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Simulation Methodology in Construction Process

Methodologie de Simulation en Processus de Construction

par

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Résumé

En accord avec les innovations de méthodes de construction et les robotisations au chantier, les ingénieures de construction ont besoin des instruments plus convenables de direction pour la planification et la programmation.

L'auteur a developpé une méthodologie alternative de simulation pour le processus de construction au chantier. Ce modèle de simulation est presenté par une graphie directive et transformé en une serie des langages de GPSS afin de simuler le processus.

Cet article montre les notations du modèle pour le processus de construction et la conception du systeme de simulation. Et puis, ce système est appliqué aux travaux d'armature au chantier.

Ce système a des aspects de facilité, flexibilité et extensibilité de simuler le processus de construction. Donc, cette méthodologie pourrait être un instrument utile pour les ingénieurs afin de planifier et améliorer les processus robotisés de construction.

Simulation Methodology in Construction Process

by

Naruo KANO

Abstracts

In accordance with innovations of construction methods and robotizations at the site, construction engineers need more relevant management tools for planning and scheduling the construction process. It has become essential to apply system simulation techniques to planning and scheduling.

The author has developed an simulation methodology for the construction process at building sites. The simulation model is presented by a directed graph and is transformed into a GPSS (General Purpose Simulation System) language set in order to simulate the process.

This paper shows the notations of the model for the construction process and the concept of the simulation system. The system is then applied to reinforcing work in a building construction site.

The system has the characteristics of easiness, flexibility and expandability. Therefore, this methodology could be adopted as a very useful tool for engineers to plan and improve robotized construction processes.

Simulation Methodology in Construction Process

Naruo KANO

1. Introduction

To plan and schedule a complex construction process where each worker performs a specific task in cooperation with other workers and equipment, engineers will need effective tools to establish a rational and scientific approach. Once construction sites have become widely mechanized, the construction processes would be more complex. Hence a planning tool will be one of constraints that govern the success of mechanization and robotization of construction sites.

This paper shows the concept of methodology for system simulation of the construction process and introduces a graphic model which represents the process. Then the author implements the methodology described here to reinforcing work by use of the simulation system, which has been developed as a prototype system in order to investigate the feasibility of the methodology.

2. System Simulation of Construction Process

The processes of construction in a building site have become too complex for engineers to optimize the allocations of resources (workers, equipment, etc.), the method of work, and the sequences of work by intuitive approaches and current static methods. The system simulation would be a competent tool to analyze the processes in dynamic manner and optimize the selection of methods, the allocations of resources and sequences of works.

The system simulation is categorized into the following domains of computer language to be used.

1. Simulation with a program language (ex. FORTRAN, BASIC, PASCAL)
2. Simulation with a simulation language (ex. GPSS, DYNAMO, Simscript)
3. Simulation with a problem-oriented language (ex. GERT, CYCLONE)

All of the above languages could be available for system simulation of construction processes; however the languages have their own characteristics which would affect the efficiency of implementation for construction planning. These characteristics are indicated in Table 1.

In the construction process, there are many differences in drawings, specifications, conditions of the work areas and resources existing among construction sites. Therefore, the critical point for evaluation of the language to be used for system simulation of construction processes is the

Table 1 Evaluation of Languages for System Simulation

Evaluation Item \ Type of Language	Program Language	Simulation Language	Problem-Oriented Language
Competence of Modeling	○	○	△
Manpower required for Modeling	×	△	○
Simplicity of Model	×	△	○
Process Time	○	△	△
Time to Master the Language	×	△	○

○ : Fine △ : Moderate × : Poor

manpower and time to be required to complete the simulation model. From this point of view, a problem-oriented language will be the best.

Extensive research has been devoted to development of simulation systems aimed at serving as a problem-oriented language, such as GERT[1] and CYCLONE[2]. CYCLONE in particular was developed by D.W.Halpin for construction processes and has proved successful from extensive applications.

The author developed an alternative method for system simulation of construction processes, which represents the process with a graphic notation called a "Process Graph"[3] into a set of GPSS (General Purpose Simulation System) language automatically in order to execute the simulation.

3. Model of Construction Process

3.1. Graphic Notations of a Model

The simulation model introduced here is intended for construction engineers to represent the sophisticated components and structures in the construction process as a graph, requiring less manpower and time. The aspects of representation for modeling the process is indicated in the following.

1. Types and quantities of resources and building elements.
2. Locations where works are performed.
3. Locations where resources and building elements exist.
4. Sequential relationships between works.
5. Uncertainties in the process.

Models should be represented in a visual manner so that an engineer can develop a model without knowledge of computer language, and can explain the substances of the process which he has represented to other engineers in order to discuss the issues of the process.

The graph which is used to represent the construction process consists of the following five nodes and eight arrows shown in Table 2.

1. Resource Node : Workers, Materials, Equipment
2. Activity Node : Operations, Works, Tasks
3. Element Node : Columns, Beams, Walls, Fixtures , etc.
4. Space Node : Work space, Stockyard, Floor, Position
5. Function Node : Release Node, Loop Node, Probability Node

Each node is configured in a different form as shown in Figure 1 and must have the attributes shown in Table 3.

3.2. Modeling of Location

The location of resources, the area where work is performed, and the position of building elements to be produced are important factors for planning and optimizing the construction process.

Table 2 Notation of Arrows

Type of Arrow \ Characteristics of Arrow	Arrow Code	Direction of Arrow	Type of line
Space Arrow	SPA	Directed	Solid
Transport Arrow	TRA	Directed	Broken
Catalyst Arrow	CTA	Bi-directed	Solid
Active Factor Arrow	AFA	Directed	Solid
Object Arrow	OJA	Bi-directed	Broken
Precedence Arrow	PRA	Directed	Solid
Control Arrow	CLA	Directed	Solid
Probability Arrow	PBA	Directed	Solid

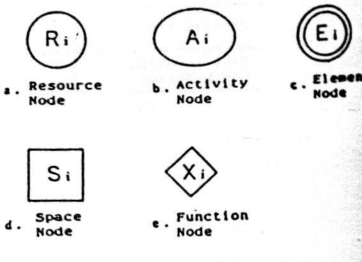

Figure 1 Notation of Nodes

Table 3 Attributes for Nodes

Type of Node / Attribute	Space Node	Activity Node	Element Node	Resource Node
Identification Code	Three Alphanumerics	Three Alphanumerics	Three Alphanumerics	Three Alphanumerics
Node Code	RSN	ACN	ELN	SPN
Item	① Initial Value of Quantity ② Area to be required for Storage	① Type of Time Distribution ② Mean Time ③ Variance of Time ④ Priority to Start	① Initial Value of Quantity ② Area to be required for Building Elements	① Area of the Space

To indicate the location with a graph notation, a Space Arrow (SPA) is used for connections between Space Node and those nodes such as Resource Node, Activity Node and Element Node.

Figure 2 shows that the resource (R1) is stored at the stockyard (S1). Figure 3 shows that the work (A1) is performed in the area (S2) at the site. Figure 4 shows that the building element (E1) will be fixed on the location (S3).

Each Space Arrow has the attributes shown in Table 4. A Space Arrow could represent the locations as a graph; however the graph will be too congested when many resources, activities and building elements are applied to the same space or location as shown in Figure 5. In this case, the location is indicated by the alternative notation, where the Space Node is placed surrounding the resources as shown in Figure 6.

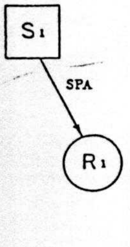

Figure 2 Process Graph for Location of Resources

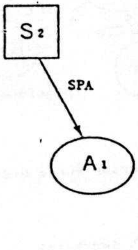

Figure 3 Process Graph for Area of Works

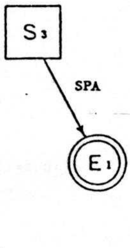

Figure 4 Process Graph for Position of Building Elements

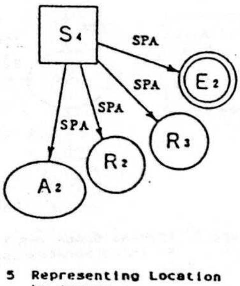

Figure 5 Representing Location by Arrows

Table 4 Attributes for Arrows (SPA)

Type of Arrow / Attributes	Space Arrow for Specifing Resources	Space Arrow for Specifing Works	Space Arrow for spcifing Building Element
Arrow Code	SPA	SPA	SPA
Item	Area to be required for Storage	Area to be required for Works	Area to be requir for Building Elem

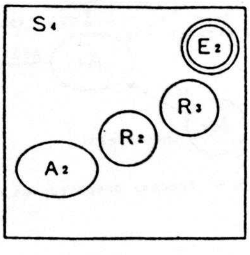

Figure 6 Representing Location by a Node

3.3. Modeling of Activities

Activities in the construction process are classified into the following three types of works.

1. Transport works : Horizontal transportaion, lifting, etc.
2. Assembly and Disassembly works : Fixing, Bending, Cutting, Dismantling, etc.
3. Miscellaneous works : Inspection, Curing, Storing, etc.

To represent a transport work of a resource, the Transport Arrow (TRA) is used for connecting the Activity Node and the two Resource Nodes, which indicate resources before transport and after transport.

Figure 7 shows the work (A3) where the resource (R4) in stockyard (S5) will be transported to another stockyard (S6). When workers and equipment are required to be specified explicitly in the graph, these resources are indicated as shown in Figure 8. The Resource Node is connected to the Activity Node by the Catalyst Arrow (CTA); the Transport Arrow and the Catalyst Arrow have the attributes as shown in Table 5.

To represent assembly and disassembly work, Active Factor Arrows (AFA) are used for connecting the Activity Node and the Resource Node (or Element Node).

Figure 9 shows the assembly work where workers (R7) assemble the materials (R8 and R9) to produce the building element (E3). Figure 10 shows the dis-assembly work where workers (R10) use a crane (R11) to disjoint scaffoldings (R12) into tubular-steel scaffolds (R13), braces (R14) and platforms (R15).

To represent such miscellaneous work as inspection and storing, Object Arrows (OJA) are used for connecting the Activity Node and the Resource Node. An Object Arrow means that there is no significant change made to the resources (or building elements) after these works have been performed.

Figure 11 shows work where a worker (R16) maintains a crane (R17).

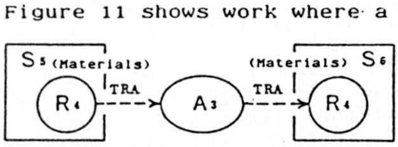

Figure 7 Process Graph for Transport Work

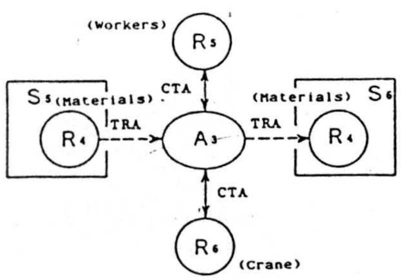

Figure 8 Process Graph for Transport Work defining Workers and a Crane

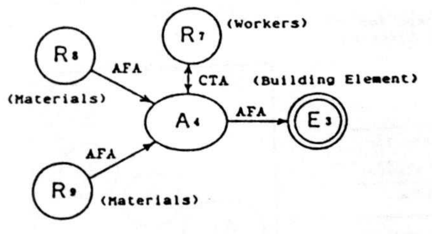

Figure 9 Process Graph for an Assembly Work

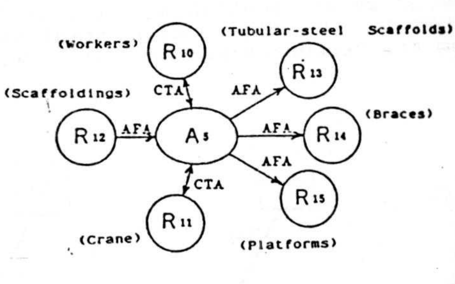

Figure 10 Process Graph for a Diassembly Work

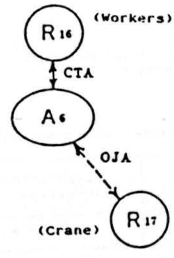

Figure 11 Process Graph for Miscellaneous Works

Table 5 Attributes for Arrows (TRA,CTA,AFA,OJA)

Type of Arrow / Attributes	Transport Arrow for Input	Transport Arrow for Output	Catalyst Arrow
Arrow Code	TRA	TRA	CTA
Item	Quantity of Resources to be carried-out	Quantity of Resources to be carried-in	Quantity of Resources to be employed
Type of Arrow / Attributes	Active Factor Arrow for Input	Active Factor Arrow for Output	Object Arrow
Arrow Code	AFA.	AFA	OJA
Item	Quantity of Resources to be input	Quantity of Building Element to be output	Quantity of Resources to be object

3.4. Modeling of Process Logic

Logic in construction processes is expressed as the relationships between activities. These relationships are classified into the following four types.

1. Precedences between activities
2. Controls from one activity to another
3. Repetitions of activities
4. Stochastic sequencial relationship in process

To represent the precedences between activities, Precedence Arrows (PRA) are used in the same manner as the precedence network. However no lead time is assigned on a precedence relationship because of simplicity for modeling. The Precedence Arrow specifies the start time of an activity using Start-to-Start relation and Finish-to-Start relation, as shown in Table 6. To control the finish time of activities, the Control Arrow (CLA) will have a function that interrupts the performance and finishes the activity as shown in Table 6. Figure 12 shows the process where the work (A7) of setting a ceiling panel requires the work (A8) of holding the panel and when the work of nailing (A9) finishes, the work (A8) will be unnecessary.

To represent the repetition of works the Release Node and the Loop Node are used for defining the link of repetitive works. This notation is similar to GERT except for the form of the nodes. Figure 13 shows the process where the activity (A11) is repeated after the completion of the work (A10) and then the work (A12) begins.

Table 6 Precedence Arrow and Control Arrow

Type of Arrow	Relation Code	Description	Bar Chart
Precedence Arrow	SS	Activity Aj starts when Activity Ai starts	Ai / Aj
	FS	Activity Aj starts when Activity Ai finishes	Ai / Aj
Control Arrow	SF	Activity Aj is interrupted when Activity Ai starts	Ai / Aj
	FF	Activity Aj is interrupted when Activity Ai finishes	Ai / Aj

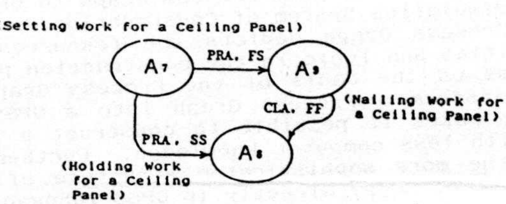

Figure 12 Process Graph for Precedences and Controls

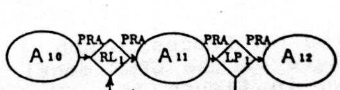

Figure 13 Process Graph for the Repetitive Work

The Release Node and the Loop Node have the attributes shown in Table 7 and 8.

To represent the stochastic sequencial relationship, the Probability Node, Probability Arrow (PBA) and Release Node are used. Figure 14 shows the process where the sequential relationship between the work (A14) and (A15) is stochastically determined from the other conditions of the process.

Table 7 Attributes for Arrows (PRA,CLA,PBA)

Type of Arrow / Attributes	Precedence Arrow	Control Arrow	Probability Arrow
Arrow Code	PRA	CLA	PBA
Item	Relation Code start-to-start <SS> finish-to-start <FS>	Relation Code start-to-finish <SF> finish-to-finish <FF>	Probability

Table 8 Attributes for Function Nodes

Type of Node / Attribute	Release Node	Loop Node	Probability Node
Identification Code	Three Alphanumerics	Three Alphanumerics	Three Alphanumerics
Node Code	RLN	LPN	PBN
Item	Number of Arrows to release	Number of Repetitions	None

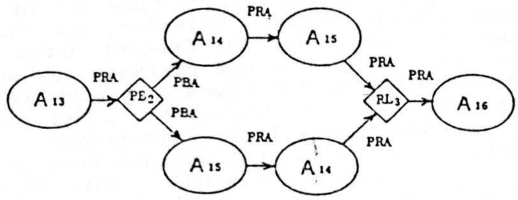

Figure 14 Process Graph for Stocastic Process

4. Transformation from Process Graph to GPSS

4.1. Simulation System of Construction Process

Process Graph depicts the resources, building elements concerned with activities and logic in the construction process. To simulate the construction process on the basis of the Process Graph, the author developed the system to transform a Process Graph into a GPSS language set automatically. This system makes it possible to construct a simulation model with less manpower and with less computer knowledge. Furthermore, this system is able to represent the more sophisticated structure of construction process by programing the part of model directly in GPSS language and integrating it with the Process Graph.

Figure 15 shows the concept of the simulation system using the Process Graph.

4.2. Transforming the Process Graph

The structure of the GPSS model into which the Process Graph is transformed is shown in Figure 16. The Resource Node, Element Node and Space Node are transformed into the SAVEVALUE BLOCK, which controls the quantities of resources, building elements and the area of space available during the simulation period. The Activity Node and Function Node are transformed into

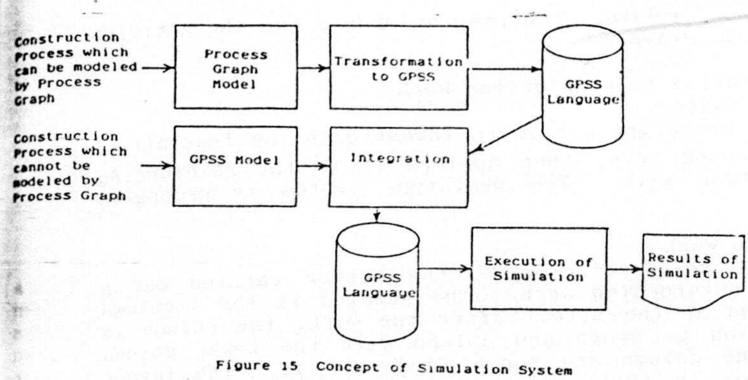

Figure 15 Concept of Simulation System

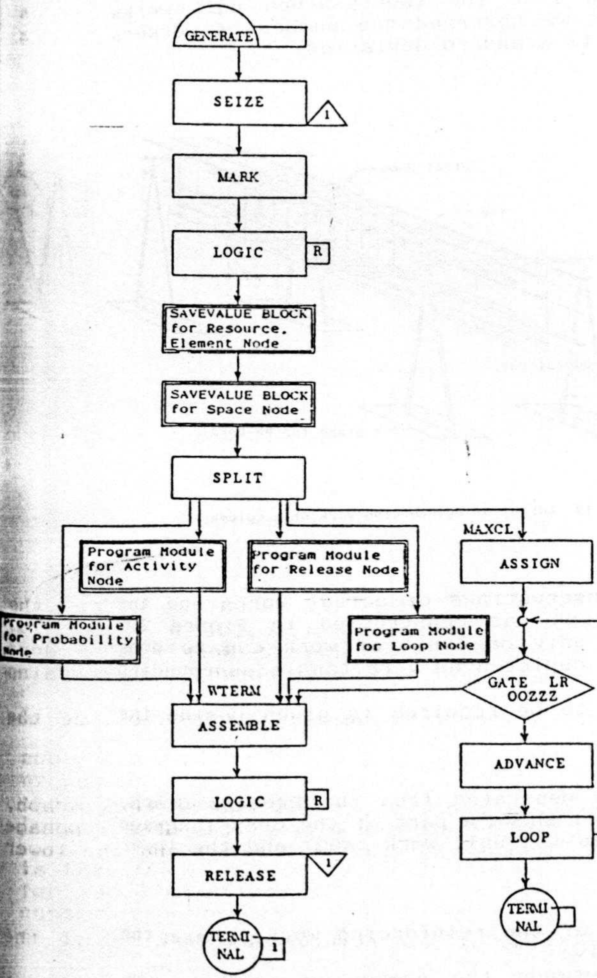

Figure 16 Structure of GPSS for Simulation

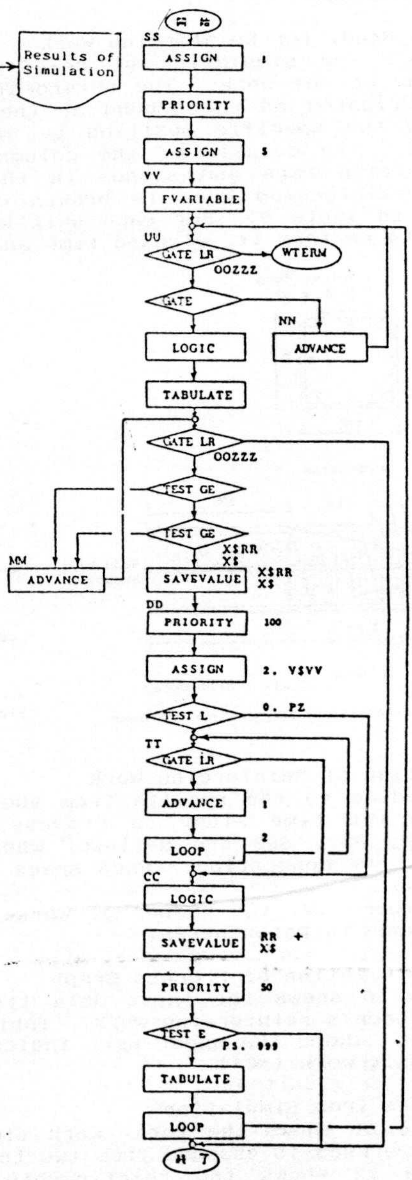

Figure 17 Program Module for An Activity Node

a GPSS language set as a program module. The program module for the Activity Node is shown in Figure 17 as an example.

5. Implementation of the Simulation to Reinforcing Work

5.1. Development of Prototype System

The author developed the prototype system to investigate the feasibility of the simulation system proposed here, then applied it to the reinforcing work in a building construction site. The prototype system is programed in PL/I language.

5.2. Time Study for Reinforcing Work

Before the simulation of reinforcing work, the author carried out a time study on the work. The reinforcing work to be studied is for a column to be fabricated on the ground at the site. After the work, the column is lifted to the specific position by crane and joined with the lower column and beams. The details of the column are shown in Figure 18. The layout of reinforcing bars and stands in the work are illustrated in Figure 19.

The reinforcing work is broken down into the twenty-seven unit works as shown in Table 9. For each unit work we observed the number of workers required to perform it, elapsed time and its standard deviation.

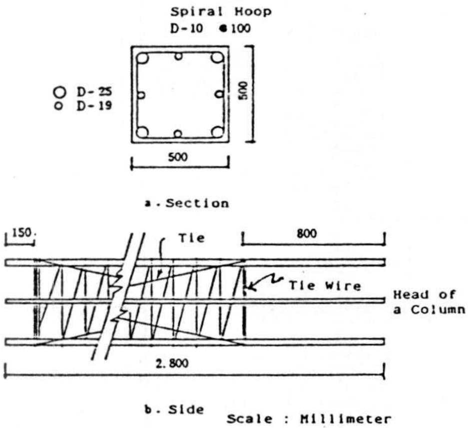

Figure 18 Details of Re-bars for a Column

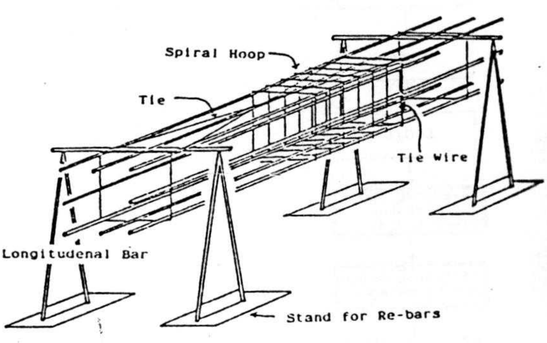

Figure 19 Layout of Reinforcing Work of a Column

5.3. Modeling of Reinforcing Work

According to the results from the observations of actual works and the data from the time study, a Process Graph was constructed in Figure 20. Spaces S01, S02, S03 are defined, where only one unit of work can be done because of the congestion. Each space is depicted as a rectangle surrounding Activity Nodes.

In Figure 20, the number of workers to be required is given beside the Activity Node in parentheses.

5.4. Transformation of Process Graph

Table 10 shows the input data lists generated from the Process Graph, which represents reinforcing work. Table 11 shows a part of the GPSS language transformed, where the upper part indicates the unit work (A02) and the lower part the unit work (A03).

5.5. Results from Simulation

Figure 21 shows the total work time of the reinforcing work, where the number of workers is changed from two to five.

Figure 22 shows the relationship between the number of workers and productivity. The productivity drops as the number of workers increase.

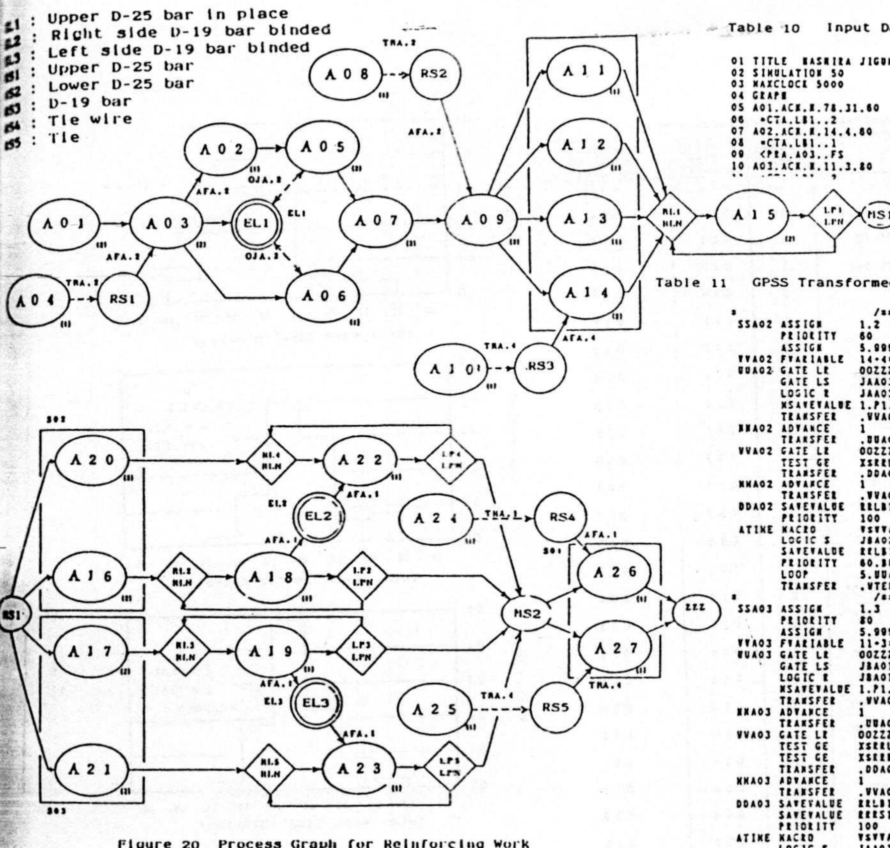

Figure 20 Process Graph for Reinforcing Work

Table 10 Input Data of Simulation

```
01 TITLE  KASHIRA JIGUKI      40 A11.ACK.K.59.50.80
02 SIMULATION 50              41  *CTA.LB1..1
03 MAXCLOCK 5000              42  <SPA.SP1..24
04 GRAPH                      43  <PRA.A09..FS
05 A01.ACK.K.78.31.60         44 A12.ACK.K.11.3.80
06  *CTA.LB1..2               45  *CTA.LB1..1
07 A02.ACK.K.14.4.60          46  <SPA.SP1..24
08  *CTA.LB1..1               47  <PRA.A09..FS
09  <PRA.A03..FS              48 A13.ACK.K.22.7.80
10 A03.ACK.K.11.3.80          49  *CTA.LB1..1
                              50  <SPA.SP1..24
                              51  <PRA.A09..FS
                              52 A14.ACK.K.95.43.80
                              53  *CTA.LB1..2
                              54  <AFA.RS3..4
                              55  <SPA.SP1..24
```

Table 11 GPSS Transformed from Input Data

```
*                          /*** NO. 2   * A02 *
 SSA02 ASSIGN      1.2
       PRIORITY    60
       ASSIGN      5.999
 VVA02 FVARIABLE   14+4*FNSNORM+0.5
 UUA02 GATE LR     00ZZZ.VTERM
       GATE LS     JAA03.NNA02
       LOGIC R     JAA03
       MSAVEVALUE  1.P1.2.M1
       TRANSFER    .WVA02
 NNA02 ADVANCE     1
       TRANSFER    .UUA02
 WVA02 GATE LR     00ZZZ.VTERM
       TEST GE     XSRRLB1.XSJBLB1.MMA02
       TRANSFER    .DDA02
 MMA02 ADVANCE     1
       TRANSFER    .WVA02
 DDA02 SAVEVALUE   RRLB1-.XSJBLB1
       PRIORITY    100
 ATIME MACRO       VSVVA02.TTA02
       LOGIC S     JBA02
       SAVEVALUE   RRLB1+.XSJAA02
       PRIORITY    60.BUFFER
       LOOP        5.UUA02
       TRANSFER    .VTERM
*                          /*** NO. 3   * A03 *
 SSA03 ASSIGN      1.3
       PRIORITY    80
       ASSIGN      5.999
 VVA03 FVARIABLE   11+3*FNSNORM+0.5
 UUA03 GATE LR     00ZZZ.VTERM
       GATE LS     JBA01.NNA03
       LOGIC R     JBA01
       MSAVEVALUE  1.P1.2.M1
       TRANSFER    .WVA03
 NNA03 ADVANCE     1
       TRANSFER    .UUA03
 WVA03 GATE LR     00ZZZ.VTERM
       TEST GE     XSRRLB1.XSJCLB1.MMA03
       TEST GE     XSRRRS1.XSJARS1.MMA03
       TRANSFER    .DDA03
 MMA03 ADVANCE     1
       TRANSFER    .WVA03
 DDA03 SAVEVALUE   RRLB1-.XSJCLB1
       SAVEVALUE   RRRS1-.XSJARS1
       PRIORITY    100
 ATIME MACRO       VSVVA03.TTA03
       LOGIC S     JAA03
       LOGIC S     JDA03
       SAVEVALUE   RRLB1+.XSJBA03
       SAVEVALUE   RREL1+.XSJCA03
       PRIORITY    80.BUFFER
       LOOP        5.UUA03
       TRANSFER    .VTERM
```

Delivery and unload of hoops

Putting upper D-25 bar in place

The results from the simulation is summarized as follows:

1. Reinforcing work requires different time due to the number of workers
   25 minutes (2 workers), 18.1 minutes (3 workers),
   15.4minutes (4 workers), 15.2 minutes (5 workers)
2. The number of workers will affect the productivity, so it should be determined to be two or three if a productivity of more than sixty percent is desired.

6. Conclusion

The author introduced the simulation methodology by which construction engineers could develop a simulation model requiring less manpower and time by use of a graphic presentation called "Process Graph". The author proposes the simulation system in which the Process Graph is transformed into a GPSS language set.

The distinctive feature of the simulation system described in this paper is the transformation to GPSS from a Process Graph. This feature compensates for the limitations of the Process Graph in modeling the real world of the construction process. Any segments that the Process Graph cannot represent as a graphic model would be programed directly in GPSS language.

The author is convinced that through application of a prototype system to reinforcing work, the methodology of simulation will prove an effective tool for construction planning and scheduling.

Table 9 Results of Observations of Reinforcing Work

ID Code	Description	Workers (Men)	Elapsed Time (Minutes)	Standard Deviation (Minutes)
A 0 1	Delivery of stands	2	0.7 8	0.3 1
A 0 2	Delivery and unload of hoop	1	0.1 4	0.0 4
A 0 3	Putting upper D-25 bar in place	2	0.1 1	0.0 3
A 0 4	Delivery of upper D-25 bar	1	0.4 0	0.1 2
A 0 5	Putting hoop in place	2	0.4 6	0.3 3
A 0 6	Marking	1	1.7 1	0.3 1
A 0 7	Arrangement of hoop	2	1.4 3	0.5 2
A 0 8	Delivery of lower D-25 bar	1	0.6 4	0.1 9
A 0 9	Arrangement of lower D-25 bar	2	0.1 5	0.0 5
A 1 0	Delivery of D-19 bar	1	0.6 8	0 2 3
A 1 1	Putting hoop in order	1	0.5 9	0.5 0
A 1 2	Putting upper D-25 bar in order	1	0.1 1	0.0 3
A 1 3	Putting lower D-25 bar in order	1	0.2 2	0 0 7
A 1 4	Arrangement of D-19 bar	2	0.9 5	0.4 3
A 1 5	Binding of D-25 bar	2	1.0 7	0.2 0
A 1 6	Preliminary binding of right side D-19 bar	2	0.1 0	0.0 3
A 1 7	Preliminary binding of left side D-19 bar	2	0.1 0	0.0 3
A 1 8	Binding right side D-19 bar	1	0.5 4	0.1 1
A 1 9	Binding left side D-19 bar	1	0.5 4	0.1 1
A 2 0	Preliminary binding of upper D-19 bar	2	0.1 0	0.0 3
A 2 1	Preliminary binding of lower D-19 bar	2	0.1 0	0.0 3
A 2 2	Binding of upper D-19 bar	1	0.5 4	0.1 1
A 2 3	Binding of lower D-19 bar	1	0.5 4	0.1 1
A 2 4	Delivery of tie wires	1	0.6 8	0.2 0
A 2 5	Delivery of tie	1	0.5 0	0.1 5
A 2 6	Binding of tie wire	1	0.1 5	0.0 5
A 2 7	Binding of tie	1	0.1 6	0.0 5

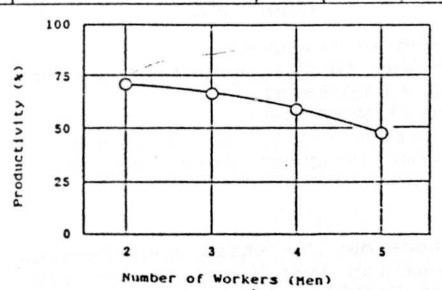

Figure 22 Relationship between Number of Workers and Productivity

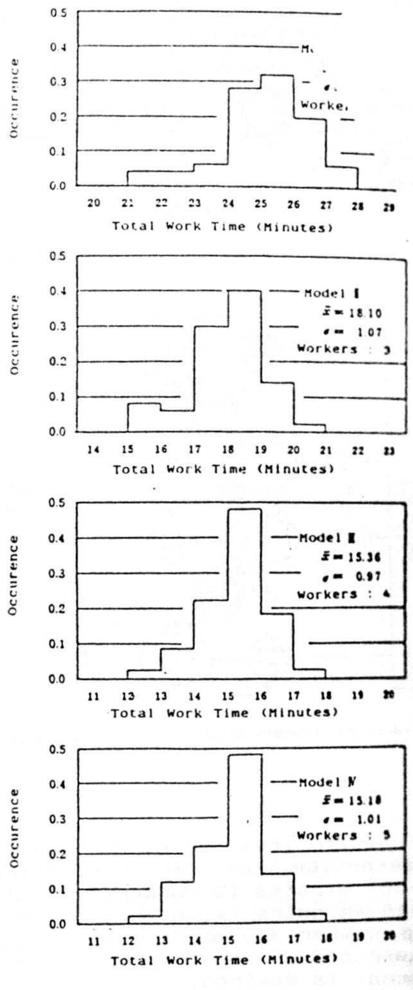

Figure 21 Distribution of Total Work Time

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