Selection 2 : Road Earthwork Quantity Take-off --

After a 2 is selected, the screen is cleared and the following is printed on the monitor :

LOADING ROAD EARTHWORK QUANTITY TAKE-OFF PROGRAM

The road earthwork quantity take-off program is then loaded.

Selection 3 : Site Plan Earthwork Quantity Take-off

-- After a 3 is entered, the screen is cleared and the following is printed on the monitor :

INSERT SYSTEM DISK VOLUME #2. THEN PRESS ENTER.

After the user inserts the system disk volume #2 and presses enter, the screen is cleared and the following is printed on the monitor :

LOADING SITE PLAN EARTHWORK QUANTITY TAKE-OFF PROGRAM

The site plan earthwork quantity take-off program is loaded next.

Selection 4 : CYCLONE for Microcomputers -- After a 4 is entered, the screen is cleared and the following is printed on the monitor :

CYCLONE FOR MICROCOMPUTERS MENU

1. BETA MODULE
2. INPUT MODULE
3. SIMULATION MODULE
4. REPORT MODULE

ENTER YOUR SELECTION.

After the user enters his/her selection, the screen is cleared and the following is printed on the monitor :

LOADING CYCLONE FOR MICROCOMPUTERS

The selected module program is loaded next.

Selection 5 : TRSDOS -- After a 5 is selected from the menu, the screen is cleared and the following message appears :

TRSDOS READY.

At this point the user is in TRSDOS (Tandy Radio Shack Disk Operating System).

C.3 ROAD DESIGN

Once the program is loaded, the screen is cleared and the following is printed on the monitor :

ROAD DESIGN MENU

1. HORIZONTAL ALIGNMENT & SUPERELEVATION
2. VERTICAL ALIGNMENT
3. TOP OF THE PAGE
4. SYSTEM MENU

ENTER YOUR SELECTION.

All these selections will now be explained.

Selection 1 : Horizontal Alignment & Superelevation

-- After a 1 is selected on the menu, the screen is cleared and the following is printed on the monitor :

ENTER 0 WHEN THROUGH.

PI STATION ?

The point of intersection station should be entered. Other prompts appear for angle of intersection, chord length and design velocity. After all entries are made, the program calculates horizontal curve alignment and provides

output in tabular form. From left to right this output reads as follows : curve midpoint station number, curve radius, length of curve, degree of curve, tangent length, superelevation, beginning of curve (PC) station number, station number of tangent intersection of curve (PI) and end of curve (PT) station number.

As a safety feature, the program automatically checks on the degree of curvature (D). If the value of the degree of curvature exceeds 10 degrees, the program prints the value of degree of curvature and returns to the beginning of the process for curve redesign. This may be accomplished by decreasing the angle of intersection or increasing the chord length.

This process is repeated until the user enters 0 for PI station. Assuming these values were entered, the following is printed :

ENTER 0 WHEN THROUGH.

PI STATION ? 133

ANGLE OF INTERSECTION IN DEGREES ? 26

CHORD LENGTH IN FEET ? 600

DESIGN VELOCITY (30,35,40,45,50,55,60) ? 60

MP STA	R	L	D	T	SE	PC STA	PI STA	PT STA
132.94	1333.62	605.18	9.47	307.89	0.05	129.92	133.00	135.97

ENTER 0 WHEN THROUGH.

PI STATION ? 0

Selection 2 : Vertical Alignment -- After a 2 is entered, the screen is cleared and the following appears on the screen :

VERTICAL ALIGNMENT

NOTE : THE USER SHOULD ENTER STARTING GRADE, ENDING GRADE, CURVE LENGTH AND ONE OF THE FOLLOWING :

1. PC STATION AND ELEVATION
2. PI STATION AND ELEVATION

STARTING GRADE (%) ?

The starting grade should be entered. Other prompts appear for ending grade, length of curve, PC station and elevation or PI station and elevation. After all these entries are made, the program displays the PT station and elevation and PC or PI station and elevation. Next the following is printed on the monitor :

TO FIND ELEVATION OF ANY CURVE STATION, ENTER THE STATION.

ENTER 1 WHEN THROUGH.

STATION ?

After the station is entered, the program displays the elevation. This process is repeated until the user enters 1 for station. Assuming these values were entered, the following is printed on the monitor :

STARTING GRADE (%) ? 3

ENDING GRADE (%) ? 0.9

LENGTH OF CURVE IN FEET ? 500

ENTER 1 FOR P.C. DATA OR 2 FOR P.I. DATA. 2

P.I. STATION IN FEET ? 5000

P.I. ELEVATION ? 630

P.C. STATION = 4750.00 P.C. ELEVATION = 622.50

P.T. STATION = 5250.00 P.T. ELEVATION = 632.25

TO FIND ELEVATION OF ANY CURVE STATION, ENTER THE
STATION.

ENTER 1 WHEN THROUGH.

STATION ? 4900

ELEVATION = 626.53

TO FIND ELEVATION OF ANY CURVE STATION, ENTER THE
STATION.

ENTER 1 WHEN THROUGH.

STATION ? 5150

ELEVATION = 631.14

TO FIND ELEVATION OF ANY CURVE STATION, ENTER THE
STATION.

ENTER 1 WHEN THROUGH.

STATION ? 1

After a 1 is entered for station, the following is
printed on the monitor :

ANY MORE VERTICAL CURVE (Y/N) ?

If 'Y' then the screen is cleared and the vertical
curve design process is repeated otherwise the screen is
cleared and the road design menu is displayed.

Selection 3 : Top of the Page -- After a 3 is
selected from the menu, the paper is advanced to the top of
the page, the screen is cleared and the menu is displayed.

Selection 4 : System Menu -- After a 4 is entered,
the screen is cleared and the system menu is loaded.

C.4 ROAD EARTHWORK QUANTITY TAKE-OFF

The road earthwork quantity take-off program is used mainly for roadway projects. The physical programming limitations of this program are as follows:

1. Identifiers are limited to 256 characters.
2. The number of stations is limited to 100.
3. The number of existing and finished data points is limited to 100 each.
4. The length of interval between the two consecutive sections is constant.
5. The output paper width is limited to 80 characters per line.
6. The vertical scale in plotting the cross sections is 1" = 10'.

The logical steps in road earthwork quantity take-off calculations are as follows:

1. Finding the intersection points at 1' increments for every section.
2. Finding the cut and fill areas between the consecutive intersection points and summing the areas.
3. Finding the total fill and cut volumes based on :

$$\text{Total Volume} = (A + A)/2 + A + \dots + A$$

where A is the cross section
area at nth section.

Once the program is loaded, the screen is cleared and
the following is printed.

DATA FILE NAME ?

The user needs to input the data file name. The name
must be 8 characters long at the most and start with a
letter. The program assigns an extension of RD to the file
name and the actual file name then becomes file name/RD as
found in the directory of the disk.

After entering the data file name, the road earthwork
quantity take-off menu appears on the screen as follows:

ROAD EARTHWORK QUANTITY TAKE-OFF MENU

1. DATA INPUT
2. REVISING THE DATA
3. MODIFYING THE STANDARD SECTION PARAMETERS
4. DATA OUTPUT
5. EARTHWORK QUANTITY TAKE-OFF CALCULATIONS
6. EQT
7. SUMMARY OUTPUT
8. PLOTTING THE DATA

- 9. TOP OF THE PAGE
- 10. SYSTEM MENU

ENTER YOUR SELECTION.

All these selections will now be explained.

Selection 1 : Data Input -- After a 1 is entered, the screen is cleared and the following is printed:

JOB IDENTIFICATION ?

The job name should be entered. Other prompts appear for the job number, number of sections, section interval, pavement depth, pavement width, cross slope, curb height, shoulder width, shoulder slope, cut slope and fill slope. After all entries are made, the user is given an opportunity to make corrections to the input. After interpreting the data entered, the screen is cleared and the entries are reprinted. Assuming these values were entered, the following is printed on the monitor:

JOB IDENTIFICATION = BEARD TRACT

JOB NUMBER = 7903

PAVEMENT DEPTH = 0.50 FT

PAVEMENT WIDTH = 24.00 FT
CROSS SLOPE = -2.00 %
CURB HEIGHT = 0.50 FT
SHOULDER WIDTH = 10.00 FT
SHOULDER SLOPE = -2.00 %
CUT SLOPE = 33.33 %
FILL SLOPE = 33.33 %

ARE THESE CORRECT (Y/N) ?

The correction routine is self explanatory. Assuming that these values are correct, after the user enters 'Y', the screen is cleared and the following is printed on the monitor:

SECTION IDENTIFICATION = 0

ENTER . WHEN THROUGH.

EXISTING DISTANCE ?

The user should input the existing distance of a known elevation from the center line of the road in feet. The right side of the centerline in the increasing station number direction is positive and the leftside is negative.

Other prompts appear for existing elevation and an opportunity to delete the entry in case of an error. The process is repeated until the user is finished with the existing data entry for section 0. The end of the existing data entry is indicated by entering '.' for existing distance.

After '.' is entered, the screen is cleared and the following appears on the monitor:

```
SECTION IDENTIFICATION = 0
```

```
-----  
-----
```

```
STANDARD SECTION (Y/N) ?
```

The user should indicate whether the section is a standard one or not. If 'Y', another prompt appears for the centerline elevation. After the entry is made, the computer automatically creates new points for the edge of pavement and edge of shoulder on both sides and determines the intersection points of the existing and finished grades. If the existing and finished grades do not tie back to each other at either side within the given data, a message appears indicating that the user must enter more existing data on one side of the centerline and the following is printed on the screen :

DO YOU HAVE ANY MORE DATA (Y/N) ?

If 'Y', then the user is given a chance to enter more existing grade data otherwise the program assumes that the section is a non-standard one and the user is directed to enter the finished grade data.

If the section is not standard, then other prompts appear for the finished distance and elevation similar to the existing data entry. After finished distance and elevation is entered, the following is printed on the screen :

ENTER 1 IF ERROR, 2 FOR VERTICAL, 3 FOR SLOPE OR PRESS ENTER.

Option 1 is used in case of an error. Option 2 is used for a retaining wall or a vertical slope at the beginning or end of a section. If the point is not the first or the last point, a message indicating that is printed on the screen. Option 3 is used when the user wants to assign a given slope at the beginning or end of a section. If chosen, a prompt for the slope in % appears. After the slope is entered, the program automatically computes the intersection point of the existing and the finished grades. If they do not intersect within the given data, a message indicating that the

intersection is not found appears on the screen and the point is ignored.

This process is repeated until the user enters '.' for the finished distance.

The data entry is repeated for the other sections. Once the data entry is finished, the screen is cleared and the menu is printed on the monitor.

Selection 2 : Revising the Data-- After a 2 is selected on the menu, the screen is cleared and the following is printed.

NOTE : THE LOWEST SECTION MUST BE UPDATED FIRST.

FOE EXAMPLE SECTION 50 MUST BE UPDATED (IF NECESSARY) BEFORE ECTION 100.

HOW MANY SECTIONS ARE YOU REVISING ?

The user should enter the number of sections that should be revised. Other prompts appear for section identification and whether the user wants to change the existing data of the section or not. If the user needs to change the existing data, the following appears on the monitor:

DO YOU WANT TO DELETE ANY POINTS (Y/N) ?

If 'Y', then other prompts appear for the lowest and the highest distance limits to be deleted and the end of the deletion process on the screen. The user should enter the corresponding values and the deletion process is continued until the user enters '.' for the end of the deletion process.

After the deletion process is finished, then the user has a chance to enter more existing data points as explained in the previous section.

If the user does not want to change the existing data or the existing data revision is finished, the following appears on the screen:

DO YOU WANT TO CHANGE THE FINISHED GRADE (Y/N) ?

If 'Y', the prompt for standard section appears. If the section is standard, another prompt for the road centerline elevation appears. Then the computer checks for the intersection points of the existing and finished grades. If the grades do not intersect on one or both sides of centerline, several prompts similar to the previous selection appear on the monitor. After the intersection points are determined, the revision process is repeated for the next section.

If the section is not standard, then other prompts appear for the deletion process similar to the existing data deletion. After the deletion process is over, other prompts appear for the addition process similar to the finished data entry in the previous selection.

If 'N', then the revision process is repeated for the next section.

The revising process is repeated for the other sections. After the revision process is finished, the screen is cleared and the menu appears on the screen.

Selection 3 : Modifying the Standard Section

Parameters-- After a 3 is entered, the screen is cleared and several prompts appear for pavement depth, pavement width, cross slope, curb height, shoulder width, shoulder slope, cut slope and fill slope. After all entries are made, the user is given an opportunity to make corrections to the input. After interpreting the data entered, the screen is cleared and entries are reprinted for correction routine as explained in the first selection. After the data is entered, the program automatically changes the finished grade of the standard sections based on the new section parameters and the centerline elevation of the proposed road. If the existing and finished grades do not tie to each other on any side, a message is printed on the printer

indicating that. The user should use the revising option in order to add more existing data to revise that section.

Selection 4 : Data Output-- After a 4 is selected on the menu, the screen is cleared and the following is printed:

1. ONE SECTION ONLY
2. RANGE OF SECTIONS
3. ALL SECTIONS
4. STANDARD PARAMETERS

ENTER YOUR SELECTION.

The user should specify his/her selection. Option one prints only one section and if chosen, other prompts appear for section identification and whether to print all the data in the section or a subset of it appears on the screen. After all entries are made, the data are printed on the line printer.

The second option prints a range of sections and if chosen, the prompts for the beginning and the ending sections appear on the screen. After all entries are made, the sections data are printed on the line printer.

The third option prints all the sections on the line printer. The last option prints the parameters of the standard section. After the completion of any of the above options, the screen is cleared and the menu is printed on the monitor. Figure C1 illustrates the data output of a section.

Selection 5 : Earthwork Quantity Take-Off Calculations

--After a 5 is selected on the menu, the screen is cleared and a prompt for shrinkage factor appears on the screen. After the user enters the shrinkage factor in percentage, the screen is cleared and the following appears on the monitor:

SECTION IDENTIFICATION =

ROAD EARTHWORK QUANTITY TAKE-OFF CALCULATIONS
IN PROGRESS

The section identification indicates the section in process at the time. After all the calculations is finished, a list of cut and fill areas of every section and total cut and fill volumes are printed on the screen. Next, the user should press enter in order to go back to the menu.

JOB IDENTIFICATION = BEARD TRACT
JOB NUMBER = 7903

May 21 , 1983

SECTION IDENTIFICATION = 950

EXISTING DISTANCE	EXISTING ELEVATION	FINISHED DISTANCE	FINISHED ELEVATION
-120.00	960.00	-52.03	952.69
-113.00	958.00	-38.00	957.37
-110.00	956.00	-30.01	957.53
-103.00	954.00	-30.00	956.23
-25.00	952.00	0.00	956.83
-14.00	950.00	30.00	956.23
-7.00	948.00	30.01	957.53
0.00	948.00	38.00	957.37
6.00	950.00	56.66	951.15
94.00	952.00		
132.00	970.00		
148.00	978.00		
161.00	984.00		

Figure C1. Typical Output of a Section

The cut and fill areas, total cut and fill volumes are stored on the disk for future retrieval.

Selection 6 : EQT-- This option is used when the user revises only one section and wants to get an updated cut and fill volumes. The advantage of this option is the reduction in calculation time. After a 6 is selected on the menu, the screen is cleared and two prompts for shrinkage factor and section identification appear on the screen. After these entries are made, earthwork quantity take-off calculations for that section only is done. The cut and fill areas of the other sections are retrieved from the disk and the new cut and fill volumes are printed on the monitor. The user needs to press enter in order to go back to the menu and store the new areas and volumes.

Selection 7 : Summary Output-- After a 7 is selected on the menu, the list of cut and fill areas of every section and total cut and fill volumes are printed on the printer. After the printing is finished, the screen is cleared and the menu is printed on the screen. Figure C2 shows a summary output.

Selection 8 : Plotting the Data-- After an 8 is selected on the menu, the screen is cleared and a prompt for horizontal scale appear on the screen. After the horizontal scale is entered, the screen is cleared and the following appears on the screen:

JOB IDENTIFICATION = BEARD TRACT
JOB NUMBER = 7903

May 21 , 1983

ROAD EARTHWORK QUANTITY TAKE OFF PROGRAM

SECTION (FT.)	CUT AREA (SQ. FT.)	FILL AREA (SQ. FT.)
0	75.77	3.85
50	46.98	1841.80
100	0.00	4211.40
150	0.00	4226.17
200	0.00	3620.30
250	0.00	3519.20
300	0.00	4713.11
350	0.00	2530.96
400	0.00	2594.70
450	0.00	2409.68
500	0.00	1310.94
550	32.19	926.12
600	363.01	568.03
650	0.00	478.87
700	0.00	425.00
750	16.25	295.06
800	0.00	378.48
850	0.00	383.91
900	0.00	449.66
950	0.00	584.40
1000	0.00	340.17
1050	0.00	552.49
1100	15.84	422.44
1150	1.98	292.45
1200	220.92	166.33
1250	91.67	227.19
1300	78.73	253.84
1350	332.65	219.71
1400	384.31	214.80
1450	113.49	237.17
1500	35.24	142.62
1550	539.25	0.00
1600	1280.83	0.00
1650	1838.53	0.00

Figure C2. Typical Summary Output

1700	1361.38	0.00
1750	1398.25	0.00
1800	1519.90	0.00
1850	647.28	0.00
1900	310.48	1141.77
1950	86.50	273.73
2000	618.88	4.00
2050	574.10	52.74
2100	604.70	31.97
2150	315.15	242.17
2200	93.97	396.34
2250	190.63	230.85
2300	362.55	236.92
2350	565.15	85.15
2400	618.17	19.28
2450	608.62	0.00
2500	1016.21	0.00
2550	1700.07	0.00
2600	2002.75	0.00
2650	1484.45	0.00
2700	2051.07	0.00
2750	1866.55	0.00
2800	1314.58	0.00
2850	517.90	21.43
2900	16.00	461.27
2950	0.00	807.78
3000	1.06	111.46
3050	0.00	1251.52
3100	1064.35	0.00
3150	1330.16	0.00
3200	872.07	0.00
3250	739.07	73.54
3300	0.00	1038.55
3350	0.00	1737.89
3400	0.00	1298.99
3450	0.00	641.11
3500	0.00	213.33
3550	170.42	25.96
3600	574.68	0.00
3650	802.98	0.00
3700	697.88	117.91
3750	438.05	339.03
3800	123.82	520.97
3850	0.00	699.07
3900	152.02	25.86

Figure C2 Cont.. Typical Summary Output

3950	299.06	92.51
4000	383.24	85.28
4050	297.88	115.43
4100	325.50	74.24
4150	461.40	64.14
4200	299.29	135.36
4250	144.27	248.35
4300	99.58	371.41
4350	6.53	186.32
4400	77.21	241.98
4450	112.09	277.93
4500	0.00	974.57
4550	0.00	1221.82
4600	0.00	1264.40
4650	0.00	1122.99
4700	0.00	459.79
4750	21.92	42.15

TOTAL CUT = 68072
TOTAL FILL = 122660

Figure C2 Cont... Typical Summary Output

PLOTTING MENU

1. ONE SECTION ONLY
2. A RANGE OF SECTIONS
3. ALL SECTIONS
4. ROAD EARTHWORK QUANTITY TAKE-OFF PROGRAM

ENTER YOUR SELECTION.

Option 1 plots only one section and if chosen, the prompt for section identification appears on the screen. After the entry is made, the section is plotted on the line printer. The vertical scale is 1" = 10'. The '*' indicates the existing grade and the '.' indicates the finished grade.

Option 2 plots a range of sections, e.g. 500 to 1200, and if chosen, the prompts for the beginning and the ending sections appear on the screen. After these entries are made, the sections are plotted on the line printer.

Option 3 plots every section. In the above options, after the plotting is finished, the screen is cleared and the plotting menu is displayed. The last option returns to the road earthwork quantity take-off program. Figures C3

through C5 illustrate the typical plots of a road cross section.

Selection 9 : Top of the Page-- After a 9 is selected on the menu, the paper is advanced to the top of the page, the screen is cleared and the menu is displayed.

Selection 10 : System Menu-- After a 10 is selected on the menu, the screen is cleared and the system menu is displayed.

C.5 SITE PLAN EARTHWORK QUANTITY TAKE-OFF

The site plan earthwork quantity take-off program is used for general civil engineering projects. The physical programming limitations of this program are as follows:

1. Identifiers are limited to 256 characters.
2. The number of stations is limited to 100.
3. The number of existing and finished data points is limited to 500 each.
4. The beginning data point must be at $x = 0$.

The first and the last existing and finished data points must be the same. Thus the existing and finished grades must tie together at the beginning and the end of every section.

5. The length of interval between the two consecutive sections is constant.

JOB IDENTIFICATION = BEARD TRACT
 JOB NUMBER = 7903
 SECTION IDENTIFICATION = 850

May 21 , 1983

* INDICATES THE EXISTING GRADE.
 . INDICATES THE FINISHED GRADE.

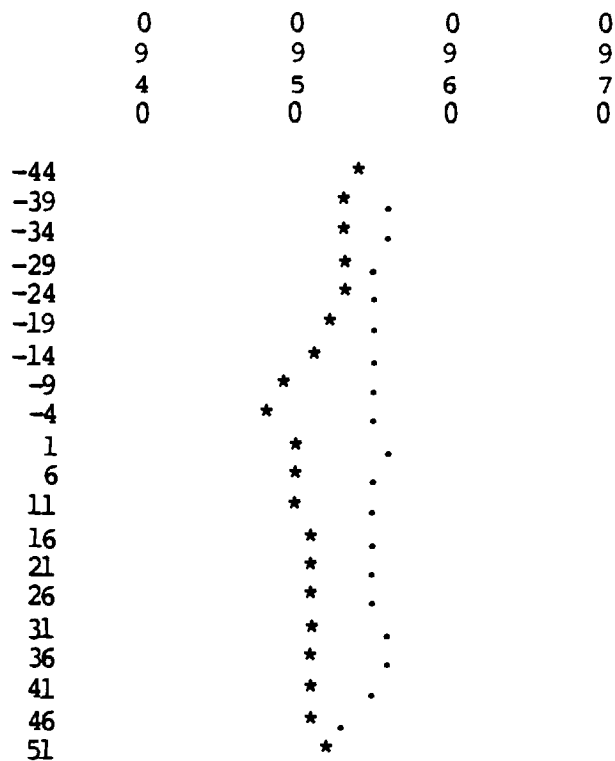


Figure C3. Typical Plot of a Fill Road Cross Section

JOB IDENTIFICATION = BEARD TRACT
 JOB NUMBER = 7903

May 21 , 1983

SECTION IDENTIFICATION = 1550

* INDICATES THE EXISTING GRADE.
 . INDICATES THE FINISHED GRADE.

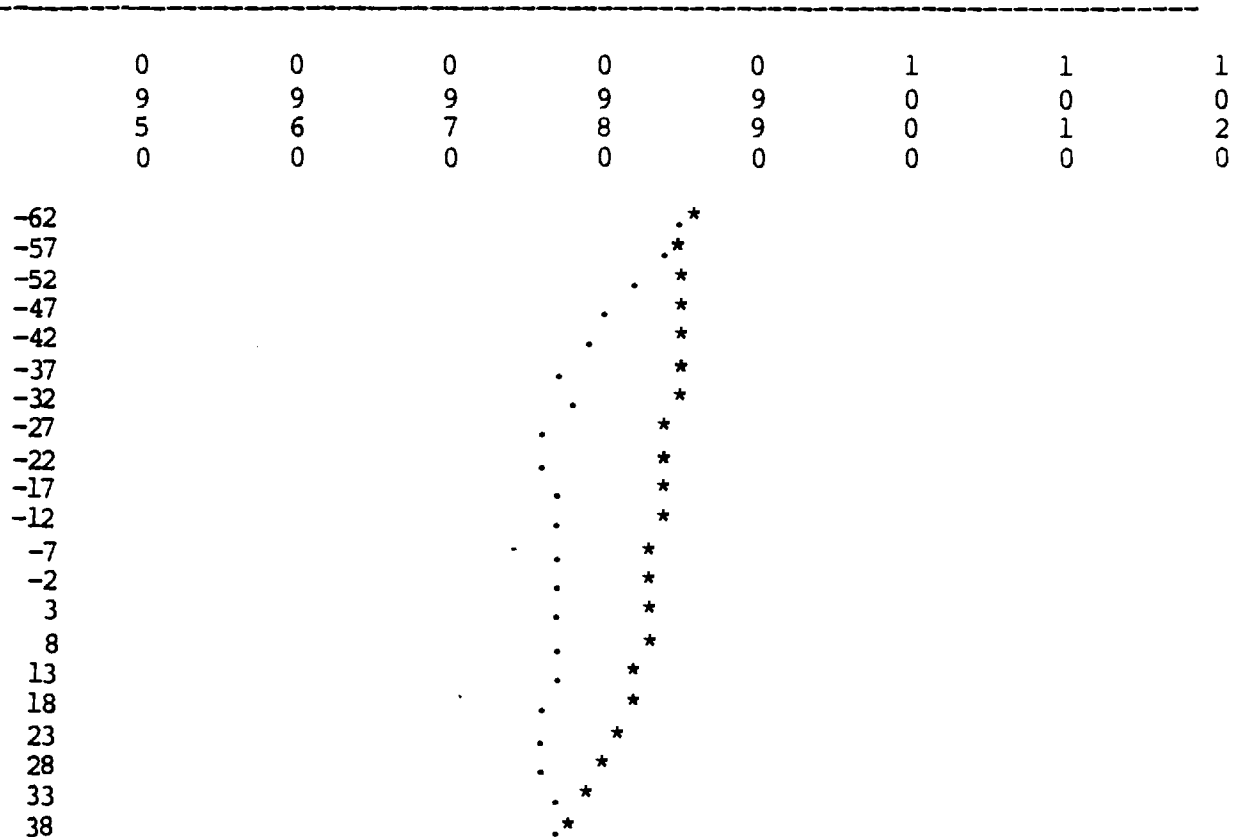


Figure C4. Typical Plot of a Cut Road Cross Section

JOB IDENTIFICATION = BEARD TRACT
 JOB NUMBER = 7903

May 21 , 1983

SECTION IDENTIFICATION = 4200

* INDICATES THE EXISTING GRADE.
 . INDICATES THE FINISHED GRADE.

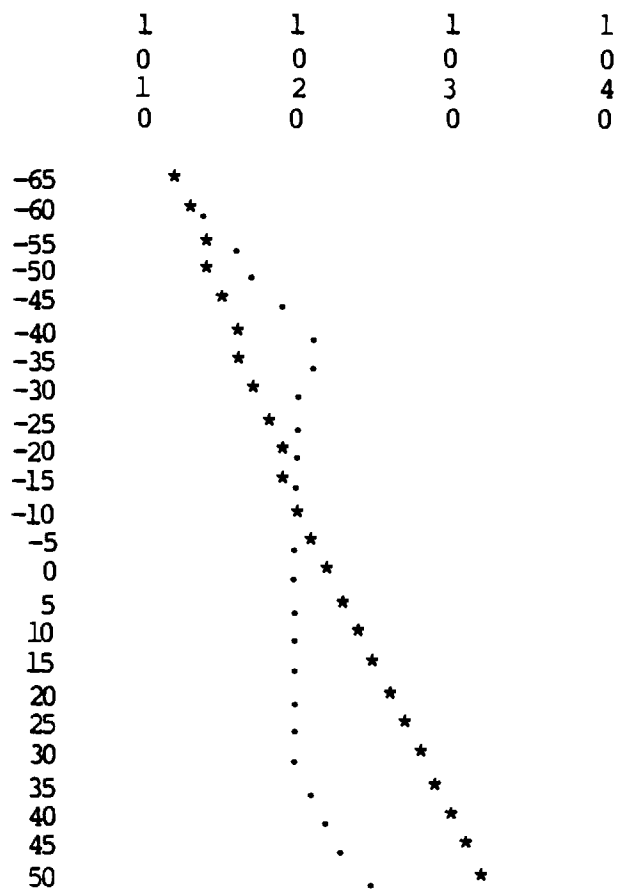


Figure C5. Typical Plot of a Cut and Fill Road Cross Section

6. The vertical scale in plotting the cross sections is 1" = 10'.

The calculation procedure is the same as road earthwork quantity take-off program.

Once the program is loaded, the screen is cleared and the following is printed:

DATA FILE NAME ?

The user should input the data file name. The name must be 8 characters long at the most and start with a letter. The program assigns an extension of /EQT to the file name and the actual file name becomes file name/EQT as found in the directory of the disk.

After entering the data file name, the site plan earthwork quantity take-off menu appears on the screen as follows:

SITE PLAN EARTHWORK QUANTITY TAKE-OFF MENU

1. DATA INPUT
2. REVISING THE DATA
3. RAISING OR LOWERING THE FINISHED GRADE
4. DATA OUTPUT
5. EARTHWORK QUANTITY TAKE-OFF CALCULATIONS

6. EQT
7. SUMMARY OUTPUT
8. PLOTTING THE DATA
9. TOP OF THE PAGE
10. SYSTEM MENU

ENTER YOUR SELECTION.

All these selections will now be explained.

Selection 1 : Data Input-- After a 1 is entered, the screen is cleared and the following is printed:

DO YOU WANT TO PRINT THE DATA ON PRINTER (Y/N) ?

The user needs to specify whether to print the data entry on the printer or not. It is a good practice to print the data so the data are not lost in case of power shutdown or some other reasons. Then the screen is cleared and the following is printed:

JOB IDENTIFICATION ?

The job name should be entered. Other prompts appear for the job number, number of sections and the section interval. After all entries are made, the user is given an

opportunity to make corrections to the input. After interpreting the data entered, the screen is cleared and the entries are printed. Assuming these values were entered, the following is printed on the monitor:

JOB IDENTIFICATION = WOOD GLEN

JOB NUMBER = 8219

NUMBER OF SECTIONS = 25

SECTION INTERVAL = 50

ARE THESE CORRECT (Y/N) ?

The correction routine is self explanatory. Assuming that these values are correct, after the user enters 'Y', the screen is cleared and the following is printed on the monitor:

SECTION IDENTIFICATION = 0

ENTER . WHEN THROUGH.

EXISTING DISTANCE ?

The user should input the existing distance of a known elevation from a datum line (e.g. property line) in feet. Other prompts appear for existing elevation and an opportunity to delete the entry in case of an error. The process is repeated until the user is finished with the existing data entry for section 0. The end of the existing data entry is indicated by entering '.' for existing distance.

After '.' is entered, the screen is cleared and the following appears on the monitor:

SECTION IDENTIFICATION = 0

ENTER . WHEN THROUGH OR S FOR SAVED AREA.

FINISHED DISTANCE ?

The user should enter the finished distance of a known elevation to the same datum line. Other prompts similar to the existing data appears on the monitor. These prompts are for finished elevation and an opportunity to delete the data entry in case of an error. The process is repeated until the user is finished with the data entry for section 0. The end of the finished data entry is indicated by entering '.' for finished distance.

In case of saved area for a length of the section, the user could either enter the distance and elevation of the contours in that segment or enter 'S' for finished distance. After entering 'S', two prompts for beginning and the end of the saved area appears on the screen. The user should enter the corresponding values. After all entries are made, the finished distance prompt appears and the process is repeated.

Once the data entry for one section is finished, the computer sorts the data in ascending order of distances. Therefore, the existing and finished data do not have to be entered in ascending order of distances. After sorting the data, the program compares the first and the last data points of the existing and finished data. If they are the same, the data for that section is saved on the disk and the data entry process is repeated for the next section until all the data are entered.

If the first and the last points of the existing and the finished grades are not the same, the data points are printed on the screen and prompts regarding the correct existing distance and elevation appear on the screen. After the entries are made, the program automatically assigns these values to the finished grade data.

The data entry is repeated for other sections. Once the data entry is finished, the screen is cleared and the menu is printed on the monitor.

Selection 2 : Revising the Data-- After a 2 is selected on the menu, the screen is cleared and the following is printed:

NOTE : THE LOWEST SECTION MUST BE UPDATED FIRST.

FOR EXAMPLE SECTION 50 MUST BE UPDATED (IF
NECESSARY) BEFORE SECTION 100.

HOW MANY SECTIONS ARE YOU REVISING ?

The user needs to enter the number of sections that should be revised. Other prompts appear on the screen for section identification and whether the user wants to change the existing data of the section or not. If the user needs to change the existing data, the following appears on the monitor:

DO YOU WANT TO DELETE ANY POINTS (Y/N) ?

If 'Y', then other prompts appear for the lowest and the highest distance limits to be deleted and the end of the deletion process on the screen. The user needs to enter the

corresponding values and the deletion process is repeated until the user enters '.' for the end of the deletion process. After the deletion process is finished, then the user has a chance to enter more existing data points as explained in the previous section. After the existing data entry is finished, the same deletion and addition processes are repeated for the finished data revisions.

If the user does not want to change the existing data, the same prompts appear for revising the finished data.

The revising process is repeated for the other sections. After the revising process is finished, the screen is cleared and the menu appears on the screen.

Selection 3 : Raising or Lowering the Finished Grade

-- After a 3 is selected on the menu, the screen is cleared and the following is printed:

NOTE : THE LOWEST SECTION MUST BE UPDATED FIRST.

FOR EXAMPLE SECTION 50 MUST BE UPDATED (IF
NECESSARY) BEFORE SECTION 100.

HOW MANY SECTIONS ARE YOU REVISING ?

The user should enter the number of sections that should be revised. Other prompts appear on the screen for section identification, lowest distance limit to be raised

or lowered, highest distance limit to be raised or lowered and how much to be raised or lowered. After these entries are made, the information inputed are printed on printer and the program automatically raises or lowers the finished grade. Then the following is printed on the monitor:

ENTER . IF THROUGH OTHERWISE PRESS ENTER.

?

This process is repeated until the user enters '.' at the end of the process. The raising or lowering process is repeated for the other sections. After the raising or lowering process is finished, the screen is cleared and the program menu is displayed. Figure C6 illustrates a raising or lowering output.

Selections 4 through 9 :-- The options 4 through 9 are similar to the options in road earthwork quantity take-off program.

Selection 10 : System Menu-- After a 10 is entered, the screen is cleared and the following is printed on the monitor :

INSERT SYSTEM DISK VOLUME #1. THEN PRESS ENTER.

JOB IDENTIFICATION = WINTERSCREEK
JOB NUMBER = 8305

May 21 , 1983

SECTION	LOWEST DISTANCE	HIGHEST DISTANCE	RAISED/LOWERED
200	100.00	500.00	-2.00
250	100.00	500.00	-2.00
300	100.00	500.00	-2.00
350	100.00	500.00	-2.00
400	100.00	500.00	-2.00
500	50.00	250.00	-1.00
500	400.00	650.00	-1.00
550	100.00	650.00	-1.00
600	100.00	650.00	-1.00
700	100.00	650.00	-1.00
700	850.00	950.00	-1.00
750	100.00	650.00	-1.00

Figure C6. Typical Raising or Lowering Output

After the user inserts the system disk volume #1 and presses enter, the system menu is loaded.

C.6 CYCLONE FOR MICROCOMPUTERS

CYCLONE for Microcomputers is made up of five different modules as follows :

1. Beta module
2. Model module
3. Input module
4. Simulation module
5. Report module.

Each module constitutes one program. These programs are internally linked together and data is transferred from one program to another with a minimum of user intervention.

Beta, input, simulation and report modules were originally developed by Lluch [22]. The author modified these modules and added the model module. The following sections are primarily a revision of user manual of CYCLONE for Microcomputers by Lluch [22].

C.6.1 Beta Module

This program consists of a decision support routine to help the user prescribe the distributions for the duration of the activities. It is a menu driven program. Values selected are stored on the diskette under the keyname of the

process and extension SET. (For a process named TRUCK, the file containing the parameters is TRUCK/SET). The importance of using the same keyname for the process throughout the five modules is emphasized.

Once the program is loaded, the screen is cleared and a prompt appears for the process keyname. The process keyname must be 1 to 8 characters or numbers starting with a letter. After the process keyname is entered, the following menu appears on the screen. It is the main menu.

1. BETA FROM GROUPED DATA
2. BETA FROM UNGROUPED DATA
3. BETA FROM MEAN, VARIANCE, LOW AND HIGH LIMIT
4. CONSTANT OR UNIFORM DURATION
5. NONSTATIONARY COMPONENT
6. SAVE DURATION SET ON DISK

ENTER SELECTION.

All these selections will now be explained.

Selection 1 : Beta from Grouped Data-- After a 1 is entered, the screen is cleared and the following is printed:

ENTER THE FOLLOWING FOR GROUPED DATA.

1. ENTER THE LOWEST OBSERVATION.

The low limit for the first interval of the collected data should be entered. Other prompts appear for the interval width and the number of intervals. After all entries are made, the user is given an opportunity to make corrections to the input. After interpreting the data entered, the screen is cleared and the entries are reprinted. Assuming these values were entered, the following is printed on the monitor:

1. ENTER THE LOWEST OBSERVATION	10
2. ENTER INTERVAL WIDTH FOR THE COLLECTED DATA	2
3. ENTER THE NUMBER OF INTERVALS	5

DO YOU WANT TO MAKE CORRECTIONS (Y/N) ?

The correction routine is self explanatory. Assuming that no corrections are needed, after the user enters 'N' for no corrections, the screen is cleared and the following is printed:

ENTER THE NUMBER OF OBSERVATIONS IN EACH INTERVAL.

1. ENTER THE OBSERVATIONS ON INTERVAL 1.

This is repeated for all the intervals. The correction routine interrupts the process after every five intervals to provide for error correction. After data is entered for the last interval, the following menu is printed:

1. PLOT FOR THE FITTED DISTRIBUTION
2. MAIN MENU

ENTER YOUR SELECTION.

The plot routine is used on selections 1, 2 and 3 of the main menu. It will now be explained.

After the user selects the plot of the distribution, 100 coordinates of the fitted beta function are calculated and plotted on the screen. Figure C7 shows a plot of a fitted beta function. The calculated beta parameters are printed on the plot. The message 'R-RETURN to MENU E-END AND SAVE VALUES' is printed below the plot. If the user is satisfied with the fitted distribution and no nonstationary parameters are to be specified, an 'E' is entered. This causes the program to jump directly to selection 6.

Selection 2 : Beta from Ungrouped Data--After a 2 is selected on the main menu, the screen is cleared and the following is printed:

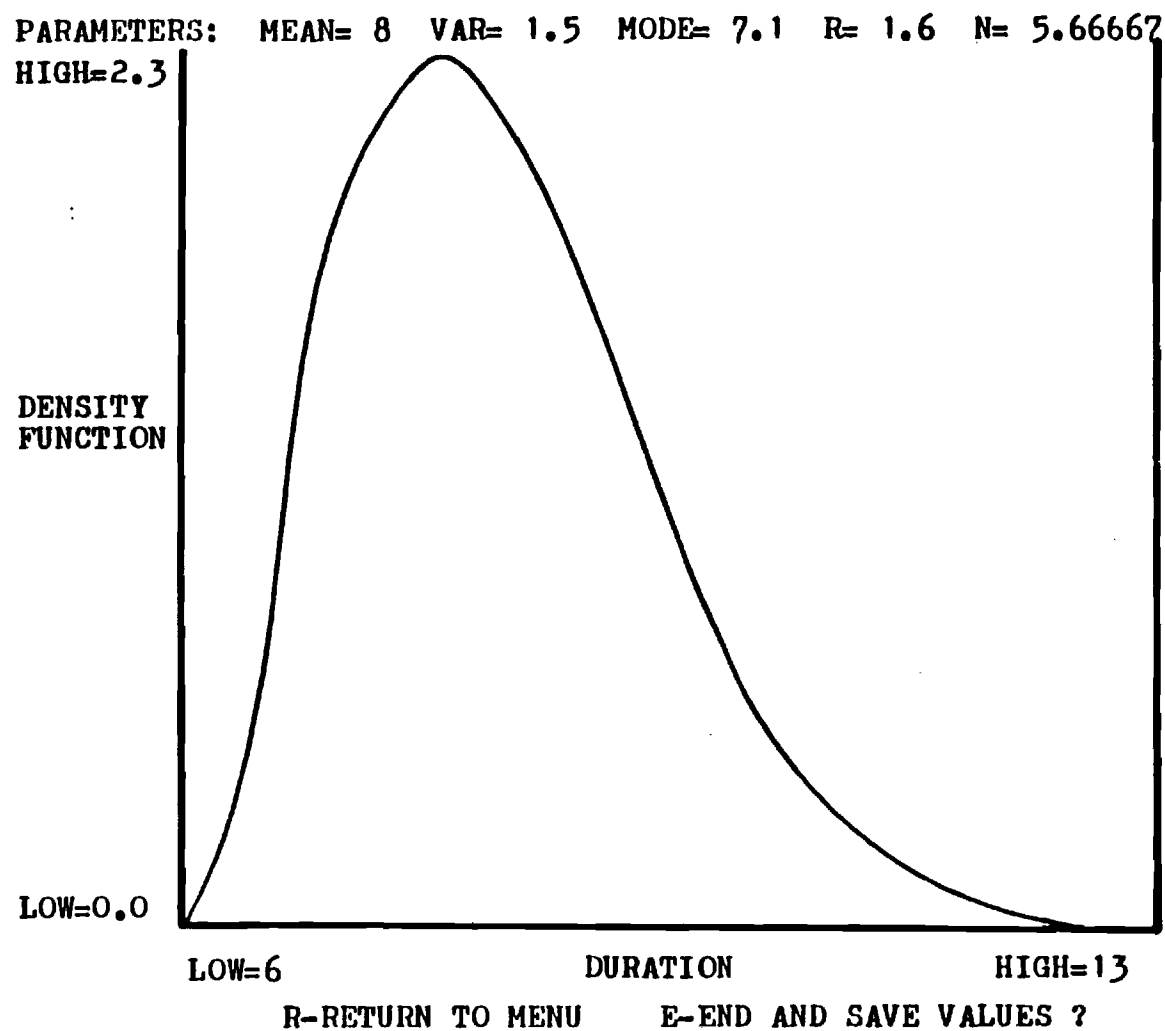


Figure C7. Typical Plot of Beta Distribution as Plotted on Screen.

UNGROUPEd DATA ANALYSIS

ENTER THE FOLLOWING NUMBER OF FIELD OBSERVATIONS.

After the number of observations for the duration of the activity is entered, the screen is cleared and the following is printed:

ENTER MORE FIELD OBSERVATIONS FOR DURATION OF
THE ACTIVITY TOTAL ENTERED UP TO NOW = 0

1. ENTER DATA POINT NUMBER 1

After entering the first data point, a prompt will appear for the second data point, etc. After five points are entered, the user is given the opportunity to make corrections on those five points. The following is printed on the screen at this moment (assuming these were the numbers entered).

1. ENTER DATA POINT 1	9.5
2. ENTER DATA POINT 2	9
3. ENTER DATA POINT 3	9.8
4. ENTER DATA POINT 4	8.5
5. ENTER DATA POINT 5	8.6

DO YOU WANT TO MAKE CORRECTIONS (Y/N) ?

This process is repeated for all observations in batches of five observations at a time. After all observations are entered, the screen is cleared and the following is printed:

1. PLOT OF THE FITTED DISTRIBUTION
2. MAIN MENU

ENTER SELECTION.

The plot routine is similar to that described under selection 1.

Selection 3 : Beta from Mean, Variance, Low and High Limit-- After the 3 is entered on the main menu, the screen is cleared and the following is printed:

ENTER THE FOLLOWING FOR THE DATA SAMPLE

1. SAMPLE MEAN

After the mean is entered, prompts appear for entering the sample variance, the low limit and high limit. The user is given a chance to corroborate the entries. Assuming these numbers were entered, the following is printed:

- | | |
|----------------------|----|
| 1. SAMPLE MEAN | 5 |
| 2. SAMPLE VARIANCE | 2 |
| 3. SAMPLE LOW LIMIT | 2 |
| 4. SAMPLE HIGH LIMIT | 10 |

DO YOU WANT TO MAKE CORRECTIONS (Y/N) ?

If no corrections are required, the following menu is printed:

1. PLOT OF FITTED DISTRIBUTION
2. MAIN MENU

ENTER SELECTION.

The plot routine is described under selection 1.

Selection 4 : Constant or Uniform Duration-- After a 4 is entered, the screen is cleared and the following is printed:

UNIFORM OR CONSTANT DISTRIBUTION (FOR CONSTANT DURATIONS ENTER THE LOW LIMIT EQUAL TO THE HIGH LIMIT)

1. ENTER THE LOWER LIMIT

After entering the lower limit, a prompt is printed for entering the high limit. The user is given the opportunity to make corrections. The following is printed at this point (assuming these numbers were entered):

1. ENTER THE LOW LIMIT	10
2. ENTER THE HIGH LIMIT	20

DO YOU WANT TO MAKE CORRECTIONS (Y/N) ?

Assuming no corrections are required, the user is given the opportunity of saving the values or returning to the main menu.

Selection 5 : Nonstationary Component--After this option is selected, the following prompt is printed on the monitor:

NONSTATIONARY COMPONENT

1. ENTER INITIAL DURATION

After the initial duration is entered, prompts are printed for entering the initial duration, the intermediate duration, number of realizations to the intermediate duration, the final duration, number of realizations to the

final duration, the interpolation method and the node to be used as counter for the realizations. The following illustrates these entries.

1. ENTER THE INITIAL DURATION	10
2. ENTER THE INTERMEDIATE DURATION	17.5
3. ENTER REALIZATIONS TO INTERMEDIATE DURATION	50
4. ENTER THE FINAL DURATION	20
5. ENTER REALIZATIONS TO FINAL DURATION	100
6. Q - Quadratic S - Spline L - Linear	Q
7. NODE TO BE USED AS REALIZATIONS COUNTER	5

DO YOU WANT TO MAKE CORRECTIONS (Y/N) ?

If no corrections are required, the program prints the following menu:

1. PLOT REPRESENTATIVE OF INTERPOLATION METHOD
2. RETURN TO MAIN MENU

If the user selected number 1, the fitted curve is plotted on the screen. The following one line menu appears below the plot:

R - RETURN TO MENU Q - QUADRATIC L - SPLINE ?

The user has the opportunity of changing the curve fitted from his/her original selection to the other two options. In the example above, if the user selects the L, a linear interpolation between the three points is plotted on the monitor and the one line menu is repeated. When the user is satisfied with the fit, the R should be entered to return to the main menu.

Selection 6 : Save Duration Set on Disk-- After the 6 is selected on the main menu, the screen is cleared and the following is printed (hypothetical numbers):

THE PARAMETERS FOR THE BETA DISTRIBUTION ARE :

A = 10 B = 15 R = 4 N = 8

1. ENTER A NUMERICAL LABEL FOR THIS PARAMETER SET

After the numerical label is entered, the set is saved on disk. The program is run again internally. This results in the main menu being printed on the screen. It is now ready for another parameter set.

C.6.2 Model Module

This program consists of standard CYCLONE models for the road construction. For each road construction activity to be analyzed, the computer describes the standard CYCLONE

networks. The user inputs process keyname, quantity, work task durations, number of resources, costs and data file name to the standard CYCLONE network to be used. After all the entries are made correctly, the program automatically generates the CYCLONE problem oriented language specification for the chosen standard CYCLONE model. Then, the input module is loaded in order to process the CYCLONE problem oriented language specification.

The user has the option in this module to reject the standard CYCLONE networks presented and to define his/her own cyclic network in CYCLONE problem oriented language format. This user defined network is then utilized for the productivity calculations and is stored for future reference and utilization.

Once the program is loaded, the screen is cleared and the following is printed on the screen. It is menu driven.

STANDARD CYCLONE MODELS MENU

1. CLEARING AND GRUBBING
2. STRIPPING
3. EXCAVATION
4. DITCHING
5. PLACING, SPREADING, COMPACTION AND GRADING OF
SUBGRADE

6. PLACING, SPREADING, COMPACTION AND GRADING OF
NONSTABILIZED BASE OR SUBBASE
7. PLACING, SPREADING, COMPACTION AND GRADING OF
STABILIZED BASE OR SUBBASE
8. ASPHALT PAVING
9. CONCRETE PAVING
10. USER SPECIFIED CYCLONE MODEL

ENTER YOUR SELECTION.

The user needs to input information regarding work task durations, number of resources, costs and etc. in Selections 1 through 9. After all entries are made, the user is given an opportunity to make corrections to the input. After the correction routine, the program automatically generates the CYCLONE problem oriented language description for the standard CYCLONE model and the input module is loaded next.

All these selections will now be explained.

Selection 1 : Clearing and Grubbing-- After a 1 is entered, the screen is cleared and the following is printed on the screen :

1. STANDARD CLEARING AND GRUBBING CYCLONE MODEL #1

THE ONLY EQUIPMENT USED IS A CLEARING/GRUBBING UNIT
(E.G. DOZER). THE WORK TASKS ARE PUSHING FORWARD,
STOCKPILING, BACKING UP AND BURNING.

2. STANDARD CLEARING AND GRUBBING CYCLONE MODEL #2

THE EQUIPMENTS USED ARE CLEARING/GRUBBING UNIT (E.G.
DOZER), LOADING UNIT (E.G. FRONT END LOADER) AND
HAULING UNIT (E.G. TRUCK). THE WORK TASKS ARE
PUSHING FORWARD, STOCKPILING, BACKING UP, LOADING,
HAULING, DUMPING AND RETURNING.

ENTER YOUR SELECTION.

If standard clearing and grubbing CYCLONE model #1 is
chosen, the screen is cleared and several prompts appear for
process keyname, area to be cleared in acres, area cleared
in each pass in square feet, pushing forward duration in
minutes, stockpiling duration in minutes, backing up
duration in minutes, number of clearing/grubbing units,
fixed and variable costs per unit and data file name. After
all entries are made, the screen is cleared and the entries
are reprinted. Assuming these values were entered, the
following is printed on the monitor :

PROCESS KEYNAME	= CLEARING
AREA TO BE CLEARED	= 5.00 AC.
AREA CLEARED IN EACH PASS	= 200.00 SQ. FT.
PUSHING FORWARD DURATION	= 2.00 MIN.
STOCKPILING DURATION	= 1.00 MIN.
BACKING UP DURATION	= 1.00 MIN.
NUMBER OF CLEARING/GRUBBING UNITS	= 1
FIXED COST	= \$0.00
VARIABLE COST	= 50.00 \$/HR
DATA FILE NAME	= CL1

ARE THESE CORRECT (Y/N) ?

The correction routine is self explanatory.

If standard clearing and grubbing CYCLONE model #2 is chosen, the screen is cleared and several prompts appear for process keyname, area to be cleared in acres, area cleared in each pass in square feet, pushing forward duration in minutes, stockpiling duration in minutes, backing up duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, number of clearing and grubbing units, fixed and variable costs per unit, number of loading units, fixed and variable costs per unit, number of hauling units, fixed and variable costs per unit and data file name.

Selection 2 : Stripping-- After a 2 is selected on the menu, the screen is cleared and the following is printed on the screen :

STANDARD STRIPPING CYCLONE MODEL

THE ONLY EQUIPMENT USED IS AN EXCAVATING/LOADING/
HAULING/DUMPING/SPREADING UNIT (E.G. SCRAPER).

THE WORK TASKS ARE EXCAVATING/LOADING, HAULING,DUMPING/
SPREADING AND RETURNING.

PRESS ENTER.

After the user presses enter, the screen is cleared and several prompts appear for process keyname, area in acres, top soil in inches, excavating/loading duration in minutes, hauling duration in minutes, dumping/spreading duration in minutes, number of excavating/loading units, fixed and variable costs per unit and data file name.

Selection 3 : Excavation-- After a 3 is entered, the screen is cleared and the following is printed on the screen :

1. STANDARD EXCAVATION CYCLONE MODEL #1

THE EQUIPMENTS USED ARE EXCAVATING UNIT (E.G. FACE SHOVEL), LOADING UNIT (E.G. FRONT END LOADER), HAULING UNIT (E.G. TRUCK) AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE EXCAVATING, STOCKPILING SOIL, LOADING, HAULING, DUMPING, RETURNING AND SPREADING DIRT.

2. STANDARD EXCAVATION CYCLONE MODEL #2

THE EQUIPMENTS USED ARE EXCAVATING/LOADING/HAULING/SPREADING UNIT (E.G. SCRAPER) AND PUSHING UNIT (E.G. PUSHER). THE WORK TASKS ARE PUSHING/LOADING, HAULING, DUMPING/SPREADING AND RETURNING.

3. STANDARD EXCAVATION CYCLONE MODEL #3

THE EQUIPMENTS USED ARE EXCAVATING/LOADING UNIT (E.G. CRANE), HAULING UNIT (E.G. TRUCK) AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE EXCAVATING, LOADING, HAULING, DUMPING, RETURNING AND SPREADING.

ENTER YOUR SELECTION.

If standard excavation CYCLONE model #1 is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., excavation duration in minutes, stockpiling duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, spreading duration in minutes, number of excavating units, production capacity in c.y., fixed and variable costs per unit, number of loading units, production capacity in c.y., fixed and variable costs per unit, number of spreading units, fixed and variable costs per unit and data file name.

If standard excavation CYCLONE model #2 is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., pushing/loading duration in minutes, hauling duration in minutes, dumping/spreading duration in minutes, returning (excavating/loading unit) duration in minutes, returning (pushing unit) duration in minutes, number of excavating/loading units, production capacity in c.y., fixed and variable costs per unit, number of pushing units, fixed and variable costs per unit and data file name.

If standard excavation CYCLONE model #3 is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., excavation duration in minutes, loading duration in minutes, hauling duration in minutes,

spreading duration in minutes, number of excavating/loading units, production capacity in c.y., fixed and variable costs per unit, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of spreading units, fixed and variable costs per unit and data file name.

Selection 4 : Ditching-- After a 4 is selected on the menu, the screen is cleared and the following is printed on the monitor :

1. STANDARD DITCHING CYCLONE MODEL #1

THE EQUIPMENTS USED ARE DITCHING UNIT (E.G. DITCHER) , LOADING UNIT (E.G. FRONT END LOADER), HAULING UNIT (E.G. TRUCK) AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE DITCHING, LOADING, HAULING, DUMPING, RETURNING AND SPREADING.

2. STANDARD DITCHING CYCLONE MODEL #2

THE EQUIPMENTS USED ARE DITCHING/LOADING UNIT (E.G. DITCHER), HAULING UNIT (E.G. TRUCK) AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE DITCHING, LOADING, HAULING, DUMPING, RETURNING AND SPREADING.

ENTER YOUR SELECTION.

If standard ditching CYCLONE model #1 is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., ditching duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, spreading duration in minutes, number of ditching units, production capacity in c.y., fixed and variable costs per unit, number of loading units, production capacity in c.y., fixed and variable costs per unit, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of spreading units, fixed and variable costs per unit and data file name.

If standard ditching CYCLONE model #2 is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., ditching duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, spreading duration in minutes, number of ditching/loading units, production capacity in c.y., fixed and variable costs per unit, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of spreading units, fixed and variable costs per unit and data file name.

Selection 5 : Placing, Spreading, Compaction and Grading of Subgrade-- After a 5 is entered, the screen is cleared and the following is printed on the screen :

STANDARD PLACING, SPREADING, COMPACTION AND FINAL
GRADING OF SUBGRADE CYCLONE MODEL

THE EQUIPMENTS USED ARE LOADING UNIT (E.G. FRONT END
LOADER), HAULING UNIT (E.G. TRUCK), WATER SPRAYING UNIT
(E.G. WATER TRUCK), SPREADING/COMPACTING UNIT (E.G.
DOZER) AND FINAL GRADING UNIT (E.G. MOTOR GRADER).

THE WORK TASKS ARE LOADING, HAULING, DUMPING, RETURNING
, WATER SPRAYING, SPREADING/COMPACTING AND FINAL
GRADING.

PRESS ENTER.

After the user presses enter, the screen is cleared and
several prompts for process keyname, quantity in c.y.,
loading duration in minutes, hauling duration in minutes,
dumping duration in minutes, returning duration in minutes,
water spraying duration in minutes, spreading/compacting
duration in minutes, final grading duration in minutes,
number of loading units, production capacity in c.y., fixed

and variable costs per unit, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of water spraying units, fixed and variable costs per unit, number of spreading/compacting units, fixed and variable costs per unit, number of final grading units, fixed and variable costs per unit and data file name.

Selection 6 : Placing, Spreading, Compaction and Grading of Nonstabilized Base or Subbase-- After a 7 is selected on the menu, the screen is cleared and the following is printed on the monitor :

STANDARD PLACING, SPREADING, COMPACTION AND GRADING OF
NONSTABILIZED BASE OR SUBBASE CYCLONE MODEL

THE EQUIPMENTS USED ARE SPREADING UNIT (E.G. DOZER),
WATER SPRAYING UNIT (E.G. WATER TRUCK) AND COMPACTION
UNIT (E.G. DOZER).

THE WORK TASKS ARE SPREADING, WATER SPRAYING AND
COMPACTION.

PRESS ENTER.

After the user presses enter, the screen is cleared and several prompts appear for process keyname, quantity in

c.y., spreading duration in minutes, water spraying duration in minutes, compaction duration in minutes, number of spreading units, production capacity in c.y., fixed and variable costs per unit, number of water spraying units, fixed and variable costs per unit, number of compaction units, fixed and variable costs per unit and data file name.

Selection 7 : Placing, Spreading, Compaction and Grading of Stabilized Base or Subbase-- After a 7 is entered, the screen is cleared and the following is printed on the screen :

1. STANDARD PLACING, SPREADING, COMPACTION AND GRADING
OF STABILIZED BASE OR SUBBASE CYCLONE MODEL #1
(MIXED IN PLACE)

THE EQUIPMENTS USED ARE SCARIFYING UNIT (E.G. SCARIFIER), STABILIZER APPLICATION UNIT (E.G. MECHANICAL SPREADER), WATER SPRAYING UNIT (E.G. WATER TRUCK), PULVERIZING/MIXING UNIT (E.G. MIXER) AND COMPACTING UNIT (E.G. ROLLER).

THE WORK TASKS ARE SOIL PREPARATION, STABILIZER APPLICATION, WATER SPRAYING, PULVERIZING/MIXING AND COMPACTION.

2. STANDARD PLACING, SPREADING, COMPACTION AND GRADING
OF STABILIZED BASE OR SUBBASE CYCLONE MODEL #2
(CENTRAL PLANT)

THE EQUIPMENTS USED ARE HAULING UNIT (E.G. TRUCK),
SPREADING UNIT (E.G. DOZER), WATER SPRAYING UNIT
(E.G. WATER TRUCK) AND COMPACTION UNIT (E.G.
ROLLER.

THE WORK TASKS ARE STABILIZER BATCH PREPARATION,
LOADING, HAULING, DUMPING, SPREADING, WATER
SPRAYING AND COMPACTION.

ENTER YOUR SELECTION.

If standard CYCLONE model #1 (mixed in road) is chosen,
the screen is cleared and several prompts appear for process
keyname, quantity in c.y., soil preparation duration in
minutes, stabilizer application duration in minutes, water
spraying duration in minutes, pulverizing/mixing duration in
minutes, compaction duration in minutes, number of
scarifying units, production capacity in c.y., fixed and
variable costs per unit, number of stabilizer application
units, fixed and variable costs per unit, number of water
spraying units, fixed and variable costs per unit, number of

pulverizing/mixing units, fixed and variable costs per unit, number of compaction units, fixed and variable costs per unit and data file name.

If standard CYCLONE model #2 (central plant) is chosen, the screen is cleared and several prompts appear for process keyname, quantity in c.y., mixing duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, spreading duration in minutes, water spraying duration in minutes, compaction duration in minutes, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of spreading units, fixed and variable costs per unit, number of compacting units, fixed and variable costs per unit and data file name.

Selection 8 : Asphalt Paving-- After an 8 is selected on the menu, the screen is cleared and the following is printed on the screen :

STANDARD ASPHALT PAVING CYCLONE MODEL

THE EQUIPMENTS USED ARE HAULING UNIT (E.G. TRUCK),
PAVING UNIT (E.G. PAVER) AND COMPACTING UNIT (E.G.
ROLLER).

THE WORK TASKS ARE ASPHALT BATCH PREPARATION, LOADING,
HAULING, DUMPING, RETURNING, PLACING AND COMPACTING.

PRESS ENTER.

After the user presses enter, the screen is cleared and several prompts appear for process keyname, quantity in c.y., preparing asphalt batch duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of paving units, fixed and variable costs per unit, number of compacting units, fixed and variable costs per unit and data file name.

Selection 9 : Concrete Paving-- After a 9 is entered, the screen is cleared and the following is printed on the monitor :

STANDARD CONCRETE PAVING CYCLONE MODEL

THE EQUIPMENTS USED ARE HAULING UNIT (E.G. TRUCK),
PAVING UNIT (E.G. PAVER) AND FINISHING UNIT (E.G.
FINISHER).

THE WORK TASKS ARE CONCRETE BATCH PREPARATION, LOADING,
DUMPING, RETURNING, PLACING AND FINISHING.

PRESS ENTER.

After the user presses enter, the screen is cleared and several prompts appear for process keyname, quantity in c.y., preparing concrete batch duration in minutes, loading duration in minutes, hauling duration in minutes, dumping duration in minutes, returning duration in minutes, placing duration in minutes, finishing duration in minutes, number of hauling units, production capacity in c.y., fixed and variable costs per unit, number of paving units, fixed and variable costs per unit, number of finishing units, fixed and variable costs per unit and data file name.

Selection 10 : User Specified CYCLONE Model-- After a 10 is selected on the menu, the screen is cleared and the following appears on the screen :

DO YOU HAVE A DATA FILE (Y/N) ?

After the user answers the above question, another prompt appears for the data file name. After the user enters the data file name, the following menu is displayed on the monitor :

USER SPECIFIED CYCLONE MODELS MENU

1. DATA ENTRY
2. ADD A LINE
3. DELETE A LINE
4. EDIT A LINE
5. DISPLAY
6. PRINT
7. SIMULATE
8. STANDARD CYCLONE MODELS MENU

ENTER YOUR SELECTION.

All these selections will now be explained.

Selection 1 : Data Entry-- After a 1 is entered, the screen is cleared and the following is printed on the monitor :

PRESS ENTER WHEN THROUGH.

LINE #1 ?

The user should enter the CYCLONE problem oriented language specification one line at a time. This process is

repeated until the user presses enter when the prompt for a new line appears.

Selection 2 : Add a Line-- After a 2 is selected from the menu, the screen is cleared and the following is printed on the monitor :

NOTE : YOU SHOULD SPECIFY THE LINE NUMBER.

E.G. ENTER 3 IF YOU WANT TO INSERT A LINE
BETWEEN LINES 2 AND 3.

ENTER 0 WHEN THROUGH.

NEW LINE NUMBER ?

After the user enters the new line number, another prompt appears for entering the line. This process is repeated until the user enters 0 for the new line number.

Selection 3 : Delete a Line-- After a 3 is entered, the screen is cleared and the following is printed on the screen :

ENTER 0 WHEN THROUGH.

LINE NUMBER TO BE DELETED ?

After the user enters the line number, the computer prints the line and gives the user an opportunity to change

his/her mind. The deletion process is repeated until the user enters 0 for the line number to be deleted.

Selection 4 : Edit a Line-- After a 4 is selected, the screen is cleared and the following is printed on the monitor :

ENTER 0 WHEN THROUGH.

LINE NUMBER TO BE EDITED ?

After the user enters the line number to be edited, the computer prints the line and a prompt for entering the revised line appears on the screen. The editing process is repeated until the user enters 0 for the line to be edited.

Selection 5 : Display-- After a 5 is selected on the menu, the screen is cleared and the first 8 lines of the CYCLONE problem oriented language specification is printed on the monitor. A prompt for continuing or returning to the previous 8 lines appears on the screen. This process is repeated until all of the CYCLONE problem oriented language specification are printed on the monitor.

Selection 6 : Print-- After a 6 is entered, the CYCLONE problem oriented language specification is printed on the printer. Then the menu is displayed on the monitor.

Selection 7 : Simulate-- After a 7 is selected on the menu, the input module is loaded for processing the CYCLONE problem oriented language specification.

Selection 8 : Standard CYCLONE Models Menu-- After an 8 is entered, the screen is cleared and the standard CYCLONE models menu is displayed on the monitor.

C.6.3 Input Module

This program contains data processing routines translating CYCLONE problem oriented language into internal data structure. It also contains error trapping routines.

While the program is being executed, it prints on the monitor the sentence that is processing at that point. If a fatal error is detected at this stage, an error message is printed below the sentence and program execution is stopped. The user should make the appropriate corrections to the CYCLONE problem oriented language specification and rerun the program. The following example illustrates the detection of an error while processing an activity :

PROCESSING LINE

10 COMBI 'DUMP' PRE 3 4 FOL 1 2

DURATION SET MISSING

BREAK

The error trapping routine is directed toward identifying errors on network logic, data omission, illogical entries and lack of data. Network errors are checked after all the CYCLONE problem oriented language specification have been processed. If there are no errors detected, the data is saved on the disk and the simulation program is run. The CYCLONE problem oriented language is described in Appendix B.

In case of an error and interruption in the program execution, the user should type RUN MODEL1/CYC and press enter in order to run the model module.

C.6.4 Simulation Module

This is the program in charge of conducting the simulation and collecting statistics. It also contains error trapping routines. If an error is detected during program execution, control is automatically transferred to the network logic report. This report is covered in the user guide for report module. This program prints on the monitor the event list and the chronological list while simulation is being conducted.

Simulation module loads data from the file "keyname of process"/DAT which is produced by the input module. It then

proceeds with simulation. Figure C8 shows the screen content during a typical simulation run. The event list shows the activities as they are scheduled while the chronological list shows the activities in time order as simulation time is advanced. When simulation ends, the output is saved on file "keyname of process"/OUT. The following menu is printed. It is self explanatory.

PLEASE SELECT

1. LOAD THE REPORT MODULE
2. REPORT BY ELEMENT IN THIS PROGRAM (MAINLY FOR
DEBUGGING)

ENTER SELECTION.

C.6.5 Report Module

This program prints various types of reports. It loads data from file "keyname of process"/OUT created at the end of simulation module. The following is printed after the data is loaded from disk.

MAIN MENU

- | | |
|------------------------|-----------------------|
| 1. REPORT BY ELEMENT | 2. CYCLONE MONITORING |
| 2. PRODUCTION BY CYCLE | 4. PROCESS SUMMARY |

```

*****
                EVENT LIST                      CHRONOLOGICAL LIST
Label  T-NOW  DURA.  E.E.T.    LABEL  T-NOW  E.E.T.  COUNTER
*****
    4      0.0   4.0    4.0      4      0.0   4.0    1
    5      4.0  15.0   19.0      5      4.0  19.0    1
    6      4.0  20.0   24.0      4      19.0  23.0    2
    4     19.0   4.0   23.0      6      4.0  24.0    1
    5     23.0  15.0   38.0      5     23.0  38.0    2
    6     23.0  20.0   43.0      4     38.0  42.0    3
    4     38.0   4.0   42.0      6     23.0  43.0    2
    5     42.0  15.0   57.0      5     42.0  57.0    3
    6     42.0  20.0   62.0      4     57.0  61.0    4
*****

```

Figure C8. Typical Simulation Run

5. NETWORK LOGIC REPORT

6. SYSTEM MENU

ENTER SELECTION.

Each report will now be explained.

Selection 1 : Report by Element-- When 1 is selected on the main menu, this secondary menu is printed:

1. SORTED BY LABEL IN INCREASING ORDER
2. USER DEFINED REPORT
3. PRECEDERS AND FOLLOWERS OF SELECTED COMBI

ENTER SELECTION.

All of these three reports provide the same information about the nodes included in the report. They only differ on the nodes included. Selection 1 includes all sorted by numerical label in increasing order. Selection 2 is used to prepare user defined reports. The third selection is very useful when studying the behavior of a COMBI activity. The only nodes in this report are the preceding Que nodes, the followers of the selected COMBI and the COMBI itself. Figure C9 shows a typical report prepared under selection 1.

Selection 2 : CYCLONE Monitoring-- This report is a list of the activities as they are executed during

```

*****
TYPE LABEL DESCRIPTION                               STATISTICS
*****

QUE      2 TRUCK IDLE      AVE WAIT =  0.44  AVE UNITS =  0.4
                                PERC BUSY = 34    UNITS END =  0

COMBI    3 DIVERT TO BCKHOE  MEAN DUR =  0.10    ARTIME =  2.4
                                COUNT =    51 AVE NUMBER = 0.042 PERC BUSY =  04

COMBI    4 DIVERT TO F.L.    MEAN DUR =  0.10    ARTIME =  2.3
                                COUNT =    52 AVE NUMBER = 0.043 PERC BUSY =  04

QUE      5 WAIT LOADED      AVE WAIT =  0.00  AVE UNITS =  0.0
                                PERC BUSY =   00    UNITS END =  0

QUE      6 BCKHOE IDLE      AVE WAIT =  0.00  AVE UNITS =  0.0
                                PERC BUSY =   00    UNITS END =  0

```

Figure C9. Typical Report by Elements

simulation. It contains the description of the activity, its numerical label, its start time (TNOW), its end event time (E.E.T.) and the number of times it has been realized (COUNT). Only ten activities are printed on the monitor at any one time. The menu 'R-RETURN TO LAST PAGE M-MAIN MENU C-CONTINUE' appears below these ten activities. A 'C' causes the next ten activities to be printed. An 'R' prints the ten previously printed activities. The 'M' takes the user back to the main menu. Figure C10 illustrates a typical cycle monitoring report.

Selection 3 : Production by Cycle-- Many processes go through a transient state at which production is changing with time. After this state, production stabilizes and gets constant or nearly constant. The production by cycle report is designed to help the user identify at what cycle or after how many iterations, the system approaches steady state behavior.

The production by cycle report prints productivity statistic for the first 100 cycles. For each cycle, the simulation time, the cycle number and the productivity are printed. Figure C11 illustrates a typical production by cycle report. The production figure is based on the units for the quantity multiplier specified in the control input paragraph and the same time units as the simulation time. As in the case of the cycle monitoring report, only ten

```

*****
DESCRIPTION                                LABEL  T-NOW  E.E.T.  COUNTER
*****
DIVERT TO F.L.                            4      0.0    0.0      1
DIVERT TO BCKHOE                          3      0.0    0.1      1
1 CYCLE F.E.L.                            8      0.1    1.6      1
1 CYCLE B.H.                             7      0.1    1.6      1
TRUCK LOADED                             12     1.6    2.4      1
TRUCK LOADED                             11     1.6    2.4      1
DIVERT TO F.L.                            4      2.4    2.5      2
DIVERT TO BCKHOE                          3      2.4    2.5      2
TRAVEL                                    15     2.4    3.9      1
TRAVEL                                    15     2.4    3.9      2
*****

```

Figure C10. Typical Cycle Monitoring Report

SIMULATION TIME	CYCLE NUMBER	PRODUCTIVITY

4.3	1	2.35
4.3	2	4.70
6.6	3	4.54
6.7	4	5.96
8.9	5	5.64
9.9	6	6.07
11.3	7	6.19
12.1	8	6.60
13.6	9	6.62
14.5	10	6.88

Figure C11. Typical Production by Cycle Report

lines can be printed on the screen at any one time. The following menu is printed below these ten lines:

R-RETURN TO LAST PAGE M-MAIN MENU C-CONTINUE

The 'R' prints the ten previously printed lines, the 'C' prints the next ten lines and the 'M' returns the user to the main menu.

Selection 4 : Process Summary -- The information included in this report is :

1. Process name and number
2. Run length
3. Final count on counter node
4. Units produced per hour
5. Total production
6. Productivity
7. Unit Cost
7. Total cost
8. Unit Cost

The production figure is based on the units for the quantity multiplier specified in the counter node and the time units of the simulation time. Some of the items in this report may be missing if not enough data is entered. Figure C12 illustrates a sample process summary report.

Selection 5 : Network Logic Report-- This report describes the logical relationship between the elements in the network. It also prints a description of the number of


```

*****
*           PROCESS REPORT                NAME : EXC2           *
*****

RUN LENGTH                                107.22
COUNT ON PRODUCTION COUNTER              41.00
UNITS PRODUCED PER CYCLE                   19.50
TOTAL PRODUCTION                           799.50
UNITS PRODUCED PER HOUR                     477.40
TOTAL COST                                1926.39

```

Figure C12. Typical Process Report

units in the Que nodes. Simulation module transfers control to this report when an error is detected during a simulation run. Figure C13 shows a typical network logic report.

Selection 6 : System Menu -- After a 6 is selected from the menu, the screen is cleared and the system menu is loaded.

```

*****
NETWORK LOGIC DUMP REPORT
*****

```

```

NODE 1 FUNCTION  FOLL 2
NODE 2 NORMAL    FOLL 3
NODE 4 COMBI     PRECED 3 7 8 FOLL 5 6
NODE 5 NORMAL    FOLL 1 9
NODE 6 NORMAL    FOLL 7
NODE 9 FUNCTION  FOLL 8

```

```

*****
QUE CONTENT DUMP REPORT
*****

```

```

QUE 3 HAS 5 UNITS. IT IS INITIALIZED WITH 1 UNITS
QUE 7 HAS 2 UNITS. IT IS INITIALIZED WITH 3 UNITS
QUE 8 HAS 1 UNITS. IT IS INITIALIZED WITH 1 UNITS

```

```

*****

```

Figure C13. Typical Network Logic Report

Appendix D

Integrated Cost Optimization

MICRO-COMPUTER
COST OPTIMIZATION OF EARTH MOVING
OPERATIONS

Introduction

The optimal allocation of resources is a well known problem. Like mother nature, human beings must continuously adapt to changed conditions and find new solutions. In the world of business, however, the available time for finding the optimal solution is very short. Especially in the construction industry errors and miscalculations in such a process can have costly effects. Systematic approaches for repetitive optimizations support the decision maker. Computers, on the other hand, allow the implementation of such structured systems, reducing the time factor considerably.

This paper presents a cost optimization system for Micro-computers which exploits modern scientific models by using the power of small computers. The program runs on Apple II and IBM-PC, both with 64-K bytes Central Memory and an 80 column Epson printer. A hypothetical small scale earthwork project is used to explain the necessary procedures. Following the presentation of the system, a discussion shows possibilities for further improvements.

Meth. dology

Three main modules represent the backbone of the system. These are (1) the Data Base, (2) the Cyclone (Cyclic Operations Network) Model and (3) the Optimization module using a linear programming algorithm. Three minor modules are responsible for user friendliness: Main-Menu, Job Description and Fleet Combinations. Appendix #1 gives an overview of the total system, stressing the relationship between the modules.

The Data Base

An accurate Data Base stores various information about equipment and supports the other modules or subprograms. These modules access the data base automatically and retrieve the necessary data. A subprogram allows the user to set up and edit the Data Base. The subprogram organizes the storing of the data. This ground work has to be done separately and before the user makes the first optimization run.

The Cyclone Model

Cyclone calculates the necessary operating days for a previously defined earthwork project. The method focuses on how an operation is accomplished and how the interplay of resources impacts the productivity. Since Cyclone is a simulation model it takes into account all the relations between the different units (e.g. loads-truck) and the site condition like material or hauling distances.

The Optimization Model

The mathematical model used for cost optimization (minimization) is linear programming (simplex algorithm). The optimal solution is that fleet combination which is able to perform the job at the lowest cost while fulfilling the defined requirements as constraints. In order to develop the hierarchy between the best solutions (suppose all are within the constraints), the optimization results in a repetitive procedure.

Since the result of the optimization is not a single number but rather a hierarchical list of the best solutions, supported with cost and other figures, the user has the opportunity of considering the different outcomes of his options. Most importantly, he is able to conduct a sensitivity analysis.

Main Menu

This subprogram is the corner-stone for running the integrated program package. The menu offers a set of options (menu) to choose from each time a module has been finished. The menu-driven organization of the model contributes to the user-friendliness of the system.

Job Description Subprogram

The Job Description module serves as the main input vehicle. Most job related information, needed to run the program, has to be keyed in. This is accomplished by answering a set of questions sequentially printed on the screen. These questions concern starting and ending dates, amount of excavating or filling, soil conditions, and similar problem constraints.

Fleet Combinations Subprogram

The task of this module is to create several equipment fleets, each of which is able to handle the job. Since the whole system is a tool to find the optimal equipment combination, it is assumed that the user has several options. At this stage the user is also able to feed in his own judgement concerning the productivity of each type of equipment as a deviation from a standard production, defined in the Data Base.

This optimization package tries to combine the user's way of thinking with modern scientific models, offering him a structured environment to exercise his own creativity and judgement. The system simplicity makes it a most efficient tool to support the repetitive decision making of an earthwork contractor.

Equipment Data Base Structure

By definition data bases are collections of data that are designed to be used for different applications. The data base module uses the traditional file method where all data are stored in one file since Micro-computers have focuses on support for a single use. The structure can be best described as an enlarged inventory record keeping structure. Enlarged here means that in addition to inhouse equipment, rented machines are also included. It must be understood that in order to assure accuracy, the database has to be updated periodically--or when a change in the equipment fleet occurs. An example of the stored data for one particular equipment category and its organization is presented in the following chart.

Data Definition

Model: The Model of the machine is used as the key for machine related data

Amount: Number of units of this model type available in the equipment part of the company. For rented models the user should declare a large number. (e.g. 999)

Bucket Size: Standard bucket size

Cycle Time: Standard time for one cycle, where one cycle is defined as the action of filling and dumping one bucket to a track.

Fixed and

Variable Cost: The user has different options in defining the model related cost figures, or leave them blank, since there will be an opportunity to edit the cost figures for each project. It is however recommended standard costs be established in order to take full advantage of the data base. The user, however, still has a lot of freedom in defining how he wants to spread the costs to the different cost categories.

Job Description

Since the accruing costs of a construction project originate from different sources and are determined by various conditions, the variables

[illegible]

which have to be considered in the decision process are numerous. Although the final outcome of each job is highly variable, the financial risk can be decreased by considering the most crucial factors in the estimating and the decision making process. The use of the systematic approach introduced here, makes sure that the user is aware of typical risk areas and that he will not overlook one of them.

Each earthwork or construction job in general encompasses variables from four main areas:

- (1) Contract
- (2) Site and Material
- (3) Equipment
- (4) Finance

The description of the job (i.e. the information needed by the system) is related to the four areas. The input required data is accomplished using a simple question and answer method.

The following questions need a specific response:

Contract

1. Start date
2. Available total operating days
3. Bid price
4. Billing concept (lumpsum, percentage of completion,
Advance payment)
5. Bank charge for project account

Site and Material

1. Amount of material for hauling (loose or bank measure)
2. Average haul distance
3. Material, aggregates, density
4. Expected number of rainy days
5. Daily job overhead (site & overhead)
6. Show up payments per rainy day/labor unit

Finance

1. Average interest rate for project related capital
2. Max allowable overdraft

Equipment

1. Job related production as deviation from standard
2. Job related productivity as deviation from standard
(breakdown, personnel, etc.)

Since the last area of data is related to a specific fleet or machine, it will not be a part of the general description but will be input when defining a given equipment combination.

Definition of Equipment Combination

In this module the system combines the power of the data base and the construction experience and imagination of the user. Since the goal of this optimization program is to find the best fleet which is able to perform the job under the given constraints, it needs at two options from which choose. Therefore the equipment definition is a repetitive procedure. Although the actual choices may be limited to one (no reason for optimization) the optimization can still be useful. The manager can profit by comparing his limited choice with other possibilities and calculating opportunity costs.

Since this subprogram is supported by the data base, the creation of fleets is simple. First the system wants to know if the fleet is based on scrapers or trucks. The next steps require the choice of category and machine item, which leads to option of reviewing and editing the standard factors stored in the data base. A rough calculation after each choice presents the number of the particular equipment which is needed to finish the job within the prescribed time. The last calculation is based on the job description and the accepted or edited figures from the data base. For example, the material conditions are automatically considered and after the cycle times for loaders are adequately adjusted.

Simulation

The simulation of the different fleets is accomplished using the Cyclone program. It is assumed that the user is fairly well acquainted with the theory of the CYCLONE simulation system, although it is not

STRUCTURE OF A FLEET DATA FILE

Fleet #	Elements and Models	Amount	Prod/Unit	Adjusted Cycle Time	Fixed Cost	Operator Cost/Day	Operation Cost/Day	Deprec. Cost/Day	O/H Cost/Day	Markup/Day
1	a)Wheeled Loaders xy b)Trucks xy yx c)Spreader xy d)Compactors xy									
2										
3										

required to know the model in great detail. Cyclone is organized in two main parts; network modeling and actual simulation. An integrated library of standard models releases the user from the modeling task and enhances the user friendliness of the package. A special subprogram matches the prepared fleets with the appropriate model. During this procedure the system combines the information stored in the data-base, job description, the cyclone model library and the previously defined fleet combinations for this job. Each fleet is therefore automatically transferred to the appropriate Cyclone network, and is ready to be simulated.

The goal of the simulation is to interrelate the different equipment of one fleet (e.g. excavator-hauler-spreader-compactor) and calculate the productive and idle times of each unit. The course of development of a single simulation can be best shown in a graph time versus productivity. (See Figure 1 below)

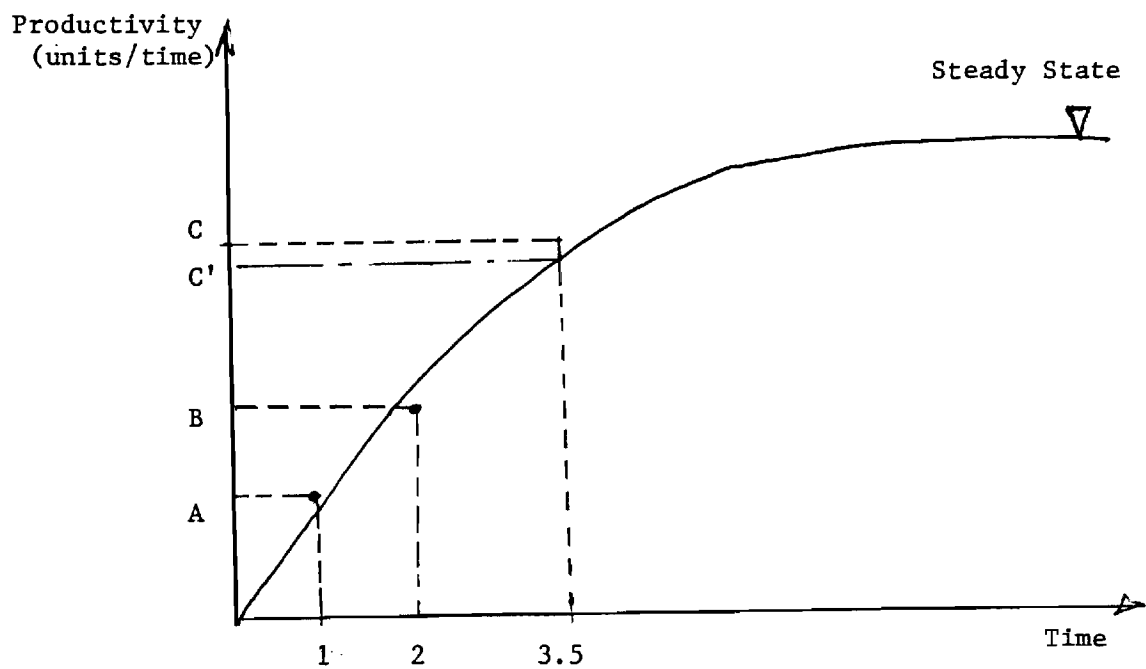


Figure 1 : Productivity Profile

A simple example will help to understand the figure. Assume that a typical excavation project is underway with one excavator and two trucks. At time zero all units (machines) are idle on the job site. Between time zero and one (0-1) the first truck is loaded, travels to the dump area and dumps its material. At this point in time, productivity in cubic yards per hour jumps from zero to A. The value of "A" can be calculated as follows:

$$A = \frac{M_1}{T_1} \times 50^*$$

M_1 = Material dumped by truck load
 T_1 = Time for loading, hauling and dumping of truck one

While truck 1 travels to the dump site, the second and perhaps the third truck(s) will be loaded and start hauling.

Time 2 represents the stage where the second truck is dumped.

$$B = \frac{M_2}{T_2} \times 50^*$$

M_2 = Material dumped by truck load
 T_2 = Time for loading of truck 1 and 2 plus hauling and dumping time of truck 2

The increase in productivity originates from the overlapping time for hauling and loading. In other words, while truck 1 is hauling truck 2 is already loading and starts hauling.

The procedures repeat until productivity reaches steady state. At this point, the highest productivity for this equipment combination is reached. Each time the cycle is interrupted (for example at the end of a working day or a lunch break), the simulation has to start at time zero again. There is a possibility that steady state cannot be reached before an interrupt (break) in activity occurs. This interrupt condition is shown in Figure 2.

This figure shows an entire working day with three breaks (coffee in

* This assumes a 50 minute work hour.

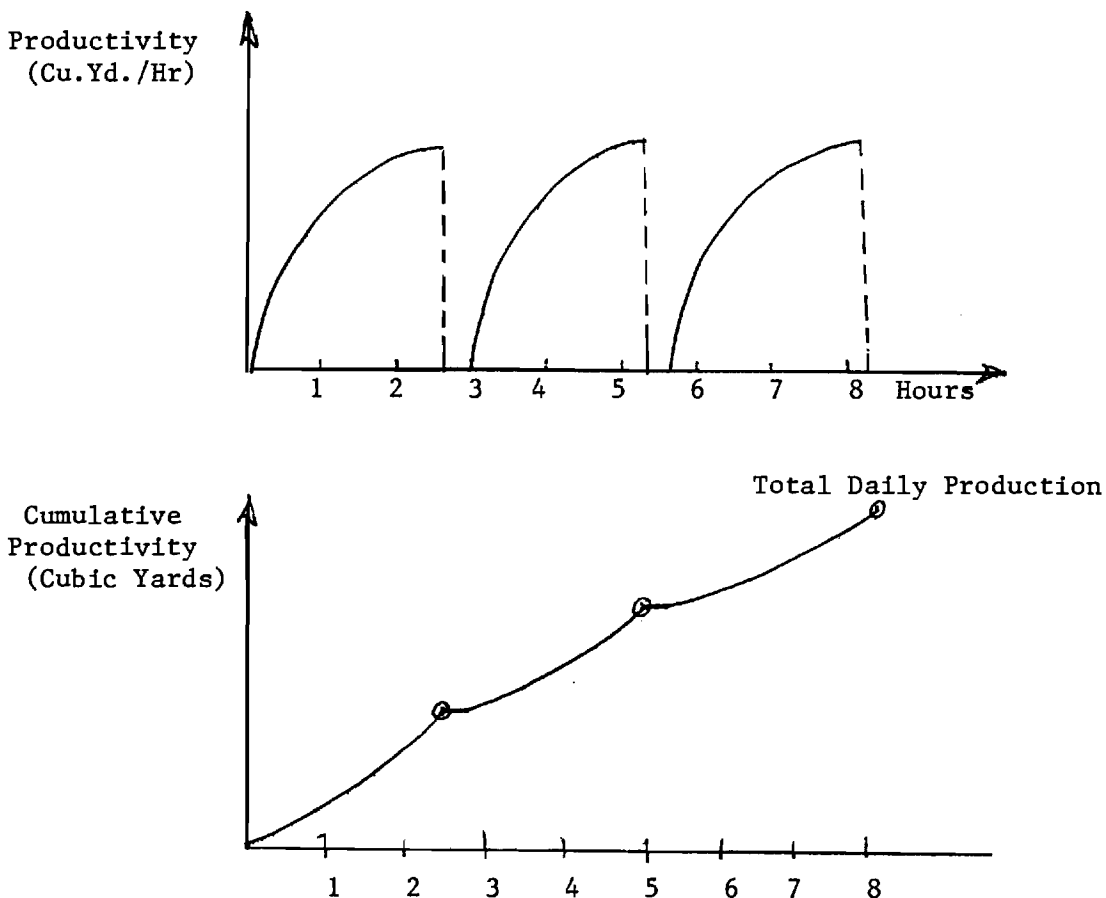


Figure 2: Interrupt Effect on Construction Productivity

the morning, lunch and end of working day). Each segment has a duration of approximately 2.5 hours. The cumulative production curve is also shown.

The system allows the user to print a hard copy of detailed information regarding the productivity. The average productivity and daily production as well as information as to whether steady state has been achieved is also printed.

Optimization

A simplistic approach to finding the cost optimal fleet is to multiply the total required working days with the daily cost for one fleet and add the fixed cost. The usage, however, of the Linear Programming approach allows the user to find the cost optimal fleet under certain constraints such as allowable working days or available capital.

Therefore, the objective of the optimization is to find the fleet with the lowest cost which satisfies a set of restrictions defined by the user in the "Job Description" section.

So far, the cost figures for each fleet combination includes only fixed and variable cost for equipment. In order to calculate the total cost, the system uses the following calculational structure:

Fixed Cost of Fleet XY	= \$.....
Total Variable Cost (Operating days x Daily Var. Cost)	= \$.....
Total Show up Cost (Expected Rain days x Factor x Cost)	= \$.....
Job Overhead (Operating Days+Rain days) x Daily O/H	= \$.....
Total Cost before Capital Cost	= \$.....
Net Cast Flow (Cash in - Cash out)	
Bank Charges for borrowed money	= \$.....
Cost of borrowed Capital (Net Cash x Interest Rate)	= \$.....
TOTAL JOB COST OF FLEET xy	= \$.....

The net cash flow calculation is based on the total job duration (including rainy days), the cash expenses (labor, variable cost-depreciation-markup, and overhead) and the effect of the billing frequency. As a by-product, the system also recognizes the required total capital for this fleet.

The restrictions or constraints which are considered in the LP formulation are as follows:

- CONSTRAINT #1 The sum of working days and expected rainy days has to be smaller than or equal to the available completion days.
- CONSTRAINT #2 The required total capital for the fleet has to be smaller than or equal to the available capital

The result of the optimization produces a hierarchical list of the fleets which satisfy the constraints starting with the cost optimal fleet.

Optimal Solution Tableau for Job

Rank	Fleet#	Operating Days	Rainy Days	Fixed Cost	Variable Cost	Total Cost

The list includes information about the required number of working days, expected rainy days, and the cost. The tableau shown above reflects the structure of the final optimization report output. This report gives the user the options available. Further detailed supporting reports are available upon request. These reports reflect details regarding the cash flow and fleet cost calculations.

Areas for Further Development

1. Calculation of Bid Prices with differing mark-ups for a given fleet.
2. Introduction of integrated equipment scheduling (i.e. updating and equipment availability control for new projects)
3. Integrating information from many project sites for overall equipment management
4. Quantity calculation and Haul Optimization
5. Multi-site optimization

FINAL PROJECT REPORT
NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I-PROJECT IDENTIFICATION INFORMATION

1. Institution and Address Georgia Institute of Technology Atlanta, GA 30332 School of Civil Engineering	2. NSF Program	3. NSF Award Number CEE-8208271
	4. Award Period From 1/15/83 To 5/31/85	5. Cumulative Award Amount \$109,571

6. Project Title

Resource Analysis Using Microcomputers

PART II-SUMMARY OF COMPLETED PROJECT (FOR PUBLIC USE)

A microcomputer-based system for the analysis of resource requirements on heavy construction operations has been developed. The system consists of five interactive modules which allow the definition of construction processes and the evaluation of resource combinations using a sensitivity approach. A special feature of the research has been the development of 26 standard networks for various types of construction processes. These standard networks greatly simplify the process definition function and are supported by screen graphics depicting various processes in network format. When using the standard networks, the user needs only define the number of each resource and appropriate work task durations. The modules were tested using actual field data. Development of quantity input is enhanced by a transportation problem approach to the distribution of earthwork on linear construction sites. Quantity development from cross-sectional drawings is supported by a graphical input module. The sensitivity module allows the user to analyze resource patterns to determine the time and cost optimal combinations.

PART III-TECHNICAL INFORMATION (FOR PROGRAM MANAGEMENT USES)

1. ITEM (Check appropriate blocks)	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (✓)	Approx. Date
a. Abstracts of Theses		1		x	Oct. 1985
b. Publication Citations		18			
c. Data on Scientific Collaborators		11			
d. Information on Inventions	x				
e. Technical Description of Project and Results		x			
f. Other (specify)					
2. Principal Investigator/Project Director Name (Typed) DANIEL W. HALPIN, Professor	3. Principal Investigator/Project Director Signature			4. Date 15 Aug. 1985	

TECHNICAL DESCRIPTION OF PROJECT AND RESULTS

Project Title: Resource Analysis Using Microcomputers

NSF Grant: CEE-8208271

I. Introduction

Repetitive processes in construction are of great interest since they account for a large part of the productive effort expended on a project. This, notwithstanding, the amount of research towards better understanding of repetitive processes in construction has been relatively small in comparison to related industries such as manufacturing, ship building and aircraft assembly. This has been in part due to the unique features of each construction site which tend to be reflected in the construction processes used. That is, construction processes must be site adapted.

Until recently it was felt that this site adaptation characteristic preempted any meaningful research regarding the basic structure of construction processes. General consensus was that the processes used had to be tailored to each project. Study was limited to equipment and crew characteristics rather than process technological characteristics.

Over the past two decades, it has been recognized that the basic structure of construction processes is a major cost determinant ranking at least equal in importance with individual machine and crew production rates. Moreover, individual resource production rates cannot be realized fully in most processes and are constrained by the set-up of an operation. This set-up is technology based and leads to the study of interface problems between machines, crews, and

materials. In other words, the rate at which a batch plant can operate may (and in most cases will) be limited by the number of trucks available to transport the batched material.

A further research limitation has been the lack of a good analytical tool or notation in terms of which operations and processes in the construction industry could be studied. Simple pictorial models lack the capacity for quantitative analysis and complex mathematical models are not able to achieve an acceptable linkage with the real world situation. A method, both graphical and analytical capable of capturing the complexity of the construction site processes, was needed.

The concept of simulation allows analysis of complex dynamic systems. However, simulations are often stylized and costly to develop. During the past 12 years a graphical modelling system which allows production simulation of construction processes has gained acceptance as an operational research tool. The CYCLONE System is described in numerous publications (13,14,20,24,26,29,30,31,33,34, 43,49,50,52,53) and offers a visually simple model of the process of interest while allowing quantitative study in terms of process simulation.

II. Research Under This Grant

A general outline of research undertaken within the scope of this grant is given in the paper by Tavakoli (see Appendix A). This paper describes a system developed as part of the work under the grant and represents the state of research in implementing a user friendly operations analysis system for heavy construction operations as of August 1983. Extension of this work by Rincones (51) and

Niederhauser (38) provides a graphical display of 26 standard processes which aid the user in defining the operation under consideration. The screen display of a typical model is shown in Figure 1. These "standard" models help the user to gain a familiarity with and understanding of CYCLONE networks. They also expedite generation of input for standard operations where only work task durations and resource variation are defined by the user. Work by Abou-Rizk (1) allows analysis of resource allocation based on a sensitivity analysis approach. This work also includes a preliminary study of production response to variation of stochastic time parameters. Ongoing work is aimed towards an improved tutorial interface with the model building system. Stylized menus such as that shown in Figure 2 are designed to simplify access to the modelling environment.

III. The Structure of Micro CYCLONE

CYCLONE was originally developed for use on mainframe computers, but versions for the microcomputer known as MicroCYCLONE were developed under this grant for use on the IPM PC and XT. The objective of this adaptation was to provide an improved environment for the analysis of resource requirements using microcomputers.

In MicroCYCLONE, construction processes are modeled as networks of circles (queues) and squares (work tasks). These graphical representations are defined for computer analysis by text input. This input is used by MicroCYCLONE to simulate a given process network. The IBM program uses a graphical display of standard processes in conjunction with a series of simple questions regarding resource allocations and work task durations to define the input.

STANDARD PLACING, SPREADING, COMPACTION AND FINAL GRADING OF SUBGRADE CYCLONE MODEL #1

ENTER PROCESS DATA FILE NAME: MODEL NO. 9

-or- press the return key to return to the standard model library.

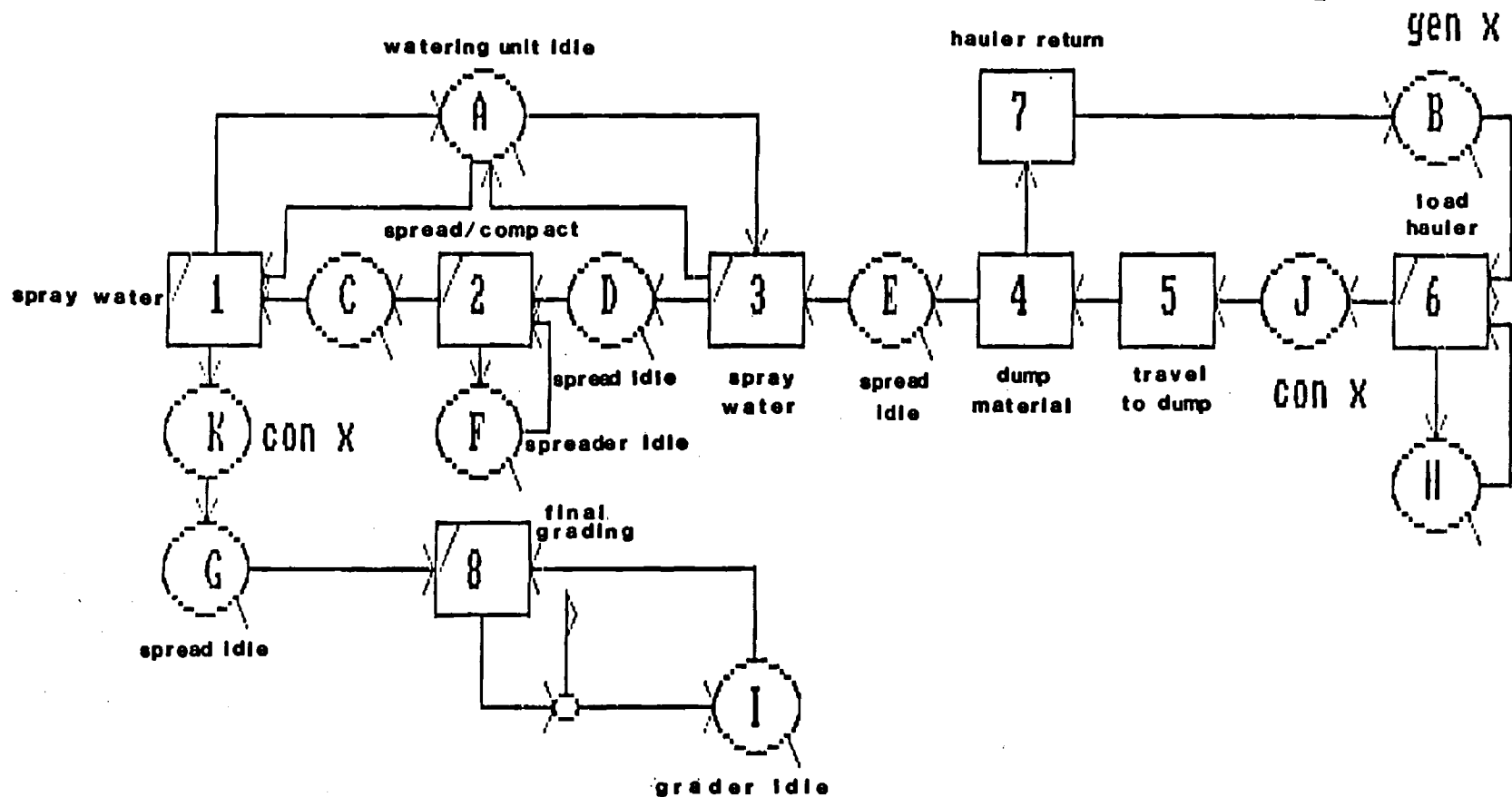


Figure 1. Screen Display of a Typical Model

PROJECT	EXAMPLE NUMBER 9 - PROJECT I-75	08-16-1985
<div><div><div><div><div>F1</div><div>F2</div><div>F3</div><div>F4</div><div>F9</div></div><div><div>⇒</div><div>⇒</div><div>⇒</div><div>⇒</div><div>⇒</div></div><div><div>Create or Edit Network File</div><div>Simulate Current Process</div><div>Simulation Reports</div><div>Sensitivity Analysis</div><div>Return to MAIN MENU</div></div></div></div><div><div><div>F10</div><div>⇒</div><div>HELP</div></div><div><div>Esc</div><div>⇒</div><div>End Session</div></div></div></div>		
ACTIVITY	WALLS	PROCESS MASON

Figure 2 - Typical Menu for Operational Simulation

This approach also helps the user gain a familiarity and understanding of CYCLONE networks. Although any process can be submitted for evaluation in text mode, the availability of "standard networks" for common construction processes reduces the complexity of defining and simulating a process. Currently twenty-six (26) models exist in a graphical format which can be reproduced on the IBM PC or any compatible system with a graphics capability. Figure 3 shows a network defining a concrete placement process.

The MicroCYCLONE system consists of five modules performing the following functions: (1) input, (2) simulation, (3) report generation, (4) beta curve generation from distributed data, and (5) sensitivity analysis. The systems main menu is the central link between the various modules. The Standard Network Model Library is a subset of the input module. What follows are brief descriptions of the MicroCYCLONE modules.

A. The input module provides the user with a selection of options which enables him to create and/or modify data input files. It is in this module that the user must decide whether to use the conventional input method or use the standard models. The conventional method is more tedious to use than the Standard Model Library, but it is essential when an adequate standard model does not exist. All the data entry, additions, deletions, and editing are performed using a text editor. New developments in the editor are making the conventional input method easier to use.

B. The simulation module executes the process simulation and

Standard Concrete Pouring Model

ENTER PROCESS DATA FILE NAME: MODEL NO. 20

-or- press the return key to return to the standard model library.

gen x

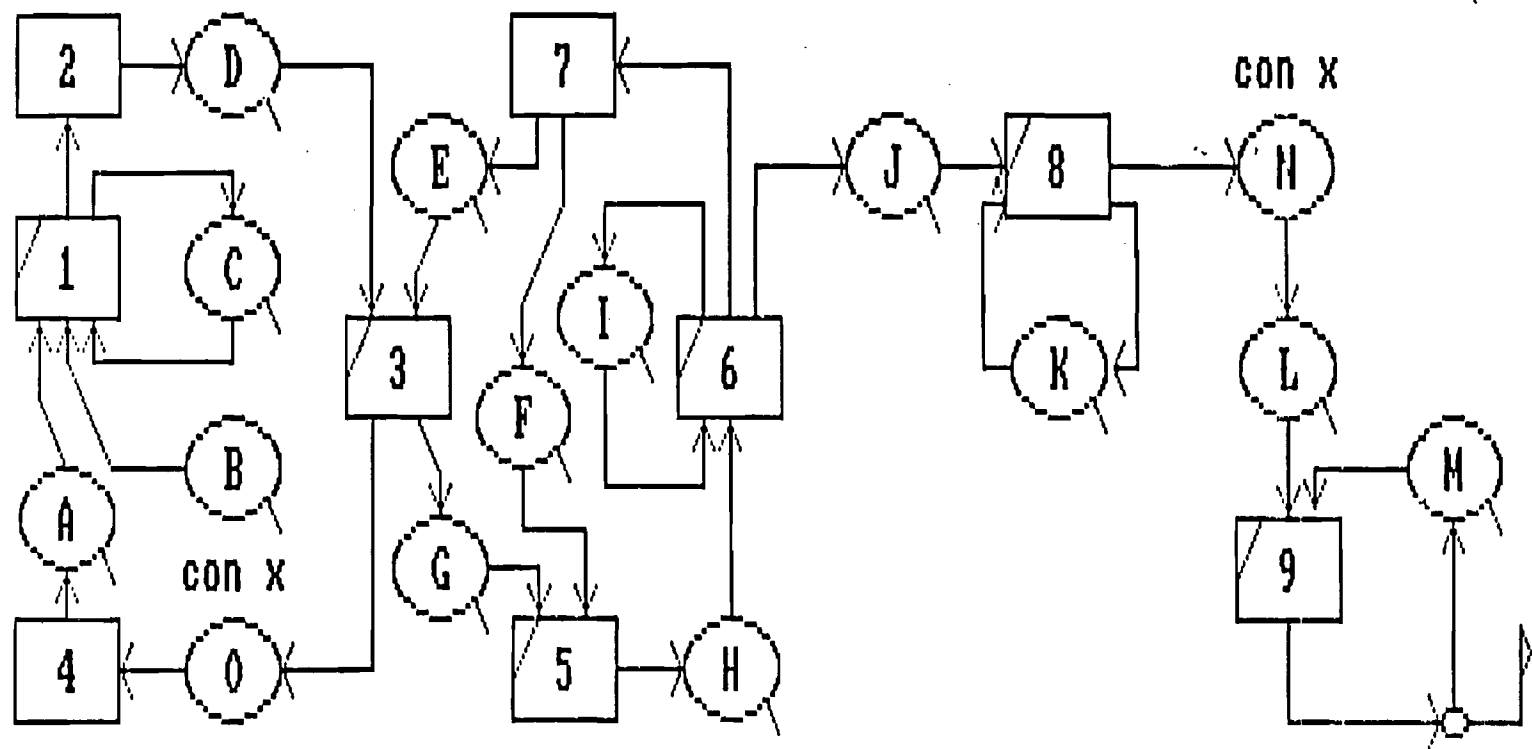


Figure 3 - Process Graphical Representation

collects all the statistical and time data during simulation. It is here that the processes observed on a construction site go through the step by step, event by event simulation. A process which may take several hours or days to complete in "real time" takes only a few seconds to perform with the process simulator. In this way, the user can study the process exhaustively to determine the best balance of resources from a cost and productivity point of view. In effect, the simulation provides the user with a "laboratory" in which the process of interest can be studied and exercised. While the simulation is underway, the system plots a production curve on the monitor and simultaneously prints an event chronological list proceeding in conformity with the model. The production curve is shown in Figure 4.

C. The reports module provides various reports regarding the productivity obtained in simulation and the idleness and imbalance occurring at the various queues (circles in the network). Information about resource idleness, work task activity, and process production is made available to the user in neat and concise reports. Upon initial entrance into the reports module, the user is given various options regarding how the reports should be formatted.

D. The Beta module enables the user to add a probabilistic dimension to the process simulation. Because construction work task durations are rarely uniform, a statistical distribution can be utilized to reflect random durations. After extensive research, the Beta distribution was selected as the distribution which best reflects random work task durations. When the process simulation is underway, the simulator assigns durations to the work tasks which are

PRODUCTION CURVE FOR: TEST17

01-01-1980

COMMENT: Concrete Pouring (Model #20)

UNITS PROD.	CLOCK
20	208.00
PRODUCTIV.:	5.8

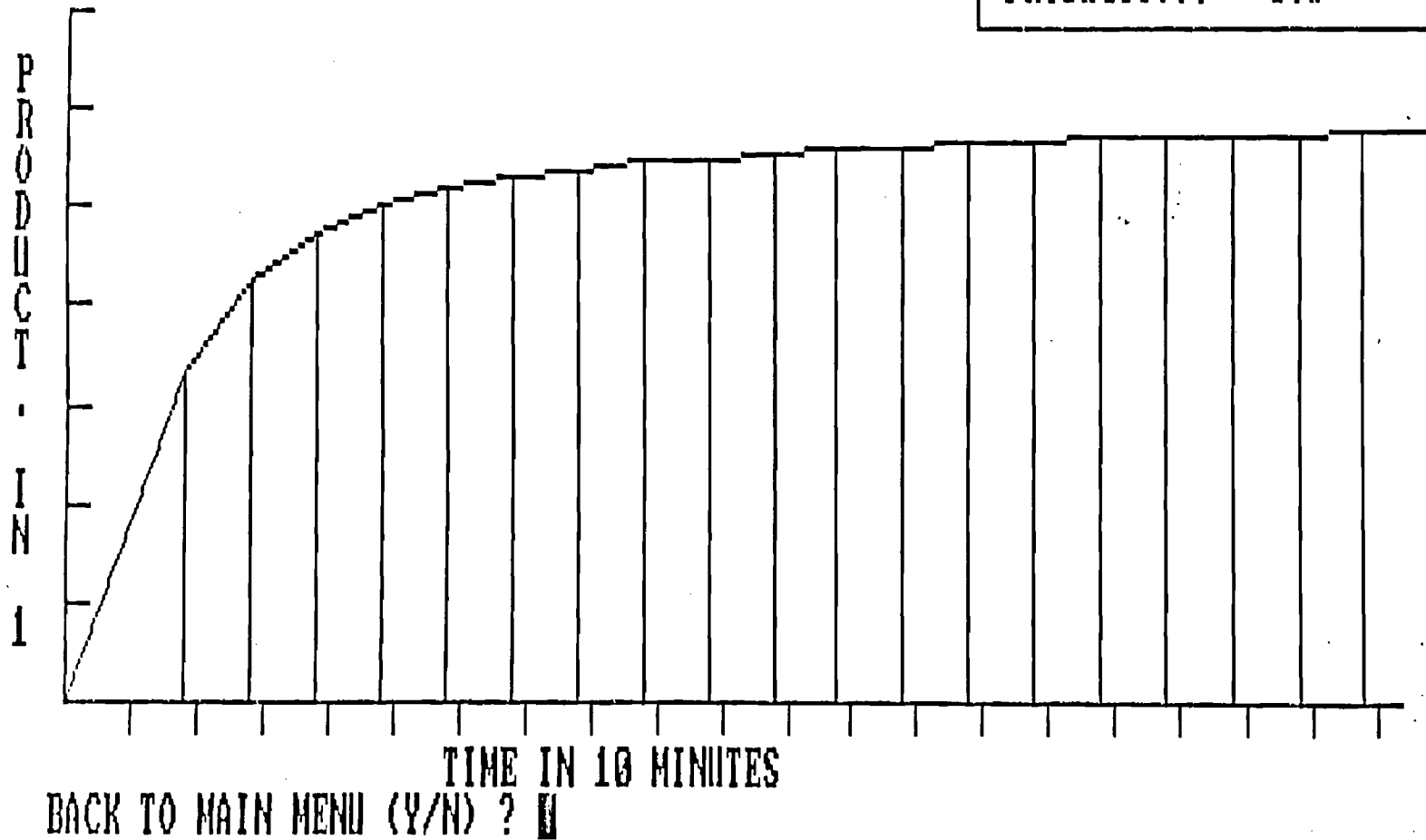


Figure 4 - Production Curve

in the range of the assigned distribution(s). The parameters describing a work task's distribution can be developed from field data input to the program in grouped or ungrouped format. From calculated parameters, the Beta module generates a data curve from which the durations assigned to the work tasks during simulation are sampled.

IV. Resource Analysis Using Sensitivity Approach

The sensitivity analysis module requires that a CYCLONE model has been defined either using conventional input or through one of the standard models available. Changes can only be tested on models which are logically correct and free of errors. The sensitivity module actually allows the user to change CYCLONE variables and parameters to test a certain objective or effect. Two types of changes are allowed: Changes by Tree algorithm and general (one run) changes.

Tree algorithm: This type of change pertains to resources only. Resources can be varied in terms of different combinations and different locations within the system with one entry of information. In other words, the effect of resource changes can be studied by simply specifying the range of resource variation. The user indicates he would like to initiate a certain base number of resources within a given cycle and the increment of change to be implemented after each run. If, for example, we would like to test the cases of having 2 trucks, 4 trucks, or 6 trucks initiated at queue 5 in the system, simulation is performed automatically for each case and the results stored for later reports.

Combination of resources and variation of initial locations is also possible in the form of a tree structure which gives the algorithm its name. Figure 5 shows such a combination of resources. Simulation of 8 different cases is performed and the results are kept for later use.

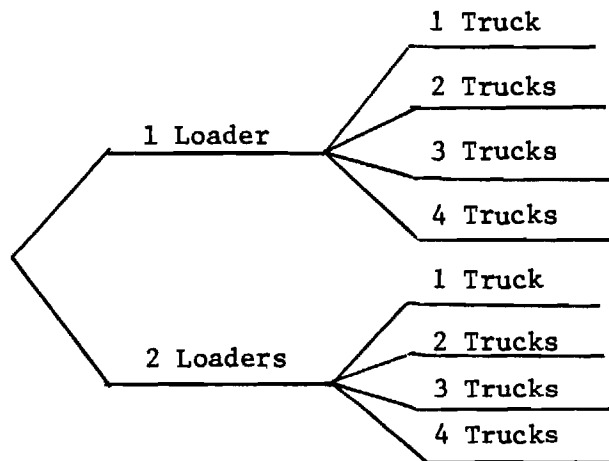


Figure 5. Tree Algorithm Example

Changes by Tree algorithm are effective in determining the bottle-neck resource in a system assuming no breakdowns occur.

General changes can be made for a single run test. The run will be added to the same data file that contains other runs for the particular process. The run file constitutes a common basis for comparison in later reports. Changes in resources, time durations and/or type, simulation length time and costs of resources etc. can be considered general changes. Actually general changes can be done and then the Tree algorithm can be applied as required.

The main objective of sensitivity analysis is to compare the effect of changing parameters on the behavior of a given model. To

help the user in reaching his decision, the sensitivity module gives reports of all runs for a given process in both tabular and graphical formats.

To demonstrate the sensitivity analysis approach consider the standard concrete pouring model shown in Figure 3. Data pertaining to the initial number of resources and to the time durations of work tasks, together with other CYCLONE parameters are input. The CYCLONE text representation is shown in figure 6. The test involves running simulation by using the Tree-algorithm. Originally the system is initialized with the following resources:

- 1 truck at que 21 (A).
- 99 units at 22 (B)
- 1 unit at queue 23 (C)
- 2 buckets at queue 25 (E)
- 1 crane at queue 26 (E)
- 1 laborer at queue 31 (J)
- 1 concrete crew at queue 31 (K)
- 1 finishing crew at queue 33 (M).

The first few runs are basically to demonstrate the idea of the tree algorithm. We desire to test the effect of changing the number of trucks on the behavior of the system. Assume we have fourteen trucks available for this operation. In fact the simulation can be performed with 1, 2, 3 trucks, etc. in the system. However, to save on time and space simulation runs with 2, 4, 6 trucks, etc. will be used. Convergence to a "best" solution will be accomplished by using

MICROCYCLONE INPUT FILE: egncr.REV

CONTROL INPUT

NAME concr LENGTH 500 CYC 10

NETWORK INPUT

1 COMBI 'LOAD T-M TRUCK' SET 1 FOLL 2 23 PREC 21 22 23
2 'TRAVEL TO SITE' SET 2 FOLL 24
3 COMBI 'LOAD BUCKET' SET 3 FOLL 35 27 PREC 24 25
4 'T-M TRUCK RETURN' SET 4 FOLL 21
5 COMBI 'LIFT & POSITION FULL BUCKET' SET 5 FOLL 28 PREC 26 27
6 COMBI 'POUR CONCRETE' SET 6 FOLL 7 29 30 PREC 28 29
7 'LOWER EMPTY BUCKET' SET 7 FOLL 25 26
8 COMBI 'VIBRATE & SPREAD' SET 8 FOLL 34 31 PREC 30 31
9 COMBI 'FINISH CONCRETE' SET 9 FOLL 50 PREC 32 33
21 QLE 'A: T-M TRUCK(s) IDLE'
22 QLE 'B: CONCRETE AVAILABLE'
23 QLE 'C: CONCRETE PLANT(s)'
24 QLE 'D: LOADED T-M TRUCK(s) IDLE' GEN 1
25 QLE 'E: EMPTY BUCKET(s) AVAILABLE'
26 QLE 'F: CRANE IDLE'
27 QLE 'G: FULL CONCRETE BUCKET IDLE'
28 QLE 'H: CONCRETE READY TO POUR'
29 QLE 'I: LABORER IDLE'
30 QLE 'J: CONCRETE READY'
31 QLE 'K: CONCRETE CREW(s) IDLE'
32 QLE 'L: CONCRETE READY'
33 QLE 'M: FINISHING CREW(s) IDLE'
34 FUNC 'N: CONSOLIDATE' FOLL 32 CONSO 1
35 FUNC 'O: CONSOLIDATE' FOLL 4 CONSO 1
50 FUNC COUNTER FOLL 33 QUANTITY 100

DURATION INPUT

SET 1 1.2
SET 2 20.1
SET 3 1.5
SET 4 17.9
SET 5 .3
SET 6 1.2
SET 7 .2
SET 8 2.4
SET 9 4.1

EQUIPMENT INPUT

1 AT 21
99 AT 22
1 AT 23
2 AT 25
1 AT 26
1 AT 29
1 AT 31
1 AT 33

ENDDATA

Figure 6 - Text Representation of Concrete Pouring Model

general changes later. The following data is given to the input section of the sensitivity analysis program:

Change resources at 1 queue in the model.
Label of the queue is 21.
Total resources available for this queue are 14.
Start simulation with 2 resources in the system
Increment by two resources

Taking all possible combinations of these resources for this queue and within the limits specified, the program simulates with the combinations described. The program finishes simulating 7 different possible combinations and chains back to the reports section of the sensitivity module. The results of primary parameters (productivity, total time, total and unit costs) are shown in table 1 (in tabular form) and in figures 7 and 8 (in graphical form).

MIX #	TOTAL TIME	PRODUCTIVITY	TOTAL GOST	UNIT COST	DESCRIPTION
1	197.70	303.49	1884.74	2.88	2 trucks
2	116.30	515.91	1205.64	1.21	4 trucks
3	83.80	715.99	938.56	0.94	6 trucks
4	75.60	793.65	909.72	0.91	8 trucks
5	67.70	886.26	871.07	0.87	10 trucks
6	67.70	886.26	927.49	0.93	12 trucks
7	67.70	886.26	983.91	0.98	14 trucks
8	46.10	1301.52	1084.89	1.08	10 trks 5 crews K&M
9	48.90	1226.99	759.58	0.76	2 trks & 2 crews K&M

Table 1 Simulation Results

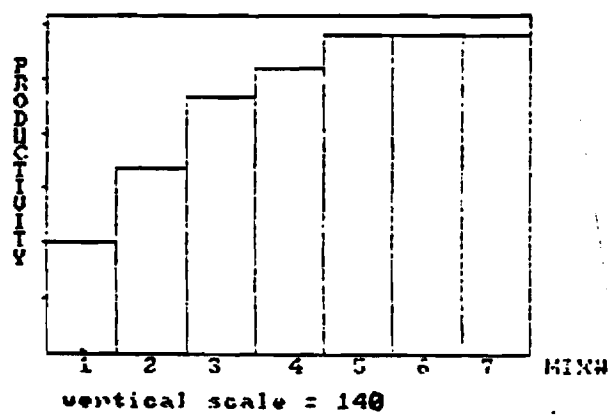


Figure 7 - Production Plot

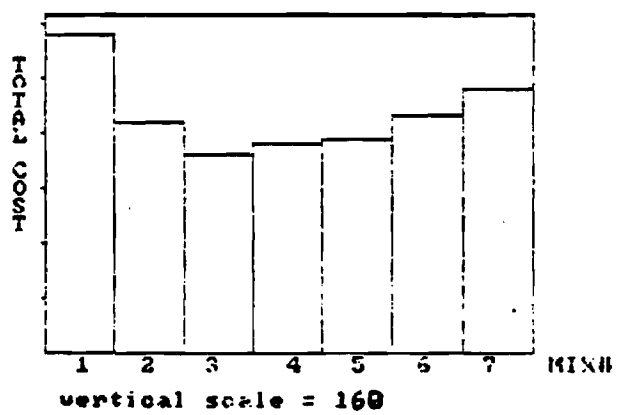


Figure 8 - Cost Plot

The table indicates that the first mix (MIX # 1) with two trucks in the system (other resources the same as described above), required a total simulation time of 197.7 minutes to complete 6 cycles. Productivity was 303.49 units per hour. 100 units are produced during each cycle. This can be interpreted as 100 sq. ft. of finished concrete surface for example. The total cost was \$1884.74 for 6 cycles. Likewise the first 7 mixes of trucks give the indicated time, productivity, and costs.

The first thing to notice in the analysis of these results is that productivity has reached a ceiling of 886.26 units/hr when 10 trucks were in the system (time limitation indicates the same conclusion). The total costs kept increasing however. This is expected from the fact that more trucks were added to the system at a fixed cost per hour with no decrease in the total time.

Table 2 shows the idle time at each queue for each run or combination. Study of the table shows that trucks at queue 21 (A) were never idle at their initial point. This is expected since there was no pre-set limit at queues 22 and 23 (concrete available and plant available). However, queue 24 (trucks idle) shows an increase in waiting time. The fact is that the waiting time of concrete at queue 30 increases as the number of trucks increases. This fact is undesirable from a technical viewpoint and at the same time tells us that one concrete crew becomes saturated as trucks are added to the system. The crew is a limiting resource. Mixes 8 and 9 use 5 and 2 crews respectively.

This example illustrates how the resources can be analyzed to achieve a cost effective and balanced system. Further studies and details can be found in the report by Abou-Rizk (1).

V. Future Work

Future work envisages the establishment of a knowledge base to be used for the design and analysis of construction operations. This work will be a direct follow-on to this grant. Major features of this future work build on information and knowledge developed using the CYCLONE System for resource analysis. This research will formalize the work done to date and focus on the development of a knowledge driven system capable of designing construction operational models based on user definition of site and materials handling characteristics. A prototype system emphasizing design of earthwork operations will be implemented to test the concept. Basic standard networks developed under this grant will be used to structure the collection of data and the implementation of a knowledge based construction process generator.

VI. Bibliography

1. Abou-Rizk, S., "Sensitivity Analysis of Construction Operations," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, March 1985.
2. Allwood et al., "Evaluation of Expert System Shells for Construction Industry Applications," Departmental Report, Department of Civil Engineering, Loughborough University of Technology, 1984.
3. Ashley, David B., "Simulation of Repetitive Unit Construction," Journal of the Construction Division, ASCE, Vol. 106, CO2, June, 1980, pp. 185-194.
4. Auslander, David M., and Paul Sagues, Microprocessors for Measurement and Control, Osborne/McGraw-Hill, Berkeley, CA, 1981.
5. Benjamin, N.B.H., and Greenwald, T.W., "Simulating Effects of Weather on Construction," Journal of the Structural Engineering Division, ASCE, Vol. 99, No. CO1, Proc. Paper 9888, July, 1973, pp. 389-404.
6. Borchherding, J.D., "Cost Control Simulation and Decision Making," Journal of the Construction Division, ASCE, Vol. 103, No. CO4, December, 1977.
7. Carr, Robert I., "Simulation of Construction Project Duration," Journal of the Construction Division, ASCE, Vol. 105, No. CO2, June 1979, pp. 117-128.
8. Carr, Robert I., and Meyer, Walter L., "Planning Construction of Repetitive Building Units," Journal of the Construction Division, Vol. 100, No. CO3, September 1974.
9. Clemmens, J.P., and Willenbrock, J.H., "The Scrapesim Computer Simulation," Journal of the Construction Division, ASCE, Vol. 104, No. CO4, December 1978, pp. 419-435.
10. Crandall, K.C., "Analysis of Schedule Simulations," Journal of the Construction Division, ASCE, Vol. 102, No. CO3, September 1976.
11. Crandall, Keith C., and John C. Woolery, "Schedule Development Under Stochastic Scheduling," Journal of the Construction Division, ASCE, Vol. 108, No. CO2, June 1982, pp. 187-200.
12. Dabbas, M.A.A., Computerized Decision Making in Construction, Ph.D. Dissertation, Civil Engineering Department, Georgia Institute of Technology, May 1981.
13. Dabbas, Majed, A.A., and Daniel W. Halpin, "Integrated Project and Process Management," Journal of the Construction Division, ASCE, Vol. 108, No. CO3, September 1982, pp. 361-374.
14. Dorman, W.F., J.L. Knott, and R.W. Woodhead, CYCLONE - Timelapse

Analysis System-Introductory User Manual, School of Civil Engineering, University of New South Wales, Kensington, New South Wales, Australia, December 1980.

15. Engineering News Record, "Wary but Interested, Construction Stretches to Make the AI Connection," March 28, 1985, pp. 20-23.
16. Fishman, G.S., Concepts and Methods in Discrete Event Digital Simulation, John Wiley and Sons, 1973.
17. Fishman, G.S., Principles of Discrete Event Simulation, John Wiley and Sons, 1978.
18. Fondahl, J.W., "Photographic Analysis for Construction Operations," Journal of the Construction Division, ASCE, Vol. 86, No. CO2, Proc. Paper 2483, May 1960, pp. 9-25.
19. Halpin, Daniel W., A Computerized Construction Management Gaming Environment, Technical Report No. SCEGIT-75-114, National Science Foundation Grant No. ENG 74-13131 A01, Georgia Tech, 1975.
20. Halpin, Daniel W., An Investigation of the Use of the Simulation Network for Modeling Construction Operations, Thesis presented to the University of Illinois at Urbana-Champaign in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1973.
21. Halpin, Daniel W., and Woodhead, R.W., Construction Management, Wiley, 1980.
22. Halpin, Daniel W., "CYCLONE: Method for Modeling of Job Site Processes," Journal of the Construction Division, ASCE, Vol. 103, No. CO3, Proc. Paper 13234, September 1977, pp. 489-499.
23. Halpin, Daniel W., and Happ, W., "Digital Simulation of Equipment Allocation for Corps of Engineering Construction Planning," U.S. Army CERL, Champaign, Illinois. 1971.
24. Halpin, Daniel W., and Woodhead, R.W., Design of Construction and Process Operations, John Wiley and Sons, 1976.
25. Hamby, Dick, "Unit Cost System," Conference on Construction Productivity Improvement, University of Texas at Austin, September 1980.
26. Hass, Richard, and Halpin, Daniel W., "Production Modeling of Precast Transportation Structures," Proceedings of International Congress on the Application of Mathematics in Engineering, Weimer, German Democratic Republic, June 1978.
27. Herbert, John E., "Applications of Simulation in Project Management," Eleventh Winter Simulation Conference 1979, San Diego, California, Institute for Electrical and Electronic Engineers, December 1979.
28. Johnston, David W., "Linear Scheduling Method for Highway Construction," Journal of the Construction Division, ASCE, Vol. 107, No. CO2,

June 1981, pp. 247-261.

29. Kalk, A. INSIGHT - Interactive Simulation of Construction Operations Using Graphical Techniques, Thesis presented to Stanford University in partial fulfillment of the requirements for the Degree of Engineer, August 1978. It was revised and published as Technical Report No. 238, The Construction Institute, Dept. of Civil Engineering, Stanford University, Stanford, California, July 1980.
30. Kalk, Anthony, and Paulson, Boyd, C., Jr., "Minicomputer Simulator for Construction Operations," ASCE Convention and Exposition, Preprint No. 3351, Chicago, Illinois, October 16-20, 1978.
31. Knot, J.L., and Woodhead, R.W., "The CYCLONE-Timelapse Analysis System," Construction Monographs, School of Civil Engineering, University of New South Wales, 1980.
32. Ledbetter, W.N., and Cox, J.F., "Are O.R. Techniques Being Used?" Industrial Engineering, Vol. 9, February 1977.
33. Lluch, Jose, and Daniel W. Halpin, "Construction Operations and Microcomputers," Journal of the Construction Division, ASCE, Vol. 108, No. C01, March, 1982, pp. 129-145.
34. Lluch, Jose, Analysis of Construction Operations Using Microcomputers, Ph.D. Dissertation, Civil Engineering Department, Georgia Institute of Technology, August 1981.
35. Matheus, R., "The Utility Value Method in Construction," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Spring 1982.
36. Moavenzadeh, F. and Markow, M.J., "Simulation Model for Tunnel Construction Costs," Journal of the Construction Division, ASCE, Vol. 102, No. C01, March 1976, pp. 51-66.
37. Mundel, M.E., Motion and Time Study, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1960.
38. Niederhauser, D., "The Application of Standard Models in Micro-CYCLONE," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, August, 1984.
39. O'Brien, J.J., CPM in Construction Management, McGraw-Hill Book Co., New York, 1965.
40. O'Brien, J.J., Editor, Scheduling Handbook, McGraw-Hill Book Co., New York, New York, 1969.
41. Parker, Henry W., and Oglesby, Clarkson H., Methods Improvement for Construction Managers, McGraw-Hill, Inc., New York, 1972.
42. Paulson, Boyd C., Jr., "Human Implementation of Computer-based Project

Management," 1976 Proceedings of the Eighth Annual Seminar/Symposium of the Project Management Institute, Montreal, Quebec, 1976.

43. Paulson, Boyd C., Jr., "Interactive Graphics for Simulating Construction Operations," Journal of the Construction Division, ASCE, Vol. 104, No. C01, March 1978, pp. 69-76.
44. Paulson, Boyd C., Jr., "Interactive Human-Computer System for Video Data Acquisition, Statistical Analysis, and Graphical Simulation of Construction Operations," Stanford University Research Proposal No. CE52-80 (N), Presented to the National Science Foundation.
45. Paulson, Boyd C., Jr., Douglas, S.A., Kalk, A., Touran, A., and Victor, G.A., Human-Computer Simulation and Analysis of Construction Operations, NSF APR-77-08249, Technical Report No. 250, The Construction Institute, Department of Civil Engineering, Stanford University, Stanford, California, July 1980.
46. Paulson, Boyd C., Jr., Douglas, S.A., Kalk, A., Touran, A., and Victor, G.A., "Simulation and Analysis of Construction Operations," Journal of Technical Topics in Civil Engineering, ASCE, in press for 1983 printing.
47. Pritsker, A.A.B., "Compilation of Definitions of Simulation," August 1979, Society for Computer Simulation, Vol. 33, No. 2.
48. Pruetz, David D., "Equipment Estimating and Scheduling for the Marine Amphibious Force," Special Research Report for M.S.C.E., School of Civil Engineering, Georgia Institute of Technology, June 1981.
49. Riggs, L.S., Sensitivity Analysis of Construction Operations, Ph.D. Dissertation, Civil Engineering Department, Georgia Institute of Technology, August 1979.
50. Riggs, L.S., "Simulation of Construction Operations," Journal of the Technical Councils of ASCE, Vol. 106, No. TCI, August 1980, pp. 145-163.
51. Rincones, L., "Computer Graphics Representation of Standard CYCLONE Models," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, March 1984.
52. Tavakoli, A., "Productivity Analysis of Heavy Construction Operations," Ph.D. Dissertation, Civil Engineering Dept., Georgia Institute of Technology, 1983.
53. Tavakoli, A., "Productivity Analysis of Construction Operations," Journal of Construction Engineering and Management, Vol. III, No. 1, March 1985, pp. 31-39.
54. Thomas, H. Randolph, Jr., and Mason P. Holland, "Work Sampling Programs: Comparative Analysis," Journal of the Construction Division, ASCE, Vol. 106, No. C04, December, 1980, pp. 519-534.

55. Touran, Ali, Construction Operations Data Acquisition and Processing Via Time-Lapse Photography Interfaced to a Minicomputer, thesis presented to Stanford University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, August, 1980.
56. Willenbrock, J.H., "Estimating Costs of Earthwork via Simulation," Journal of the Construction Division, ASCE, Vol. 98, No. C01, March 1972, pp. 49-60.

APPENDIX A

ARTICLE BY TAVAKOLI

PRODUCTIVITY ANALYSIS OF CONSTRUCTION OPERATIONS

By Amir Tavakoli,¹ A. M. ASCE

ABSTRACT: An interactive system for analysis of construction operations is proposed. The analysis is carried out in the context of various work modules which address quantity development, resource definition, and production and cost analysis. The quantity work module generates quantities based on information available in the design documents. The resource definition module receives and stores data regarding the labor/equipment combination to be used to execute work tasks. This module provides the user with a set of standard useful construction process models. For each construction operation to be analyzed, the terminal describes the standard models. The user makes input of a set of parameters for process keyname, quantity, work task durations, number of resources, production capacity of each unit, and cost per hour of each unit to the standard model to be used. Using input from the resource definition module, the productivity and cost analysis module generates production rates and unit costs based on process simulation using CYCLONE methodology.

INTRODUCTION

Traditionally, contractors have relied on their experience and engineering intuition in making decisions about the technology, equipment, and labor for a particular operation or process. Quantitative methods for the analysis of construction operations can improve the decisions made, resulting in gains in productivity, efficiency, and accuracy of cost estimates.

Several quantitative decision-making models are available for contractors. Simulation is one of the appropriate methods for analysis of construction operations. In general, simulation is the term given to the mathematical representations that take random samples from a probability distribution curve in order to simulate a real-life situation.

Simulation has several advantages and disadvantages (6). Design of the model forces the analyst to examine all the elements of the system in detail. This examination may lead to a better understanding of the system and may even lead to changes before simulation takes place. Furthermore, simulation of complex systems can give insight into which variables are important and how they interact. Thus, simulation can serve as a teaching device. Also, simulation allows the user to experiment with different strategies without the risk of disturbing the real system. Finally, simulation enables one to study dynamic systems in compressed time. Simulation also has disadvantages—not the least of which is interpretation of data. Simulation is not an exact science. That is, there is still an art to the application of the science. Other disadvantages might include excessive costs; model parameters may be difficult to collect or determine; and some relevant items may be left out inadvertently.

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DESCRIPTION OF RESEARCH

This paper proposes an interactive system for analysis of construction operations. It integrates quantity development and process simulation to estimate productivity and cost; it also provides the user with a set of standard useful process models frequently encountered in construction projects.

The process of producing a cost estimate for construction tasks consists of six steps:

1. Develop quantity estimate.
2. Establish pool of available equipment.
3. Select equipment combination to perform task.
4. Determine productivity to be achieved by selected equipment.
5. Calculate unit cost based on fleet cost (i.e., resource cost) and productivity rate.
6. Allow for changes of fleet based on optimization of parameters, e.g., cost, equipment utilization, labor utilization, and time.

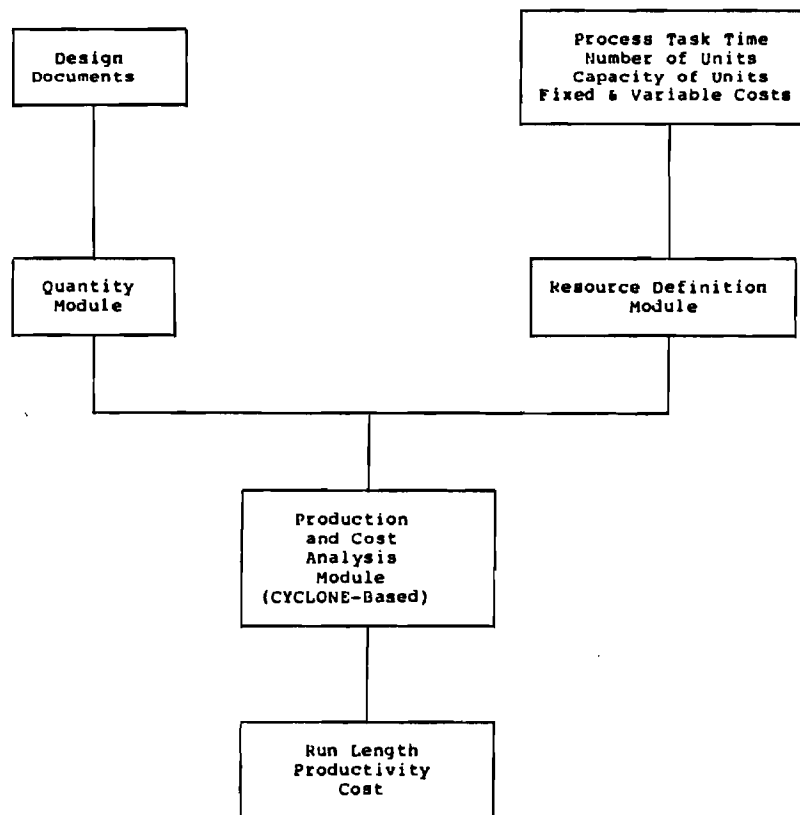


FIG. 1.—Relationship of Modules

The objective of this research is to develop microcomputer modules which will allow the user to perform each of these steps. The microcomputer implementation will consist of the following modules:

1. Quantity Module.
2. Resource definition module.
3. Production and cost analysis module.

The rationale behind a microcomputer implementation lies in the fact that microcomputers have the characteristics required for construction field office utilization. They are small enough to fit on top of a desk and are inexpensive. Their price range is between \$2,500 and \$10,000. A microcomputer provides total control to the user over his/her data. It reduces the risk of others accessing his/her data base. However, the system could be implemented on mini or mainframe computer as well.

The set of standard useful process models is limited to road construction projects and CYCLONE methodology is used for modeling and simulation of these operations (1,4,5,7,8,9). Beta distribution is used to model random work task durations. Quantity development is limited to earthwork.

The relationships between these modules is shown schematically in Fig. 1. The nature of the work that is accomplished in developing each of these modules is described in the following sections.

QUANTITY MODULE

The quantity module generates quantities based on information available in the design documents. This module is primarily an earthwork quantity take-off program with special features for the road construction projects.

The most important feature of this program is the capability of defining a standard road cross section. After entering the existing grade data,

TABLE 1.—Standard Models Menu

STANDARD MODELS MENU	
1.	CLEARING AND GRUBBING
2.	STRIPPING
3.	EXCAVATION
4.	DITCHING
5.	PLACING, SPREADING, COMPACTION, AND GRADING OF SUBGRADE
6.	PLACING, SPREADING, COMPACTION, AND GRADING OF NONSTABILIZED BASE OR SUBBASE
7.	PLACING, SPREADING, COMPACTION, AND GRADING OF STABILIZED BASE OR SUBBASE
8.	ASPHALT PAVING
9.	CONCRETE PAVING
10.	USER SPECIFIED MODEL
ENTER YOUR SELECTION.	

TABLE 2.—Standard Excavation Models Descriptions**1. STANDARD EXCAVATION MODEL #1**

THE EQUIPMENTS USED ARE EXCAVATING UNIT (E.G. FACE SHOVEL), LOADING UNIT (E.G. FRONT END LOADER), HAULING UNIT (E.G. TRUCK), AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE EXCAVATING, STOCKPILING SOIL, LOADING, HAULING, DUMPING, RETURNING, AND SPREADING DIRT.

2. STANDARD EXCAVATION MODEL #2

THE EQUIPMENTS USED ARE EXCAVATING/LOADING/HAULING/SPREADING UNIT (E.G. SCRAPER) AND PUSHING UNIT (E.G. PUSHER). THE WORK TASKS ARE PUSHING/LOADING, HAULING, DUMPING/SPREADING, AND RETURNING.

3. STANDARD EXCAVATION MODEL #3

THE EQUIPMENTS USED ARE EXCAVATING/LOADING UNIT (E.G. CRANE), HAULING UNIT (E.G. TRUCK), AND SPREADING UNIT (E.G. DOZER). THE WORK TASKS ARE EXCAVATING, LOADING, HAULING, RETURNING, AND SPREADING.

ENTER YOUR SELECTION.

the user could either enter the finished grade data or the center line elevation of the proposed road at any station. In the latter case, the computer automatically generates a few points that define the finished grade. Points of intersection are found, including the slope intercepts at both ends of the stations. Volumes are computed between each station. This option reduces the process time significantly.

Another important feature of this program is the capability of changing some or all of the standard section parameters for sensitivity anal-

TABLE 3.—Set of Parameters in Standard Excavation Model #1**STANDARD EXCAVATION MODEL #1**

PROCESS KEYNAME?
QUANTITY IN C.Y.?
EXCAVATION DURATION (LOW LIMIT (MIN.), HIGH LIMIT,
MEAN VARIANCE)?
STOCKPILING DURATION (LL, HL, M, V)?
HAULING DURATION (LL, HL, M, V)?
DUMPING DURATION (LL, HL, M, V)?
RETURNING DURATION (LL, HL, M, V)?
NUMBER OF EXCAVATING UNITS?
PRODUCTION CAPACITY IN C.Y.?
FIXED COST IN \$?
VARIABLE COST IN \$/HR.?
NUMBER OF SPREADING UNITS?
FIXED COST IN \$?
VARIABLE COST IN \$/HR.?
DATA FILE NAME?

ysis. For example, the user could easily change the fill or cut slope and get a new cut and fill volume.

The data could be revised, printed or plotted easily. The program also prints a list of cut and fill areas of every section and total cut and fill volume.

RESOURCE DEFINITION MODULE

The application of simulation in the analysis of construction operations has been hindered to some extent previously by the model building process. The purpose is to provide the user with a set of standard useful process models frequently encountered in road construction projects. Perhaps with slight modification, the user would be able to use the

TABLE 4.—Typical CYCLONE Problem Oriented Language Specification for Standard Excavation Model #1

```

CONTROL INPUT
NAME EXCAVATION CYCLES 200 LENGTH 1E + 38
NETWORK INPUT
ACT 1 QUE 'EXCAVATING' UNIT IDLE'
ACT 2 COMBI 'EXCAVATE' PRE 1 16 FOL 3 16 SET 2
ACT 3 NOR 'STOCKPILE SOIL' FOL 1 4 SET 3
ACT 4 QUE 'SOIL STOCKPILE IDLE'
ACT 5 COMBI 'LOAD' PRE 4 11 17 FOL 6 17 SET 5
ACT 6 FUN FOL 7 CON 10
ACT 7 NOR 'HAUL' FOL 8 SET 7
ACT 8 NOR 'DUMP' FOL 9 12 SET 8
ACT 9 NOR 'RETURN' FOL 10 SET 9
ACT 10 FUN 'COUNT' FOL 11 QUANTITY 20
ACT 11 QUE 'HAULING UNIT IDLE' GEN 10
ACT 12 QUE 'DUMPED LOADS IDLE'
ACT 13 COMBI 'SPREAD DIRT' PRE 12 14 FOL 14 15 SET 13
ACT 14 QUE 'SPREADING UNIT IDLE'
ACT 15 SINK 'DIRT SPREAD'
ACT 16 QUE 'GROUND AVAILABLE'
ACT 17 QUE 'LOADING UNIT IDLE'
EQUIPMENT INPUT
1 AT 1 FI 0 VA 50
1 AT 11 FI 0 VA 50
10 AT 16
1 AT 14 FI 0 VA 50
1 AT 17 FI 0 VA 50
DURATION INPUT
SET 2 2 2 2 0
SET 3 1 1 1 0
SET 5 2 2 2 0
SET 7 5 5 5 0
SET 8 1 1 1 0
SET 9 4 4 4 0
SET 13 2 2 2 0
END DATA

```

standard defined models as his or her model. The available set of standard process model types primarily assists users in the model building process. This standard process model concept reduces considerably the time required to initiate an input, and the user proceeds to simulation quickly. The inputs required are:

1. Process keyname.
2. Quantity.
3. Work task durations (low limit, high limit, mean, variance).
4. Number of resources of each category defined.
5. Production capacity of each unit.
6. Cost per hour of each resource.

For each road construction activity to be analyzed, the computer describes the standard networks. The user makes input of the items previously noted (e.g., durations, resource numbers) to the standard network to be used.

The user has the option in this module to reject the standard networks presented and to define his or her own cyclic network in CYCLONE problem oriented language format. The user could easily edit the model specification interactively. This user defined network is then utilized for the productivity and cost analyses and is stored for future reference and use.

The sequence of events in road construction are usually as follows:

1. Clearing, grubbing, and stripping.
2. Road and drainage excavation.
3. Placing, spreading, compaction, and final grading of the subgrade.
4. Placing, spreading, compaction, and grading the material for the subbase, if used.
5. Placing, spreading, compaction, and final grading of base.
6. Paving.

The models for the above standard activities in road construction are

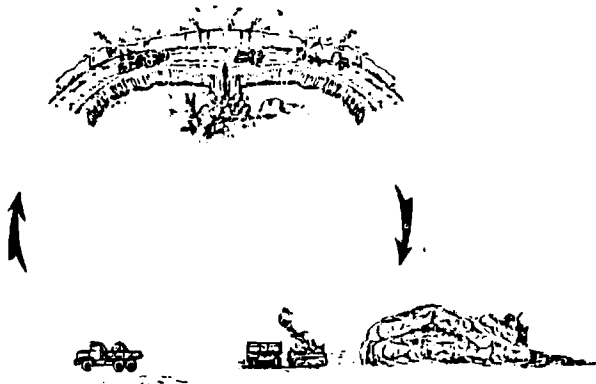


FIG. 2.—Graphical Representation of Standard Excavation Model #1

developed in conjunction with several practicing construction professionals. These models are not the ultimate standard models, but they are adequate and are realistic representations of the actual work done in the field. These models are used in structuring the input to the resource definition module and the processing of the productivity and cost analysis module.

The standard models menu is illustrated in Table 1. If the excavation is chosen, a description of each of the standard excavation models is printed on the screen as shown in Table 2. If the standard excavation model #1 is chosen, several prompts appear as shown in Table 3. After all the entries are made and corrected, the computer generates the problem oriented language specification for the standard model #1 as illus-

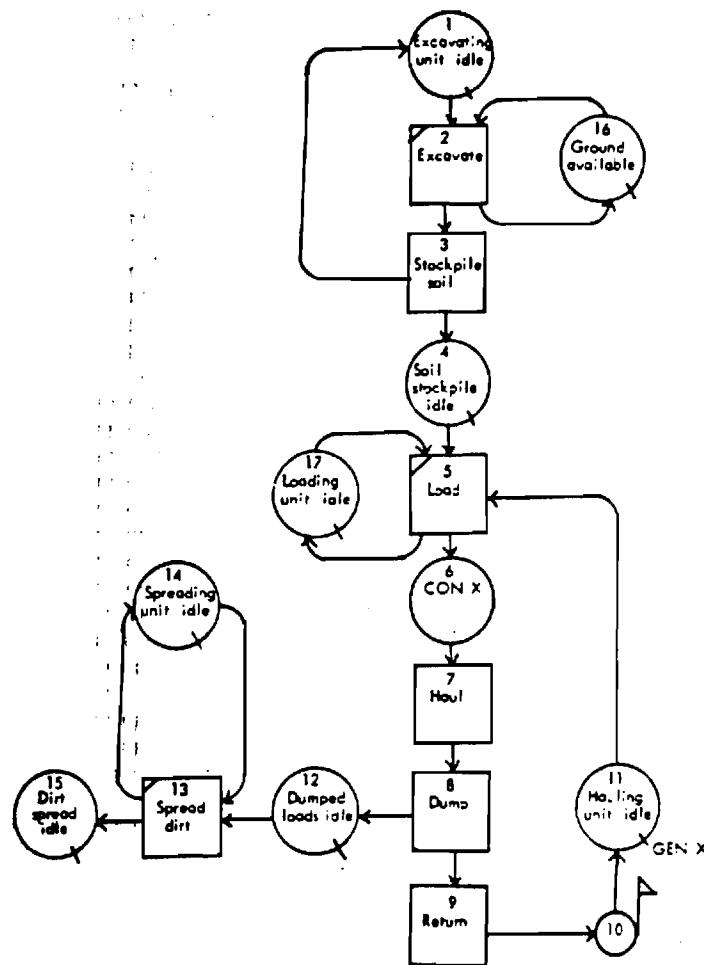


FIG. 3.—Standard Excavation Model #1

trated in Table 4. (Fig. 2 is a graphical representation of the model and Fig. 3 shows the standard excavation model #1.)

PRODUCTIVITY AND COST ANALYSIS MODULE

The productivity and cost analysis module operates on data shipped to it from the resource definition module. Processing will be simulation based and will utilize the microcomputer implementation of CYCLONE. Times related to the standard or user defined models for each construction task will be passed to this module from the resource definition module. Based on the selected cost per hour of fleet selected and production rate, a unit cost is computed.

CONCLUSION

This research advances the level of user accessibility to simulation-based techniques. The research makes these techniques available within a microcomputer environment and applies them within a professional user-oriented context. These concepts (simulation based) have been traditionally considered too abstract and remote to be of use to the practitioner. The system developed in this research is practice-oriented and designed to demonstrate the applicability and accessibility of these techniques. Development and acceptance of such systems should contribute to the wider use of simulation. The system described is not limited to construction applications only. It has a potential for broad applications in other production-oriented areas as well. A stylized adaption of this system can be developed to cover any production process where quantities are developed by resource sets, and time and cost management are of interest.

APPENDIX.—REFERENCES

1. Dabbas, M. A. A., and Halpin, D. W., "Integrated Project and Process Management," *Journal of the Construction Division*, ASCE, Vol. 108, No. CO3, Sept., 1982, pp. 361-374.
2. Halpin, D. W., "CYCLONE: Method for Modeling of Job Site Processes," *Journal of the Construction Division*, ASCE, Vol. 103, No. CO3, Proc. Paper 13234, Sept., 1977, pp. 489-499.
3. Halpin, D. W., and Woodhead, R. W., *Design of Construction and Process Operations*, John Wiley and Sons, Inc., New York, N.Y., 1976.
4. Kalk, A., "INSIGHT—Interactive Simulation of Construction Operations Using Graphical Techniques," *Technical Report No. 238*, The Construction Inst., Dept. of Civ. Engrg., Stanford University, Stanford, Calif., July, 1980.
5. Lluch, J., and Halpin, D. W., "Construction Operations and Microcomputers," *Journal of the Construction Division*, ASCE, Vol. 108, No. CO2, Mar., 1982, pp. 129-145.
6. Naylor, T. H., "Computer Simulation Experiments with Models of Economic Systems," John Wiley and Sons, Inc., New York, N.Y., 1971.
7. Paulson, B. C., Jr., "Interactive Graphics for Simulating Construction Operations," *Journal of the Construction Division*, ASCE, Vol. 104, No. CO1, Mar., 1978, pp. 69-76.
8. Riggs, L. S., "Simulation of Construction Operations," *Journal of the Technical Councils*, ASCE, Vol. 106, No. TC1, Proc. Paper 15628, Aug., 1980, pp. 145-163.
9. Tavakoli, A., "Productivity Analysis of Heavy Construction Operations," Ph.D. dissertation, presented to the Georgia Inst. of Technology, in 1983, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

APPENDIX B

ABSTRACTS

M.S. Special Topic

Abstract

SENSITIVITY ANALYSIS OF CONSTRUCTION OPERATIONS
(USING MICRO-CYCLONE)

BY

SIMAAN ABOU-RIZK

Allocating resources to various tasks on a job site is usually done by experience and with minimal planning. With the modelling concepts presented in CYCLONE a more scientific tool is available to aid the manager in planning. Whether the model used is a standard one or created by the user himself, resources can be manipulated and the results of simulation tested and compared to other cases. All of this is done in a testing environment where minimal cost is incurred, and where all possible combinations of resources for an optimal allocation can be checked. The CYCLONE concept and the sensitivity analysis program presented in this research form the basis of this testing environment. Resources can be actually initiated at different locations in the system, their number and combinations varied, and simulation of each case performed separately for later analysis. The program developed allows determination of optimal resource allocation based on a sensitivity analysis approach.

M.S. Special Topic

Abstract

ANALYSIS AND DEVELOPMENT OF AN EQUIPMENT
ALLOCATION TECHNIQUE FOR HIGHWAY EARTHWORK
(EXCAVATION AND HAUL) PROJECTS

BY

PATRICK G. FINDLAY

The purpose of this research is the analysis of existing construction scheduling approaches and development of resource allocation methods specifically for earthwork excavation and hauling as applied to highway construction projects. The need for resource allocation concerns the practical aspects of how equipment is employed in the field, combined with the limitation on earthwork equipment resources.

This project considers earthwork in highway construction as the excavation and hauling of dirt from one location to another. The purpose of this work is generally to level out terrain variations, causing the final highway grade to be smooth thus allowing safe, rapid movement of vehicles. One objective of earthwork is to do this with a minimum expenditure of resources.

M.S. Special Topic

Abstract

THE APPLICATION OF STANDARD MODELS
IN MICROCYCLONE

BY

DAVID EDWARD NIEDERHAUSER

With the availability of a system that provides a method for simulation of construction processes, a problem arises as to how one accurately and practically represents the wide variety of construction operations which can be simulated and evaluated by MICROCYCLONE. This research offers a solution to this problem in the form of a library of standard MICROCYCLONE network models ranging from excavation to bricklaying. Currently, twenty-six (26) models exist in a graphical format which can be reproduced on the IBM PC or any compatible system with a graphics capability.

For a complete description of the CYCLONE simulation system please refer to the text "Design of Construction and Processes Operation" by D.W. Halpin and R.W. Woodhead published by John Wiley and Sons, Inc.

M.S. Special Topic

Abstract

AUTOMATED COST CONTROL
FOR EQUIPMENT

BY

PAUL HANNA NOCHAHARLI

This research focuses on presenting a system for equipment cost control and developing a computer program automating an existing system. The purpose of the control system is to provide management with a powerful means of controlling the equipment expenses. This can be achieved by detecting the variance between the planned and the budgeted costs at various stages of the project and making the suitable decisions to keep the cost within the budget limits.

The second purpose of this research is to facilitate the implementation of the control system. This will be accomplished through automation.

M.S. Special Topic

Abstract

COMPUTER GRAPHICS REPRESENTATION OF
STANDARD CYCLONE MODELS

BY

LUIS E. RINCONES

The objective of this special problem is to facilitate data input to the "MICRO CYCLONE" system through a computer graphic representation of standard CYCLONE models. Graphics representation of these models will hopefully improve the understanding of them by field personnel and consequently enhance communication. The standard CYCLONE models are:

1. - Standard Clearing and Grubbing Cyclone Model #1
2. - Standard Clearing and Grubbing Cyclone Model #2
3. - Standard Stripping Cyclone Model
4. - Standard Excavation Cylone Model #1
5. - Standard Excavation Cyclone Model #2
6. - Standard Excavation Cyclone Model #3
7. - Standard Ditching Cyclone Model #1
8. - Standard Ditching Cyclone Model #2
9. - Standard Placing, Spreading, Compaction and final grading
of subgrade Cyclone Model #1

Ph.D. Thesis

Abstract

PRODUCTIVITY ANALYSIS OF HEAVY CONSTRUCTION
OPERATIONS

BY

AMIR TAVAKOLI

CYCLONE for Microcomputers is extended in this research. The extended version provides an interactive environment for analysis of construction operations. The analysis is carried out in the context of various work modules which address:

1. Quantity Development .
2. Resource Definition
3. Production and Cost Analysis

The quantity work module generates quantities based on information available in the design documents. The resource module receives and stores data regarding the labor/equipment combination to be used to execute work tasks. Using input from the quantities module and the resource module, the productivity and cost analysis module generates production rates and unit cost based on process simulation using CYCLONE methodology.

Road construction is selected for implementation of the system on TRS-80 Model III microcomputer. Standard activities in road construction are developed, modeled and applied using CYCLONE methodology.

The transient response in productivity of two of the standard excavation CYCLONE models is also investigated in this research.

M.S. Special Topic

Abstract

THE DEVELOPMENT OF AN
EARTH DISTRIBUTION ANALYSIS PROGRAM
FOR MICROCOMPUTERS

BY

ROBERT S. TOOMY

The purpose of this study was to evaluate the use of microcomputers and linear optimization techniques in the planning of earthmoving operations. This subject was chosen because of the relative lack of work being done in applying construction management techniques to this area of civil engineering. The paper describes the development of a computer program that will produce an optimal earth distribution plan for a linear earthmoving project. The user inputs the cut and fill volumes for the project and the program uses a two-part solution procedure involving section-to-section matching and the transportation algorithm to devise this plan. Output is in the form of a graphical display and printed copy. The program was tested using data from actual highway projects.

M.S. Special Topic

Abstract

DEVELOPMENT AND TESTING OF A
ROAD EARTHWORK QUANTITY TAKE-OFF PROGRAM
FOR THE IBM-PC

BY

THOMAS A. TYE

The purpose of this study was to develop and thoroughly test a Road Earthwork Quantity Take-Off program that is accurate, provides graphical representation of data and can interface with a transportation optimization program. The report describes the development of the program and uses the data of interstate highway I-675 as a test.

The user inputs the data of the existing and final grades of the cross sections of a highway. The program calculates the volumes of excavation and embankment associated with each section. Output is in the form of graphical display and printed copy.

APPENDIX C

PUBLICATION CITATIONS

Publication Citations

1. Abou-Rizk, S., "Sensitivity Analysis of Construction Operations," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, March 1985.
2. Bernold, Leonard, "Teaching Construction Management Students Process Control," Session 2222, Proceedings, 1985 Annual Conference, American Society for Engineering Education, Atlanta, GA, June 1985.
3. Bernold, L., "Productivity Transients in Construction Processes," Ph.D. Thesis, School of Civil Engineering, Georgia Institute of Technology, 1985 (in press).
4. Bernold, L. and Halpin, D.W., "Microcomputer Cost Optimization of Earth Moving Operations," Vol. 2, Proceedings, 4th International Symposium on Organization of Construction, U. of Waterloo, Waterloo, Ontario, July 1984.
5. Findlay, Patrick G., "Analysis and Development of an Equipment Allocation Technique for Highway Earthwork Projects," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, August 1985.
6. Halpin, D.W., "The Age of Graphics," Stratagem, Volume 2, Issue 1, Fall 1984 published by Project Management Associates, Inc., Ann Arbor, Michigan.
7. Halpin, D.W., "Solving Everyday Construction Field Problems Using the Microcomputer," presented in Session 142, 64th Meeting of the Transportation Research Board, Jan. 16, 1985.
8. Halpin, D.W., "Resource Analysis Using Microcomputers - Final Report, NSF Grant CEE-8208271," School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, September 1985 (in press).
9. Halpin, D.W., "Impact of Small Computers on the Practice of Construction in the U.S.," Proceedings of the Conference on "The Use of Microcomputers in the Construction Industry," Budapest/Rackeve, Hungary, September 1984.
10. Halpin, D.W., "What's New in Construction?" - Invited Lecture presented to the Construction Management Center, Washington U., St. Louis, MO, on 20 February 1985.
11. MicroCYCLONE User's Manual, Version July 1985, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, July, 1985.
12. Niederhauser, D., "The Application of Standard Models in Micro-

CYCLONE," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, August 1984.

13. Nochaharli, Paul H., "Automated Cost Control for Equipment," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, August 1984.
14. Rincones, L., "Computer Graphics Representation of Standard CYCLONE Models," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, March 1984.
15. Tavakoli, A., "Productivity Analysis of Heavy Construction Operations," Ph.D. Dissertation, Civil Engineering Dept., Georgia Institute of Technology, Atlanta, 1983.
16. Tavakoli, A., "Productivity Analysis of Construction Operations," Journal of Construction Engineering and Management, Vol. III, No. 1, March 1985, pp. 31-39.
17. Toomy, R.S., "The Development of an Earth Distribution Analysis Program for Microcomputers," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, May 1984.
18. Tye, Thomas A., "Development and Testing of a Road Earthwork Quantity Take-off Program for the IBM PC," M.S. Special Topic, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, August 1984.

APPENDIX D

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