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A process for scheduling urban interchange reconstruction

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A process for scheduling urban interchange reconstruction

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH BACKGROUND

Interstate 235 (I235) is a major highway going through the Des Moines metropolitan area in Iowa. It is 14 miles (23 kilometers) long and has been open to public traffic since 1965. From then on, it has been the most heavily used interstate highway in Iowa. Its reconstruction has been a major issue in Des Moines for the past several years, which includes the widening and replacement of about 80 bridges, installation of noise walls, reconstructing about 20 interchanges, and finally repaving the road. It is expected to start in early 2002, and it probably will not be completed until at least 2006. The total project is expected to cost $469 million.

The corridor I235 is likely to be among the nation's largest and most complicated highway reconstruction projects, because the current urban traffic flow has to be maintained during the construction, and all of the bridges, roads, interchanges, noise walls, retaining walls, and various utility works must be coordinated through the corridor.

To meet these challenges, good planning and scheduling strategies are necessary to ensure that the corridor will be completed within time frame and budget. Generally speaking, the preconstruction project engineering and management phase involves the interaction of the owner, architect, engineering consultants, general contractor, and subcontractors from schematic design through final working drawings. During this phase, timely and accurate scheduling inputs will ensure that the final design, timing, and cost of the work are totally consistent with the project objectives. They can identify and realize savings at the earliest possible opportunity as shown in Figure 1.

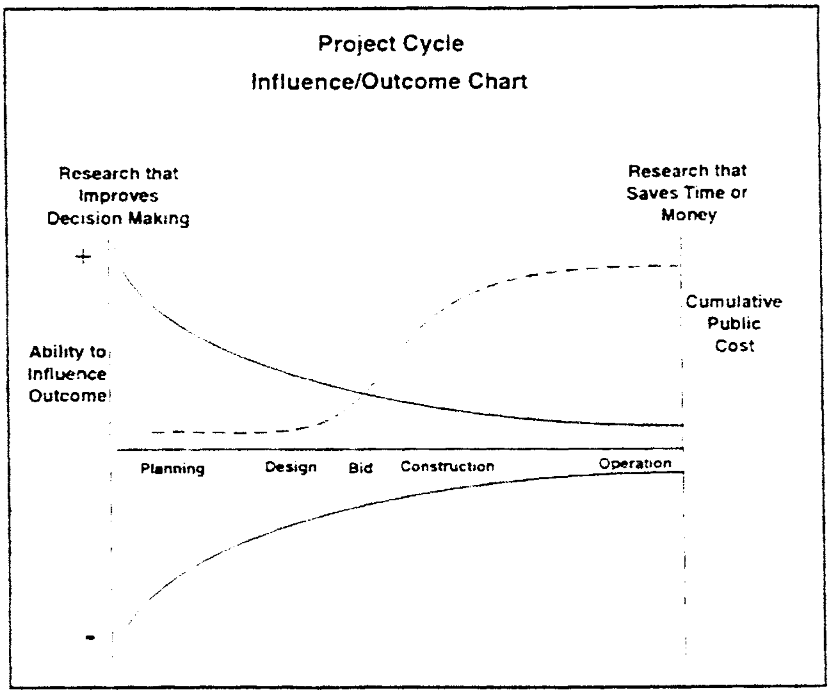

Figure 1: Project Cycle Influence/Outcome, from Construction Industry Institute, Austin, TX, Appearing in Several Publications

The researchers from Iowa State University have worked with the Iowa Department of Transportation (DOT) since August 1999, and developed computer-based schedules using Microsoft Project 2000, a project management software, to predict project completion, expose and adjust conflicts between trades or subcontractors, evaluate the effect of changes on project completion and cost, track projects' progress, and so on. Microsoft Project's characteristics, application situation, and comparison with Primavera (another project management software) are described in Appendix A.

1.2 PROBLEM STATEMENT

The corridor I235 includes projects of bridges, interchanges, main line paving and utility work. These projects have logical relationships between each other and will influence each other's construction. Based on the DOT's staging and standard production rates, some projects cannot be completed according to the DOT's required completion dates, so they require acceleration.

1.3 OBJECTIVES OF THESIS

This thesis will describe a method to create schedules for urban freeway interchange reconstruction projects and procedures and tables that assist with planning and accelerating.

The use of the above is demonstrated in a case study: Martin Luther King Jr. (MLK) and Cottage Grove Avenue projects in Interstate 235.

1.4 THESIS ORGANIZATION

Chapter 2 describes the establishment of DOT project contract durations to make readers understand the reason for the difference between contract durations and actual construction durations. Chapter 3 talks about construction calendars, which will be used to create construction schedules in the following chapter. Chapter 4 describes in detail the process of identifying the need of project acceleration using example projects in the corridor I235. Chapter 5 recommends acceleration measures and compares their advantages and limitations. And the last chapter, Chapter 6, is the summary and recommendations for future research.

CHAPTER 2: AN OVERVIEW OF CONTRACT DURATION ESTABLISHMENT

2.1 METHODS TO DETERMINE CONTRACT DURATIONS

Usually, if it is predicted that a project's real construction will take more time than its contract's duration, it is necessary to accelerate the project. To create a process to identify the necessity of acceleration, it is needed to know the methods used in determining contract durations.

Different state transportation agencies use different methods to determine contract durations. Some researchers, like J.E. Rowings [3], Z. Herbsman [5], and D.E. Hancher [3], have done considerable research work to identify the procedures adopted by various departments of transportation in the United States. It is found that most transportation agencies use Gantt charts to create their schedules for highway projects, as indicated in Table 1, because they are simple to prepare and understand; the other two popular scheduling methods, Critical Path Method (CPM) and Linear Scheduling Method (LSM) are little used in transportation agencies.

Table 1: Methods Used by 38 DOTs to Establish Contract Time Durations for Highway Construction Projects

METHOD	NUMBER USING	PERCENTAGE
Gantt Chart (no production rates)	3	8%
Gantt Chart (production rates)	19	50%
Critical Path Methods	4	11%
Tables or Curves (Time vs Cost or Quantities for Project Types)	5	13%
Judgment of Senior Personnel	7	18%
Total	38	100%

Hancher [3] thought that CPM was better for detailed scheduling and too cumbersome for conceptual scheduling. Another researcher from Iowa State University, David John Harmelink [4], who researched LSM, believed that LSM has not realized wide application in the construction area. The reasons are as follows:

1. LSM is essentially graphical and cannot be adopted to numerical computerization as readily as CPM schedules and Gantt charts.
2. LSM is less effective when repetitive activities are regularly interrupted, such as the construction of corridor I235, which is often interrupted by urban traffic.
3. In some complex projects, where a mutual scale for different activities cannot be fixed, LSM cannot be used to schedule the whole project.

Iowa DOT engineers use the actual work quantities supplied from the design personnel and standard production rates from the contract office, to select a duration for each activity. After that, they create a Gantt chart according to the logical relationships between these activities, and adjust the schedule based on their judgment and experience. Then the contract time duration for a project is established.

2.2 DOT STANDARD PRODUCTION RATES

The standard production rates used in the process of contract time duration establishment are very critical, because they influence the contract durations directly. However, based on the research of Rowings [3], Herbsman [5], and Hancher [2], the DOT standard production rates are different from the production rates derived from collected data of actual projects and consulting of experienced contractors.

ISU researchers consulted some personnel in the Iowa DOT Contract Office concerning this production rates difference. It is said that Iowa DOT's standard production rates, as shown in Table 2 and Table 3, are used mainly to determine contract durations. They should be kept lower to attract as many as possible contractors to bid projects, or else fewer contractors will bid the projects. Another reason for the difference is the Iowa DOT standard production rates are based on the collected data from both urban and rural highway projects, in which production rates can be significantly different.

So it is possible for the project duration in actual construction to be different from, and hopefully less than, its contract duration.

Table 2: DOT Standard Production Rates

SUGGESTED DAILY CONSTRUCTION RATES - METRIC

BID ITEM	UNIT	RATE/DAY
ACC Resurfacing	MG	1300
Backfill, Selected	M3	1350
Backfill, Selected	MG	1100
Base Cleaning and Preparation	KM	2.5
Bridge Approach	M2	200
Bridge Construction - Driving Piling	M	75
Bridge Construction - Reinforcing Steel	KG	2300
Bridge Construction - Structural Concrete	M3	16
Bridge Floor Overlay	M2	800
Bridge Floor Repair (Class A)	M2	15
Clearing and Grubbing	UNIT	400
Clearing and Grubbing	HA	0.5-1
Cold-In-Place Recycling	M2	10000
Compaction with Moisture Density Control	M3	1500
Concrete Barrier Rail	M	20
Concrete Open Rail	M	15
Cracking and Seating	HEAD START	5 DAYS
Cracks 1,2,3,4,5	M	1500
Culvert Pipe	M	50
Curb and Gutter	M	80
Delineators	EACH	50
Earth Shoulder Construction	M	3000
Embankment-In-Place	M3	700
Erosion control - Seeding	HA	3
Erosion control - Sodding	M2	1400
Erosion control - Wood Excelsior Mat	M2	900
Excavation Class 10, Bridges	M3	150-300 *
Excavation Class 10, Roadway and Borrow	M3	CHART 2
Excavation Class 12	M3	75 *
Excavation Class 20, Bridges	M3	40 *
Excavation Class 20, RCB	M3	150 *
Excavation Class 20, RCB Extensions	M3	40 *
Fence - Chain Link	M	150
Field Fence - Type 47	M	300
Gabions	M3	20
Guardrail, Cable	M	100
Guardrail, Steel Beam	M	60
Guardrail, Steel Beam (Structures)	M	30
Intakes	EACH	1.5

* Increase the Rate per Day when the quantities become unusually large

Table 3: DOT Standard Production Rates (Continued)

SUGGESTED DAILY CONSTRUCTION RATES - METRIC

BID ITEM	UNIT	RATE/DAY
Joints - Pressure Relief	M	10
Lighting - Poles	EACH	0.5
Longitudinal Joint Repair	M	1000
Longitudinal Subdrain	M	1000
Micro Surfacing	KM	4 @ 1 LANE
Mowing	HA	6
Patches, Full Depth by Area	M2	90
Pavement Markings	M	15000
Pavement Scarification	MG	1050
Paving Notch	EACH	2-6 DAYS
PCC, Rural	M2	3400
PCC, Urban	M2	Review Staging
Removal of Pavement < 16000	M2	800
Removal of Pavement > 16000	M2	3400
Rip- Rap (larger amounts)	MG	400
Rip-Rap	MG	150
Salvage and Demo	EACH	1-5 DAYS
Seal Coat	KM	8 @ 1 LANE, 4 @ 2 LANES
Sealing Water Wells	EACH	2
Shoulders, Granular	MG	1300
Sign Footings	EACH	4
Sign Posts	EACH	10
Signs - Large	EACH	5
Signs - Small	EACH	10
Steel Reinforcing (Bridge Floor Repair)	KG	500
Storm Sewer	M	50
Structural Concrete - Bridge Floor Repair	M3	2
Structural Concrete - RCB Extension, w/ steel	M3	4
Structural Concrete - Single RCB, w/ steel	M3	9
Structural Concrete - Triple RCB, w/ steel	M3	9
Structural Concrete - Twin RCB, w/ steel	M3	9.5
Structural Plate Pipe Culvert	M	10
Topsoil Strip, Salvage and Spread	M3	1050
Traffic Signals	EACH	30 for 1st, +10 for additional
Trees and Shrubs < 200	EACH	25
Trees and Shrubs > 200	EACH	50-100
Watering (13250 L/tank x 4)	KL	53

CHAPTER 3: CONSTRUCTION CALENDAR

3.1 WORKING-DAY DURATION AND CALENDAR-DAY DURATION

The contract duration is expressed by working days, but in the schedule for actual project construction, the duration for each activity is expressed by calendar days. Working-day duration is the direct sum of working days (usually it is assumed that there are 8 working hours for every day). Calendar-day duration is the time span between the specific calendar day of project start and the calendar day of project completion. It includes holidays, delayed time because of weather conditions, geographical locations, and so on. The calendar-day duration is more useful than the working-day duration in schedule creating, tracking, changing, and updating.

To figure out the construction schedule, both of the working-day duration and calendar-day duration are important. The working-day duration is the direct result of duration calculation. Calendar-day durations can be obtained by applying construction calendars on the working-day durations.

3.2 CONSTRUCTION CALENDAR

A construction calendar defines the days and hours during which resources (labor, materials and equipment) are available for work. It determines how resources assigned to tasks are scheduled and how tasks themselves are scheduled.

Which days are nonworking depend on different criteria and should be carefully considered. Different nations, states, and cultures can have different construction calendars.

The most commonly used construction calendar in the US will take into account the following factors:

1. Five-day work week

   A base construction calendar assumes a Monday through Friday work week from 8:00 A.M. to 5:00 P.M. with one hour for lunch and rest, which is Microsoft Project 2000's default project calendar setting.

2. Holidays

   Standard six holidays: New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving, and Christmas.

3. Geographical location of the construction site and weather

   For example, the low temperature in winter will increase the cost and time for concrete curing, and sometimes even make it impossible. So in Iowa, usually the pavement work cannot be done in December, January and February. This is an example of weather influence on construction calendar. In addition, geographical location has influence on construction calendar too. For example, in the lower elevation areas of southern California, the winter temperature is much higher than that in Iowa, so paving work is not a problem there.

Close attention must be paid to how different work and resource groups have different construction calendars, because weather, geographical locations and other factors have different influences on them. For example, in Iowa, there are no working days available in January for grading and paving work, while bridgework can have 10 available working days in January, which are mainly for demolition of existing bridges and central piers work.

Research work of collecting data from state transportation agencies has been done by researchers to create specific construction calendars for specific work items in different states. A researcher, H. Randolph Thomas [7], concluded the construction calendars for

Pennsylvania and Oregon DOTs, as indicated in Table 4 and Table 5. From them, it is very easy to see the influence of weather and geographical location on different works.

Table 4: Pennsylvania DOT Seasonal Adjustment Table [7]

Working Day Schedule

Month	Normal	Dist. 1	Dist. 2			Dist. 10	Bridges
			Mufflin S.Centre S.Clinton	Elk,Cameron N.Centre N.Clinton Clearfield	McKean Potter	Clarion Jefferson	
January	2	1	2	0	0	2	5
February	2	1	2	0	0	2	5
March	7	1	5	2	2	4	10
April	12	3	7	6	5	5	14
May	18	12	12	11	8	16	18
June	18	17	16	15	14	18	18
July	18	17	16	15	14	18	18
August	18	15	16	15	14	18	18
September	18	15	16	15	14	11	18
October	15	13	14	13	10	9	15
November	5	6	10	9	5	5	10
December	2	1	2	2	2	2	5
Total	**135**	**102**	**118**	**103**	**88**	**110**	**154**

Numbers indicate the anticipated amount of working days during a particular calendar month within certain districts of Pennsylvania.

Table 5: Oregon DOT Seasonal Adjustment Table [7]

Month	Areas 1 & 2	Areas 3 & 4
January	0	0
February	0	0
March	12	13
April	14	16
May	12	15
June	17	18
July	18	19
August	20	20
September	18	20
October	15	17
November	9	13
December	0	0
Total	135	151

Numbers indicate the anticipated amount of working days during a particular calendar month within a geographical area of Oregon.

Syuin-Chet Tee [6], an ISU researcher, interviewed some experienced contractors in Iowa and Iowa DOT construction engineers, analyzed daily production rate data from projects of the Iowa DOT, and created some construction calendars that can be used in Project I235. Table 6 and Table 7 are two construction calendars extracted from Tee's thesis.

Table 6 shows the construction calendar of grading and paving work that can be used in Project I235. Because of the cold weather, almost no grading and paving work can carry on in January, February and December. With weather getting warmer, more calendar days become available working days. The earliest construction for grading work is in March, and paving work usually starts in the middle of April. In general, there are about 141 available working days in a construction season for grading and paving work in Iowa.

Table 6: I235 Construction Calendar for Grading and Paving Work

Grading and Paving Work	
Month	**Available Working Days**
January	0
February	0
March	8
April	12
May	16
June	20
July	20
August	20
September	18
October	18
November	9
December	0

In Table 7, a construction calendar for bridgework is indicated. We can see that weather is still a very important factor influencing the construction of bridges. In January, there are about 10 available working days mainly for existing bridge demolition and central piers work.

Table 7: I235 Construction Calendar for Bridgework

Bridge Work	
Month	**Available Working Days**
January	10
February	0
March	8
April	12
May	16
June	20
July	20
August	20
September	18
October	18
November	9
December	0

The method of assigning construction calendars to a schedule will be discussed in the following chapter.

CHAPTER 4: THE PROCESS TO IDENTIFY THE NEED OF PROJECT ACCELERATION

To identify the need of project acceleration, avoid unnecessary delay and make sure the corridor I235 can be completed within time frame and budget, it is very important to create an efficient process to identify project acceleration.

Some example projects in Project I235, the MLK and Cottage Grove projects, will be used to demonstrate the project-acceleration-identification process.

In the Martin Luther King Jr. Parkway (MLK) and Cottage Grove Avenue area, there are three projects that have intimate relationships with each other and influence the construction of each other. These three projects are MLK bridge replacement, Cottage Grove bridge replacement and roadwork in the MLK and Cottage Grove area. Their locations are indicated in Figure 2, and Table 8 describes the activities included in Figure 2 and Figure 3.

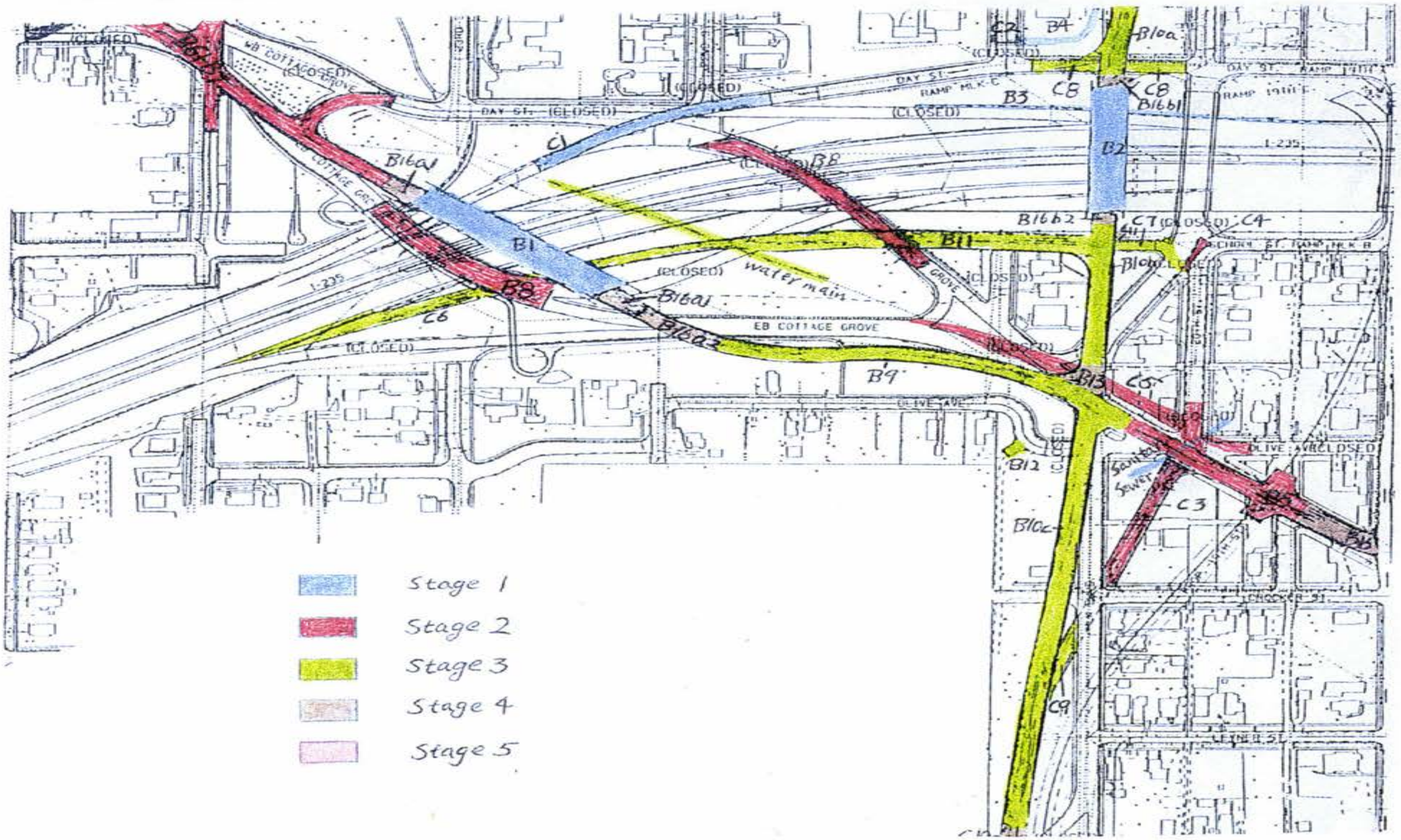

Figure 2: Staging Map of MLK and Cottage Grove Projects from Iowa DOT

Table 8: Activities Description for Figure 4

Code	Description	Stage
B1	Cottage Grove Bridge	1,2,3
B2	MLK Bridge	1,2,3
B3	Retaining Wall near MLK Bridge	1
B4	Alley Connection Between MLK and 21st St.	1
B4?	21st St. closure and alley connection	4
B5	Cottage Grove from east of MLK to east of relocated 19th St.	2
B6	Cottage Grove from 25th St. to west approch of Cottage Grove bridge	2
B7	Kingman Blvd., 24St. And Day St. from Cottage Grove to east of 23rd St.	2
B8	Old Cottage Grove bridge removal	2
B9	Cottage Grove from south of the eastbound I-235 off-ramp to east of MLK	3
B10	MLK from north of Center St. to south of Atkin St., gapping at the Cottage Grove crossover and the bridge	3
B11	Ramp MLK-B	3
B12	maintenance turnaround and close Olive St. (west of MLK)	3
B13	Gap in MLK just north of Cottage Grove	4
B14	Westem protion of MLK from Atkins St. to north end of project	4,5
B15	Cottage Grove between relocated 19th St. & old 19th St.	4
B16a	Cottage Grove bridge approach & the remainder of Cottage Grove	4
B16b	MLK bridge approach	4
B17	Curb & gutter on old 19th St. at Olive St. west	4
B19	East leg of Atkins St.	5
C1	Temporary pavement from Day St. to Cottage Grove westbound on-ramp	1
C2	Temporary pavement between 21st St. and the alley connection to the east	1
C3	Temporary pavement from the new Cottage Grove pavement to 20th St. on the north and to MLK at Crocker St. on the south	2
C4	Removal of the curb & construction of temporary pavement in the island between MLK, 20th St. and School St.	2
C5	Temporary pavement from EB Cottage Grove to Olive St. on the north side of existing Cottage Grove (2 separate areas)	2
C6	Temporary pavement between I235 & Ramp MLK-B	3
C7	Wedge course between new MLK & School St.(under traffic) & temporary pavement between new MLK pavement & School St.	3
C8	Temporary pavement between new MLK pavement & Day St. on both sides	3
C9	Temporary pavement between new MLK pavement & existing MLK south of Crocker St.; wedge course between temporary pavement and existing MLK south of Crocker St. (under traffic)	3
C10	Temporary pavement between the new MLK pavement and existing MLK at the south end of the project	4
C11	Temporary pavement east of the south MLK bridge approach section	4
C12	Temporary pavement between 20th St. and Atkins St.	5

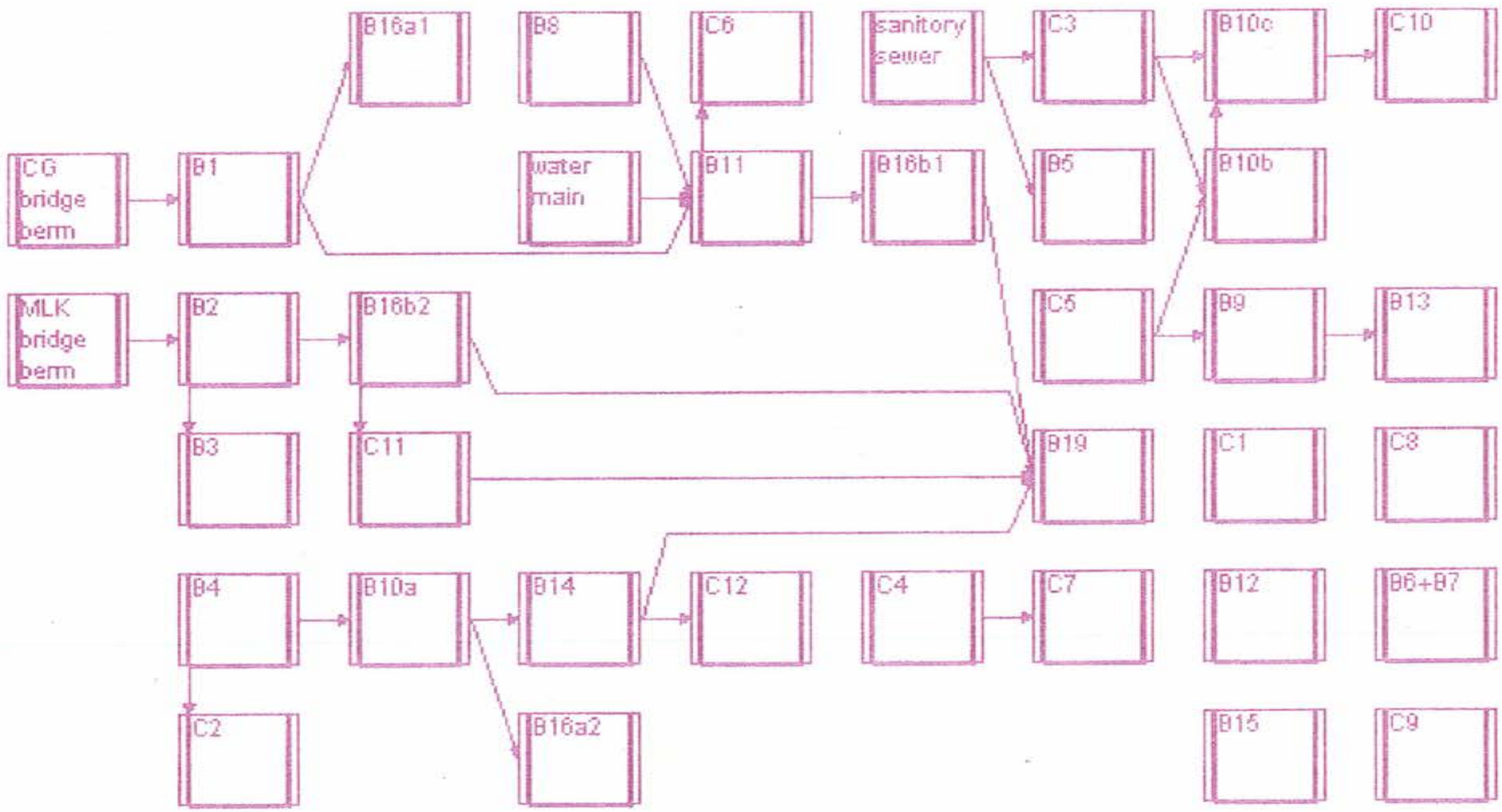

Figure 3: Activity-on-Node Diagram of MLK and Cottage Grove Projects

4.1 STEP 1: IDENTIFY THE LOGICAL RELATIONSHIP BETWEEN ACTIVITIES

Activities in projects are performed in a certain order, which is called "logic." And how an activity relates to any other activity is called its "logical relationship." Figure 3 shows the logical relationships among the activities in the MLK and Cottage Grove projects. In Figure 3, some activities, like C1 and B12, have no relationship with other activities, which means they can start at any time in the construction.

There are four kinds of logical relationships:

1. Finish - to-start

   A finish-to-start (FS) relationship means activity B cannot start until activity A is finished, which is the most common relationship. (A is B's predecessor, and B is A's successor.) For example, there is an FS relationship between activity B16b2 (MLK bridge south approach) and activity B2 (MLK bridge), which means B16b2 cannot start until B2 is finished. B2 is B16b2's predecessor, and B16b2 is B2's successor.

2. Start-to-start

   A start-to-start (SS) relationship means activity A and activity B must start at the same time. For example, there is an SS relationship between activity B2 (MLK bridge) and activity B3 (retaining wall near MLK bridge). These two activities must start at the same time because the MLK bridge abutment will be built on part of the retaining wall.

3. Finish-to-finish

   A finish-to-finish (FF) relationship means activity A and activity B must be finished at the same time.

4. Start-to-finish

   A start-to-finish (SF) relationship means activity A must start after activity B is finished, which is not often used because it is somewhat confusing.

In this step, Critical Path Method (CPM) can be used to create activity-on-node (AON) diagrams to show the logical relationships between activities, like the one in Figure 3. The AON diagram can show the logical relationships more clearly than Gantt charts. So it is very useful in this step to help understand the logical relationships between activities.

4.2 STEP 2: CALCULATING STANDARD DURATIONS OF ACTIVITIES

Standard durations are the calculated activity durations using Iowa DOT standard production rates and charts, which are used for the Iowa DOT to decide the contract durations. The methods are described in Syuin-Chet Tee's thesis [6]. In this thesis, the calculation is demonstrated in detail by the example of the MLK and Cottage Grove projects.

4.2.1 STANDARD DURATIONS OF BRIDGEWORK

The standard duration of a bridgework can be obtained by using the DOT Standard Bridge Calculation Chart, as shown in Figure 4.

In Figure 4, the points represented by legends are data points for different activities; the power regression line is the fitting line for the combination of all the different activities; and the suggested use line is created based on the power regression line and considering a safety factor. The suggested used line is almost 15 days more than the corresponding duration obtained from the power regression line.

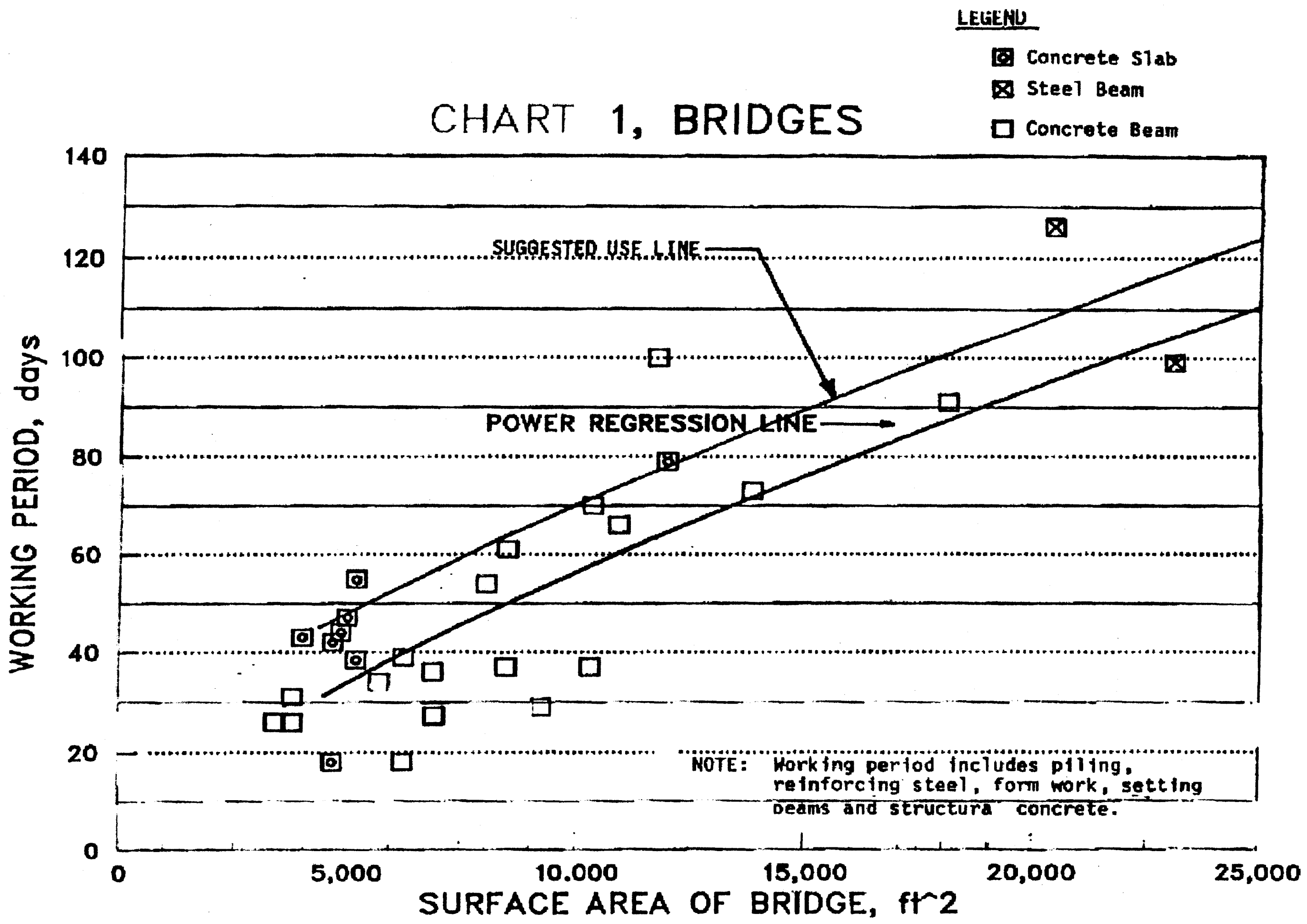

Figure 4: DOT Standard Bridge Calculation Chart

It is very quick and easy to obtain the working duration for a bridgework, if the surface area of that bridge is known. However, the working period obtained from the chart only includes those of piling, reinforcing steel, form work, setting beams, and structural concrete. There are still some other necessary activities for bridge construction that need to be considered, such as bridge barrier rail, traffic control, clean up, mobilization, demobilization, and so on. So ISU researchers decided to multiply the bridgework duration, obtained from the DOT standard chart, by a constant of 1.5 to cover all the other work mentioned above and the busy urban traffic influence on the bridge construction.

According to the design plans, the MLK bridge is a welded girder bridge, which is 83.9 m long and 12.6 m wide. The surface area of the MLK bridge can be obtained by the formula as follows:

$83.9 \text{ m} \times 12.6 \text{ m} = 1{,}057.14 \text{ m}^2 = 11{,}381.76 \text{ ft}^2$

Using the suggested use line, we obtain the working period corresponding to 11,379 ft^2, which is 80 working days. Multiply the result by 1.5, and we get the final result of the MLK bridge construction work, 120 days, which is close to the duration in the MLK bridge contract of 125 days.

The Cottage Grove bridge is a 116.5 m x 12.6 m welded girder bridge. The surface area of the Cottage Grove bridge is 1,467.90 m^2 (15,800 ft^2). Using the suggested use line, we obtain the working period corresponding to 15,800 ft^2, which is 92 working days. Multiply the result by 1.5, and we get the final result of the Cottage Grove bridge construction work, 138 days, which is close to the duration in the Cottage Grove bridge contract of 140 days.

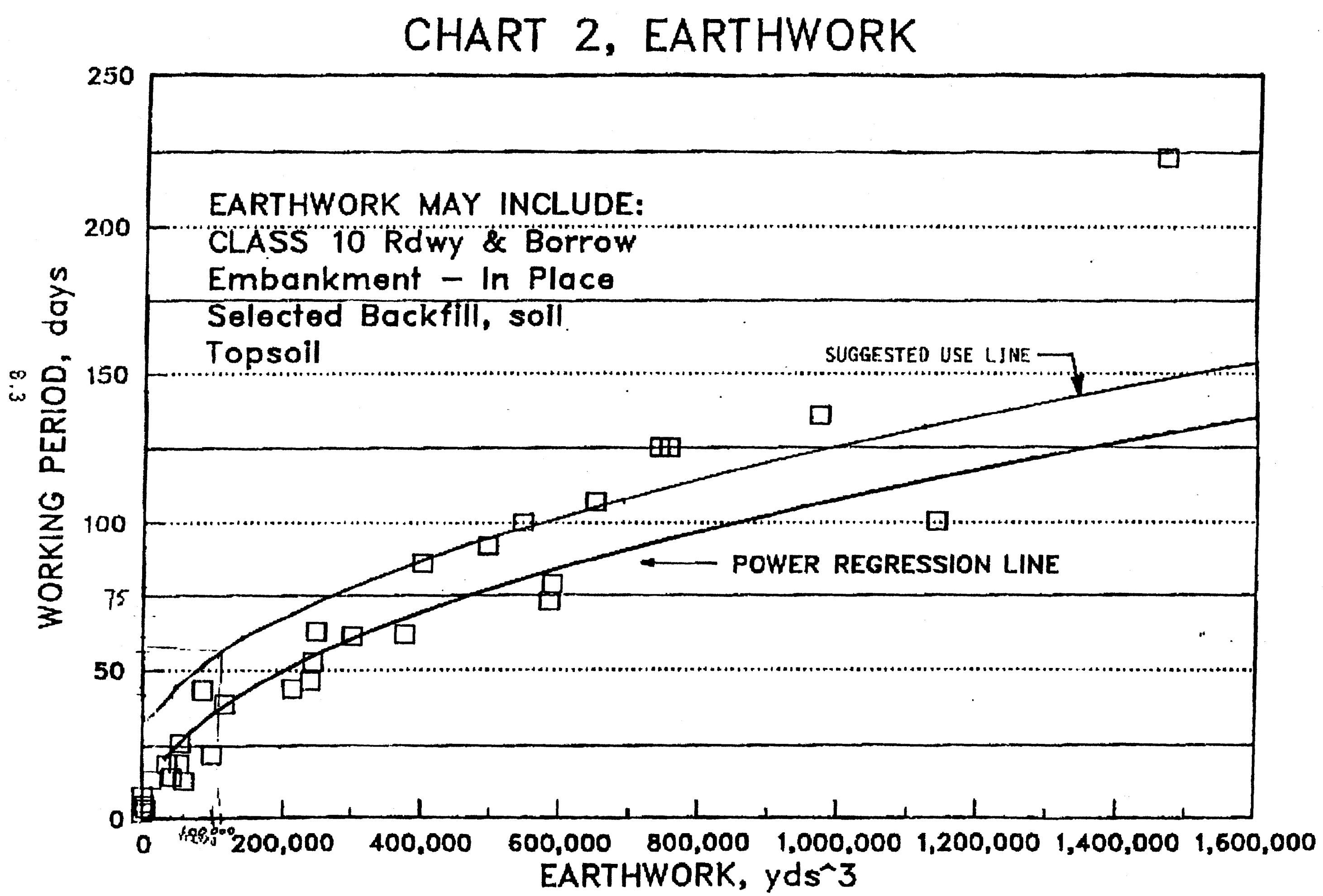

Figure 5: DOT Standard Earthwork Calculation Chart

4.2.2 STANDARD DURATIONS OF ROADWORK

Usually, Iowa DOT uses a standard earthwork calculation chart, as shown in Figure 5 to calculate roadwork duration. However, in the MLK and Cottage Grove projects, the amount of earthwork for each roadwork activity is comparatively small, and it is not very correct to use the standard chart to do the calculation. Therefore, ISU researchers worked out another process to calculate the roadwork duration in this case.

The roadwork in the MLK and Cottage Grove area is divided into two types: permanent pavement and temporary pavement. Temporary pavement is used for detours while the permanent road is under construction.

PERMANENT PAVEMENT

For the MLK and Cottage Grove projects, the permanent pavement roadwork is Portland cement concrete (PCC) paving. In the duration calculation for the PCC paving work, ISU researchers included in their calculation such operations as old pavement removal, earthwork, storm sewer installation, longitudinal subdrain installation, subbase work, PCC machine paving, and PCC hand paving. During the calculation for each operation except storm sewers, one day was added for surveying, equipment mobilization, and other items.

Activity B5 (Cottage Grove from east of MLK to east of relocated 19th Street) will be used as an example to demonstrate the calculation procedure for roadwork.

According to the design plan, the old pavement removal quantity is 1,756.87 m^2, and the DOT standard production rate for old pavement removal is 3,400 m^2/day (as shown in Table 3). So the working days for old pavement removal is 1,756.87/3,400 + 1 = 2 days.

Because there was no earthwork quantity available at that time, based on the typical calculation results, ISU researcher decided to use three times the subbase work duration, which will be described later, as earthwork duration. So the earthwork will take 7 days (including one day for surveying, equipment mobilization, and so on).

The storm sewer is 209 m long, and there are 6 intakes. Using production rates of 50 m/day and 1.5 intakes/day, the storm sewer operation will take 209/50 + 6/1.5 + 1 = 9 days.

The longitudinal subdrain pipe is 260 m long, and its standard production rate is 1,000 m/day. So the duration will be 260/1000 + 1 = 2 days.

The subbase work quantity is 528 m^3. Using production rate of 540 m^3/day, the duration will be 528/540 + 1 = 2 days.

PCC paving is further divided into two types: machine paving and hand paving.

Machine paving means the paving work is performed by paving machine, which is usually used on regular-shaped paving areas whose paving width is wide enough to set an appropriate paving machine. These areas can be a highway main line, local road, and so on.

The hand paving production rate is lower than that of machine paving. There are two occasions for the application of hand paving:

1. Narrow-width paving areas

   In narrow-width paving areas, like tapers in an interchange, the paving width is much less than the fixed paving width of paving machines. So machine-paving is impossible. By consulting some people having interchange construction experience, ISU researchers decided to adopt 70% machine - paving production rates as the corresponding hand-paving production rates in narrow-width paving areas. So the DOT standard production rate of PCC machine paving is 550 m^3/day, and that of PCC hand paving should be 550 x 70% = 385 m^3/day.

2. Irregular-shaped paving areas

A typical example of an irregular–shaped paving area is the edge of the intersection of two roads. In these areas, the paving machine, which can only move in the direction of a straight line, cannot be manipulated to pave according to irregular shapes. Because the surface areas are not easy to calculate for these irregular-shaped areas, the assumption of a 70% machine-paving production rate is not very practical here. So ISU researchers use 6 placements/day as the hand paving production rate by construction experience. Examples are areas C4, C7, and C9 in Figure 2.

For activity B5, the PCC machine paving quantity is 402.22 m^3, and the PCC hand paving quantity is 4 placements. So the duration is 402.22/550 + 1 + 4/6 + 1 = 4 days.

For the work of driveways, sidewalks, and backfill behind curbs, ISU researchers allow 1 day if the PCC machine paving quantity (PCC Qty) is < 100 m^3, 2 days if 100 m^3 < PCC Qty < 1000 m^3, and 4 days if PCC Qty > 1000 m^3. So the working days for driveways, sidewalks, and backfill behind curbs in activity B5 is 3 days.

The total duration for activity B5 is the sum of the working days of the listed operations plus 2 days for curing consideration. So the working days for activity B5 is 2 days (old pavement removal) + 7 days (earthwork) + 9 days (storm sewer) + 2 days (longitudinal subdrain) + 2 days (subbase) + 4 days (PCC paving) + 3 days (driveways, sidewalks and backfill behind curbs) + 2 days (curing) = 31 days.

The calculation results for permanent pavement in the MLK and Cottage Grove area are indicated in Table 9.

Table 9: Duration Calculation for Permanent Pavement in the MLK and Cottage Grove Area

		Length (m)										Old Pavement Removal		Earth Work		Storm Sewer			Longitudinal Subdrain		Subbase		PCC Machine Paving		PCC Hand Paving			
Name	Stage	MLK Bld.	Cottage Grove	19th St.	Kingman Bld.	Atkins /Day /OliveSt.	21st St.	24th St.(1)	24th St.(2)	Alley	Ramp	Quantity (m2)	Duration (days)	Quantity (m3)	Duration (days)	Pipe Length (m)	# of Intakes	Duration (days)	Quantity (m)	Duration (days)	Quantity (m3)	Duration (days)	Quantity (m3)	Duration (days)	Quantity (placement)	Duration (days)	Side walk Curb bac kfill sod paint	Total Duration (days)
	Start up																											4
B4	1	0	0	0	0	0	0	0	0	80	0	251.59	2		4	80	0	2	160.00	2	0.00	1	57.60	2	0	0	2	17
B5	2	0	108	22	0	0	0	0	0	0	0	1756.87	2		7	209	6	9	260.00	2	528.00	2	402.22	2	4	2	3	31
B6+B7	2	0	232	0	44	56	0	38	44	0	0	5156.94	3		10	725	13	24	828.00	2	918.72	3	1180.64	4	13	4	4	56
B9	3	0	214	0	0	0	0	0	0	0	0	2809.82	2		9	455	6	14	428.00	2	847.44	3	643.28	3	5	2	3	40
B10a	3	104	0	0	0	0	0	0	0	0	0	1601.74	2		7	182	6	8	208.00	2	474.24	2	366.70	2	1	2	3	30
B10b	3	68	0	0	0	0	0	0	0	0	0	1047.29	2		6	83	2	3	136.00	2	310.08	2	239.77	2	2	2	3	24
B10c	3	286	0	0	0	0	0	0	0	0	0	4404.78	3		12	518	8	16	572.00	2	1304.16	4	1008.44	3	4	2	4	48
B11	3	187	0	0	0	0	0	0	0	0	130	4173.57	3		10	740	10	22	634.00	2	1055.52	3	955.50	3	2	2	3	50
B13	4	28	0	0	0	0	0	0	0	0	0	431.24	2		5	58	3	4	56.00	2	127.68	2	98.73	2	Large	3	2	24
B14	4	54	0	0	0	0	0	0	0	0	0	831.67	2		6	64	2	3	108.00	2	246.24	2	190.40	2	Large	3	3	25
B15	4	0	44	0	0	0	0	0	0	0	0	577.72	2		5	44	0	1	88.00	2	174.24	2	132.26	2	2	2	3	21
B16a	4	0	90	0	0	0	0	0	0	0	0	1181.70	2		6	100	2	4	180.00	2	356.40	2	270.54	2	5	2	3	25
B16b	4	24	0	0	0	0	0	0	0	0	0	369.63	2		5	44	2	3	48.00	2	109.44	2	84.62	2	5	2	2	22
B19	5	46	0	0	0	26	0	0	0	0	0	932.64	2		6	72	0	2	144.00	2	209.76	2	213.52	2	Large	3	3	24
	Clean Up																											4

Notes:

1. Old Pavement Removal (3400 m2/day)
   The total removal area = 25,527.2 m2. Distribute it to different parts of roads according to correponding new pavement proportion.
2. Earth Work includes subgrade treatment, average 3 ft cut or fill, 1350 m^3 per day.
3. Storm Sewer (50m/day, 1.5 intakes/day)
4. Longitudinal Subdrain (1000m/day)
5. Subbase (540m3/day)
6. PCC Machine-Paving (550 m3/day); PCC Hand-Paving (6 placements/day)
7. ACC machine-paving production rate = 1300 MG/day, ACC hand-paving production rate = 900 MG/day. ACC density = 2.325 MG/m3
8. For each operation, except storm sewers, one day is added for surveying, equipment mobilization, and other items. For storm sewers, two days are added to finish intakes and two day for surveying, mobilization and other.
9. In Stage 3, permanent construction on Cottage Grove between MLK and Proposed 19th Street takes longer than nearby detour construction.
10. The production rates used above are based on DOT standard production rates (including many rural projects).
11. The driveways, sidewalks and backfill behind curb: Allow 1 day if PCC machine paving quantity is < 100 m^3, 2 days if 100<PCC Qty<1000, 4 days for PCC Qty > 1000.
12. The total duration includes 2 additional days for each activity for curing consideration.

Table 10: Duration Calculation for Temporary Pavement in the MLK and Cottage Grove Area

		Length (m)							Old Pavement Removal		Storm Sewer			Earth Work		Subbase		PCC Machine Paving		ACC Machine Paving		PCC/ACC Hand Paving			
Name	Stage	Detour 1	Detour 2	Detour 3	Detour 4	Detour 5	Detour 6	Detour 7	Quantity (m2)	Duration (days)	Pipeline Length (m)	Number of Intakes	Duration (day)	Quantity (m3)	Duration (days)	Quantity (m3)	Duration (days)	Quantity (m3)	Duration (days)	Quantity (MG)	Duration (days)	Quantity (placement)	Duration (days)	Clean up (day)	Total Duration (days)
c1	1	124	0	0	0	0	0	0	921.69	2	147	0	3		2	152.52	2	181.29	2	452	2	0	0	2	15
c3	2	0	131	0	0	0	0	0	1189.50	2	97	2	3		3	196.50	2	233.97	2	588	2	8	3	2	18
c4	2	0	0	0	0	0	0	0	small	1	0	0	0		1	0.00	1	0.00	0	0	0	2	2	1	9
c5	2	0	0	191	0	0	0	0	1734.32	2	278	6	6		3	286.50	2	341.13	2	857	2	7	3	2	22
c6	3	0	0	0	0	0	0	0	small	1	0	0	0		1	0.00	1	0.00	0	0	0	4	2	1	9
c7	3	0	0	0	34	0	0	0	296.28	2	60	2	3		2	48.96	2	58.28	2	146	2	4	2	1	14
c8	3	0	0	0	0	64	0	0	475.71	2	65	0	2		2	78.72	2	93.57	2	233	2	4	2	1	14
c9	3	0	30	0	0	0	0	0	272.41	2	54	0	2		2	45.00	2	53.58	2	135	2	4	2	1	14
c10	4	0	0	0	0	0	25	0	313.94	2	25	0	2		2	51.75	2	61.75	2	156	2	2	2	1	13
c11	4	0	0	0	0	0	0	0	small	1	0	0	0		1	0.00	1	0.00	0	0	0	1	2	1	9
c12	5	0	0	0	0	0	0	22	199.76	2	25	1	2		2	33.00	2	39.29	2	99	2	2	2	1	13

Notes:

1. Old Pavement Removal (3400 m2/day)
   The total removal area = 35,117 m2 (including old pavement, sidewalk and driveway). Distribute it to different parts of roads according to correponding new pavement proportion.
2. Earth Work includes subgrade treatment, average 3 ft cut or fill, 1350 m^3 per day.
3. Storm Sewer (100m/day, 3 intakes/day)
4. Longitudinal Subdrain (1000m/day)
5. Subbase (540m3/day)
6. PCC Machine-Paving (550 m3/day); ACC Mahine-Paving (1300MG/day); ACC density = 2.325 MG/m3; PCC/ACC Hand-Paving (6 placements/day)
8. For each operation, except storm sewers, one day is added for surveying, equipment mobilization, and other items. For storm sewers, two days are added to finish intakes and two day for surveying, mobilization and other.
9. In Stage 3, permanent construction on Cottage Grove between MLK and Proposed 19th Street takes longer than nearby detour construction.
10. The production rates used above are based on DOT standard production rates (including many rural projects).
11. The driveways, sidewalks and backfill behind curb: Allow 1 day if PCC machine paving quantity is < 100 m^3, 2 days if 100<PCC Qty<1000, 4 days for PCC Qty > 1000.
12. It is assumed that contractors will use PCC pavement, so the total duration will include 2 more days for curing consideration.

TEMPORARY PAVEMENT

Temporary pavements can be PCC or asphalt cement concrete (ACC) paving, depending on contractors' choice, and the pavement thickness is usually less than that of permanent pavement. The duration calculation process is similar to that of permanent pavement, and the calculation results are listed in Table 10.

4.3 STEP 3: CREATING GANTT CHART SCHEDULES

After the activities' standard durations and the logical relationships between them are obtained, a Gantt chart can be created using a scheduling application software, such as Microsoft Project 2000, as shown in Figure 6.

In this schedule, a standard project calendar is assigned on every activity by the default of Microsoft Project 2000, in which it is assumed that there are 5 working days available for every week, not considering weather, holidays, and so on. According to the standard project calendar, the MLK and Cottage Grove project will be finished on February 27, 2003.

In Figure 6, there are five different colors for bars, which stand for five different stages (Stage I – blue, Stage II – red, Stage III – green, Stage IV – maroon, and Stage V – fuchsia). The bars with solid colors stand for the critical activities. In the MLK and Cottage Grove (CG) projects, there are two critical paths according to DOT's required project completion date of November 2002. They are listed below:

Critical Path I: CG bridge berm → CG bridge (B1) → ramp MLK-B (B11) → MLK bridge north approach (B16b1) → east leg of Atkins Street (B19).

Critical Path II: MLK bridge berm → MLK bridge (B2) → MLK bridge south approach (B16b2) and temporary pavement on east of MLK bridge south approach (C11) → east leg of Atkins Street (B19).

Generally, the critical path means the sequential combination of activities and relationships from project start to finish that requires the longest time to complete [1], like Critical Path I. However, the ISU researcher found Critical Path II is also critical to the required project completion date of November 2002, because without acceleration, the activities on Critical Path II will delay the required project completion date.

So in the accelerating process analysis, we regard critical activities as activities that must be accelerated to satisfy the required project completion date. In this case, we can see that both bridgework and roadwork are critical.

4.4 STEP 4: ASSIGNING CONSTRUCTION CALENDARS ON ACTIVITIES

As described before, the actual construction is conducted according to each activity's specific construction calendar, which will take more calendar days than the standard project calendar. A schedule with construction calendars reflects a more realistic project progress than a schedule with a standard project calendar.

Microsoft Project 2000 provides a very convenient operation for assigning construction calendars to activities. People can use the "Change Working Time" dialogue box (as shown in Figure 7) to create their customized construction calendars, and then use the "Task Information" dialogue box (as shown in Figure 8) to assign a construction calendar to its corresponding activity.

ISU researchers created two different kinds of construction calendars (bridgework calendar and roadwork calendar), and assigned them to the corresponding activities in the schedule created in step 3. After that, a MLK and Cottage Grove schedule based on DOT staging and construction calendar is obtained as indicated in Figure 9.

From the schedule we can see that the predicted actual construction completion date will be August 15, 2003, which is much later than February 27, 2003, in the schedule based on standard project calendar.

Till this point, we can say the MLK and Cottage Grove projects will be completed on August 15, 2003, according to the DOT staging, construction calendars, and standard project conditions, in which no delay or acceleration happens.

However, the Iowa DOT requires that the projects be completed by November 2002. It is obvious that activity acceleration is needed to achieve this goal.

ID	Task Name	Duration	Text1	Predecessors
1	CG bridge berm	8 days		
2	CG bridge	140 days	B1	1
3	MLK bridge berm	8 days		
4	MLK bridge	125 days	B2	3
5	retaining wall near MLK bridge	60 days	B3	4SS
6	alley between MLK & 21 St	17 days	B4	
7	temp. pav. betw. 21 St & alley	4 days	C2	6SS
8	temp. pav. from Day St to CG WB on-ramp	15 days	C1	
9	sanitory sewer	10 days		
10	CG from E of MLK to E of relocated 19 St	31 days	B5	9
11	CG from 25 St to CG bridge W approach (incl. Kingman Blv., 24 St & Day St)	56 days	B6+B7	
12	old CG bridge removal	10 days	B8	
13	temp pav from new CG to 20 St on N and to MLK at Crocker on S	18 days	C3	9
14	curb removal & temp pav in island betw. MLK, 20 & School St	9 days	C4	
15	temp pav from EB CG to Olive St	22 days	C5	
16	CG from S of EB off-ramp to E of MLK	40 days	B9	15
17	MLK from N Center St to S Atkin St (I)	30 days	B10a	6
18	MLK from N Center St to S Atkin St (II)	24 days	B10b	15,13
19	MLK from N Center St to S Atkin St (III)	48 days	B10c	18SS,13
20	water main	30 days		
21	ramp MLK-B	50 days	B11	2,20,12
22	maintenance turnaround and close Olive St	1 day	B12	
23	temp pav betw I235 & ramp MLK-B	9 days	C6	21SS
24	Wedge course & temp pav betw new MLK & School St.	14 days	C7	14
25	temp pav betw new MLK & Day St	14 days	C8	17SS
26	temp pav betw new & old MLK; wedge course betw temp pav and old MLK (on S of Crocker St)	14 days	C9	
27	gap in MLK on N of CG	24 days	B13	16
28	Western portion of MLK from Atkins to N end of project	25 days	B14	17
29	CG between relocated and old 19 St	21 days	B15	
30	CG bridge approach	16 days	B16a1	2
31	the remainder of CG	9 days	B16a2	17
32	MLK bridge north approach	13 days	B16b1	21
33	MLK bridge south approach	9 days	B16b2	4
34	temp pav betw new & old MLK at S end of project	13 days	C10	19
35	temp pav on E of MLK bridge south approach	9 days	C11	33SS
36	east leg of Atkins St	24 days	B19	28,32,33,35
37	temp pav betw 20 St & Atkins St	13 days	C12	28

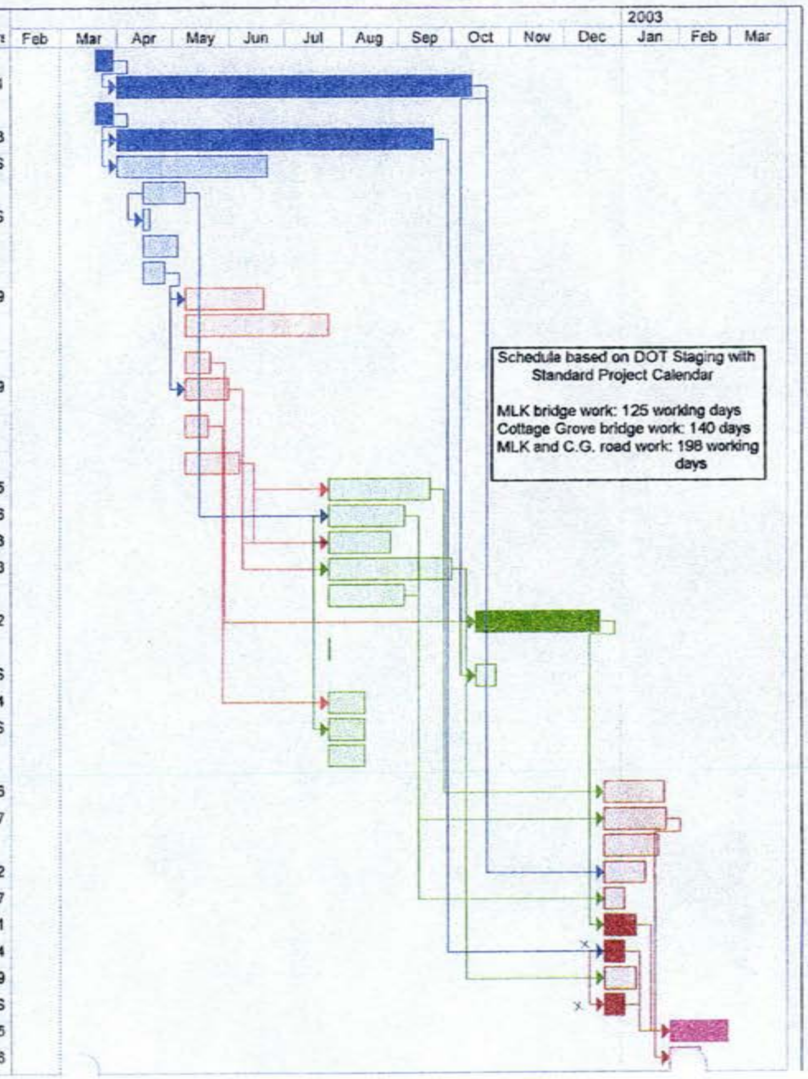

Figure 6: MLK and Cottage Grove Schedule Based on DOT Staging with Standard Project Calendar

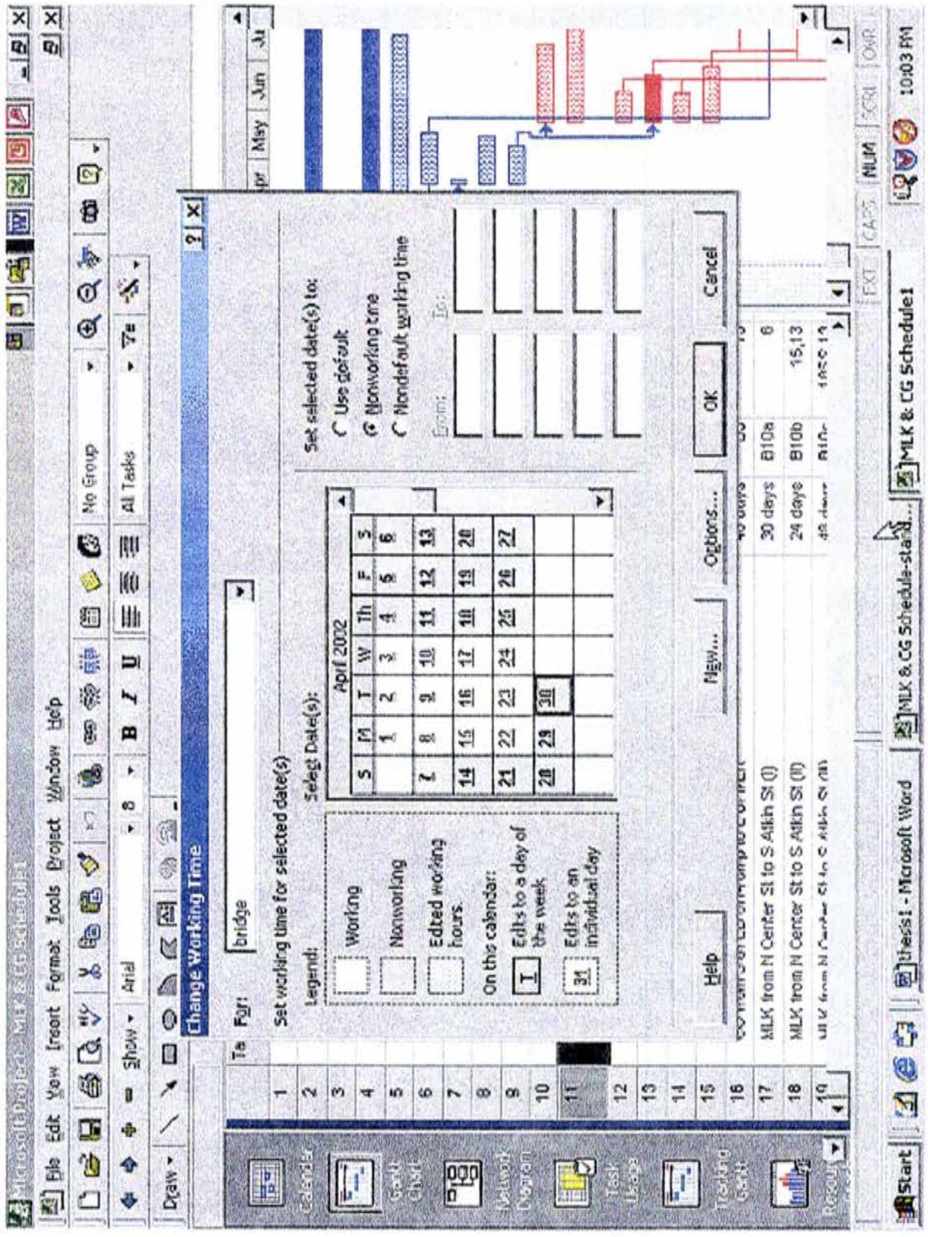

Figure 7: Dialogue Box to Create Construction Calendars

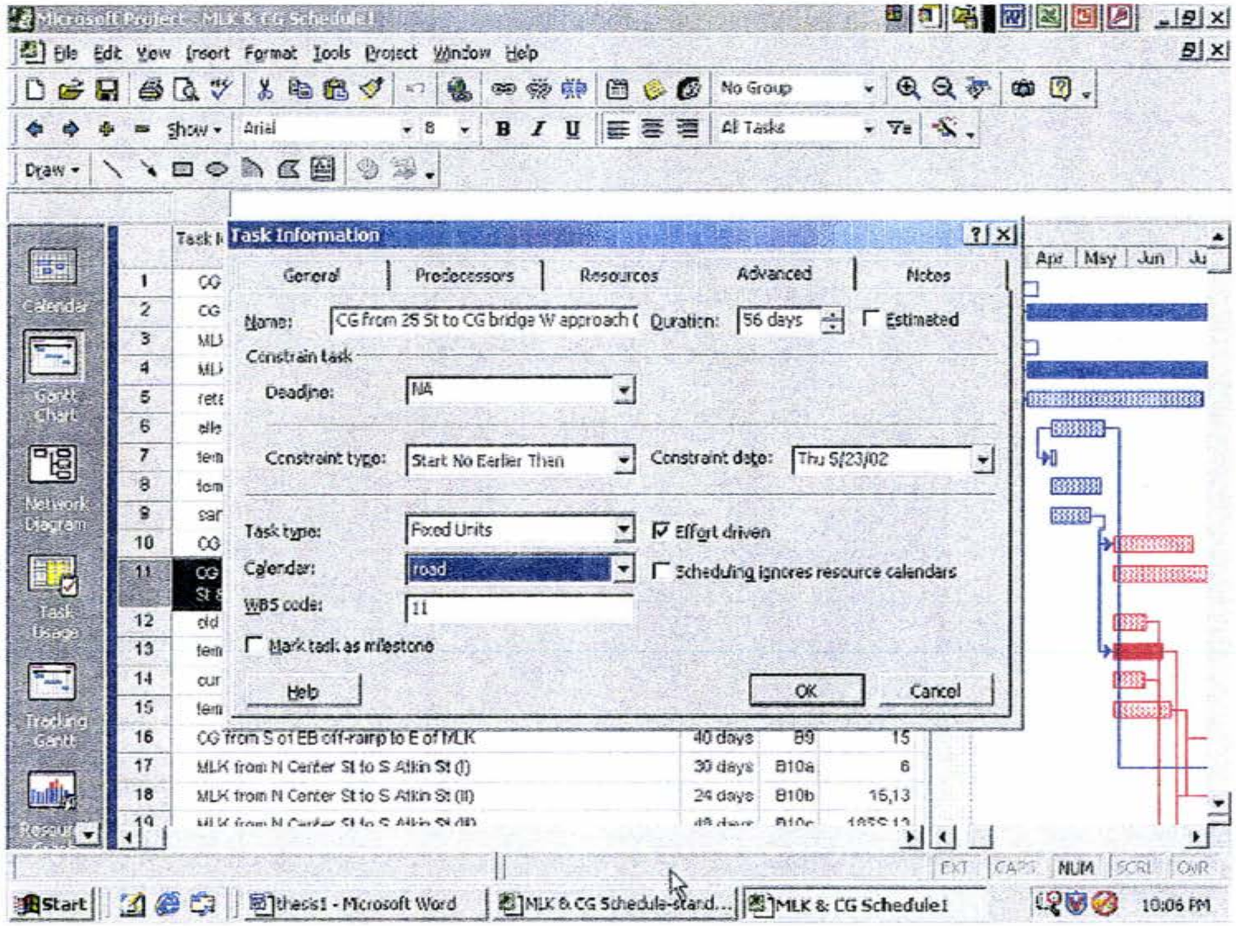

Figure 8: Dialogue Box to Assign Construction Calendars to Corresponding Activities

ID	Task Name	Duration	Text1	Predecessors
1	CG bridge berm	8 days		
2	CG bridge	140 days	B1	1
3	MLK bridge berm	8 days		
4	MLK bridge	125 days	B2	3
5	retaining wall near MLK bridge	60 days	B3	4SS
6	alley between MLK & 21 St	17 days	B4	
7	temp. pav. betw. 21 St & alley	4 days	C2	6SS
8	temp. pav. from Day St to CG WB on-ramp	15 days	C1	
9	sanitory sewer	10 days		
10	CG from E of MLK to E of relocated 19 St	31 days	B5	9
11	CG from 25 St to CG bridge W approach (incl. Kingman Blv., 24 St & Day St)	56 days	B6+B7	
12	old CG bridge removal	10 days	B8	
13	temp pav from new CG to 20 St on N and to MLK at Crocker on S	18 days	C3	9
14	curb removal & temp pav in island betw. MLK, 20 & School St	9 days	C4	
15	temp pav from EB CG to Olive St	22 days	C5	
16	CG from S of EB off-ramp to E of MLK	40 days	B9	15
17	MLK from N Center St to S Atkin St (I)	30 days	B10a	6
18	MLK from N Center St to S Atkin St (II)	24 days	B10b	15,13
19	MLK from N Center St to S Atkin St (III)	48 days	B10c	18SS,13
20	water main	30 days		
21	ramp MLK-B	50 days	B11	2,20,12
22	maintenance turnaround and close Olive St	1 day	B12	
23	temp pav betw I235 & ramp MLK-B	9 days	C6	21SS
24	Wedge course & temp pav betw new MLK & School St	14 days	C7	14
25	temp pav betw new MLK & Day St	14 days	C8	17SS
26	temp pav betw new & old MLK; wedge course betw temp pav and old MLK (on S of Crocker St)	14 days	C9	
27	gap in MLK on N of CG	24 days	B13	16
28	Western portion of MLK from Atkins to N end of project	25 days	B14	17
29	CG between relocated and old 19 St	21 days	B15	
30	CG bridge approach	16 days	B16a1	2
31	the remainder of CG	9 days	B16a2	17
32	MLK bridge north approach	13 days	B16b1	21
33	MLK bridge south approach	9 days	B16b2	4
34	temp pav betw new & old MLK at S end of project	13 days	C10	19
35	temp pav on E of MLK bridge south approach	9 days	C11	33SS
36	east leg of Atkins St	24 days	B19	28,32,33,35
37	temp pav betw 20 St & Atkins St	13 days	C12	28

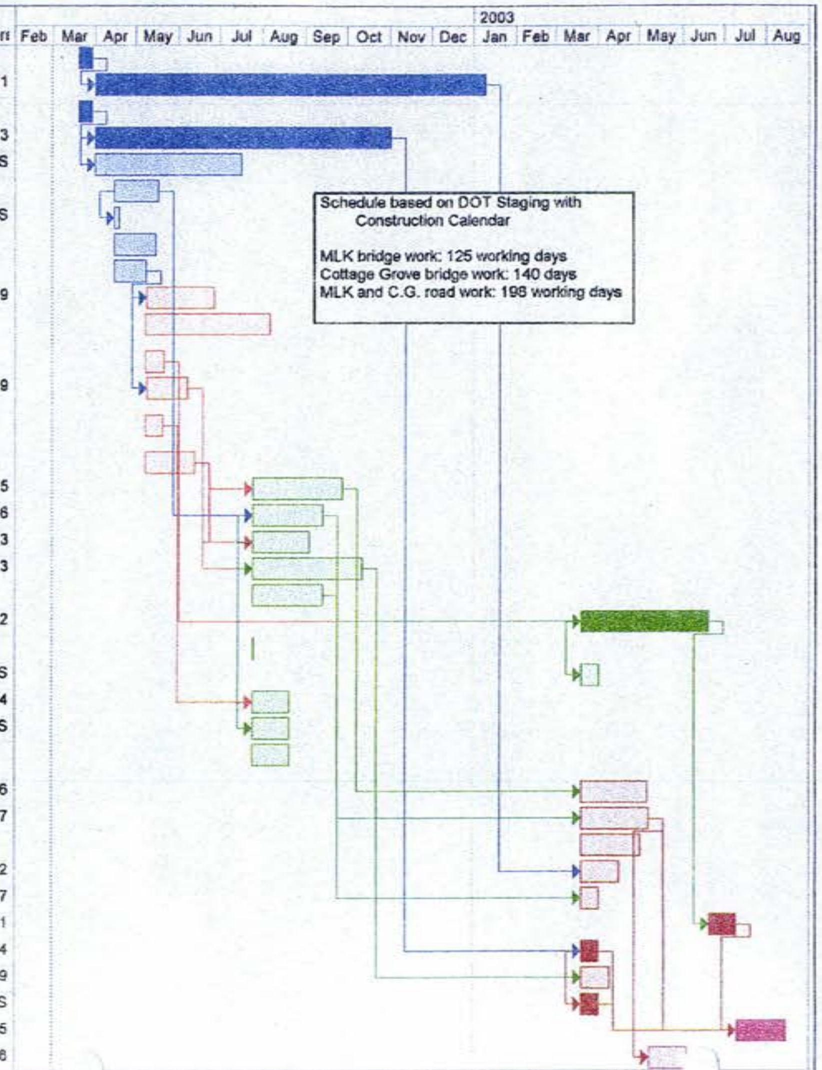

Figure 9: MLK and Cottage Grove Schedule Based on DOT Staging with Construction Calendars

CHAPTER 5: ACCELERATION MEASURES

To accelerate the projects, there are several different measures that can be considered. They can be used separately or combined together in a project. Through analysis and comparison, the most economical and practical measure will be recommended to accelerate the construction of projects. When using these measures to accelerate projects, sufficient material, equipment, and labor should be guaranteed.

5. 1 MEASURE I: CHANGING STAGING SEQUENCE

According to the Iowa DOT's original staging plan, activities should start as specified. Actually, some activities can start earlier than they are staged if there is no material, equipment, and labor conflicts with concurrent activities. For example, the old Cottage Grove bridge removal (B8) has no predecessor, so it can start in Stage I, even if it is staged in Stage II.

Usually using this method alone cannot satisfy acceleration requirements, because this measure seldom has influence on critical paths (critical activities have no float, which is a measure of the ability of a given activity to have its performance time extended while the total project completion date will not be influenced [1]). However, this measure can help to prevent noncritical activities from becoming critical and hindering the required project completion date while other measures are adopted. So this method is often combined with other measures as listed below to accelerate project schedule.

Another schedule was created as shown in Figure 10, assuming that every activity can start as early as possible without any material, equipment, and labor conflicts with other activities. The project completion date is still August 15, 2003. So in this case, Measure I alone cannot accelerate the project.

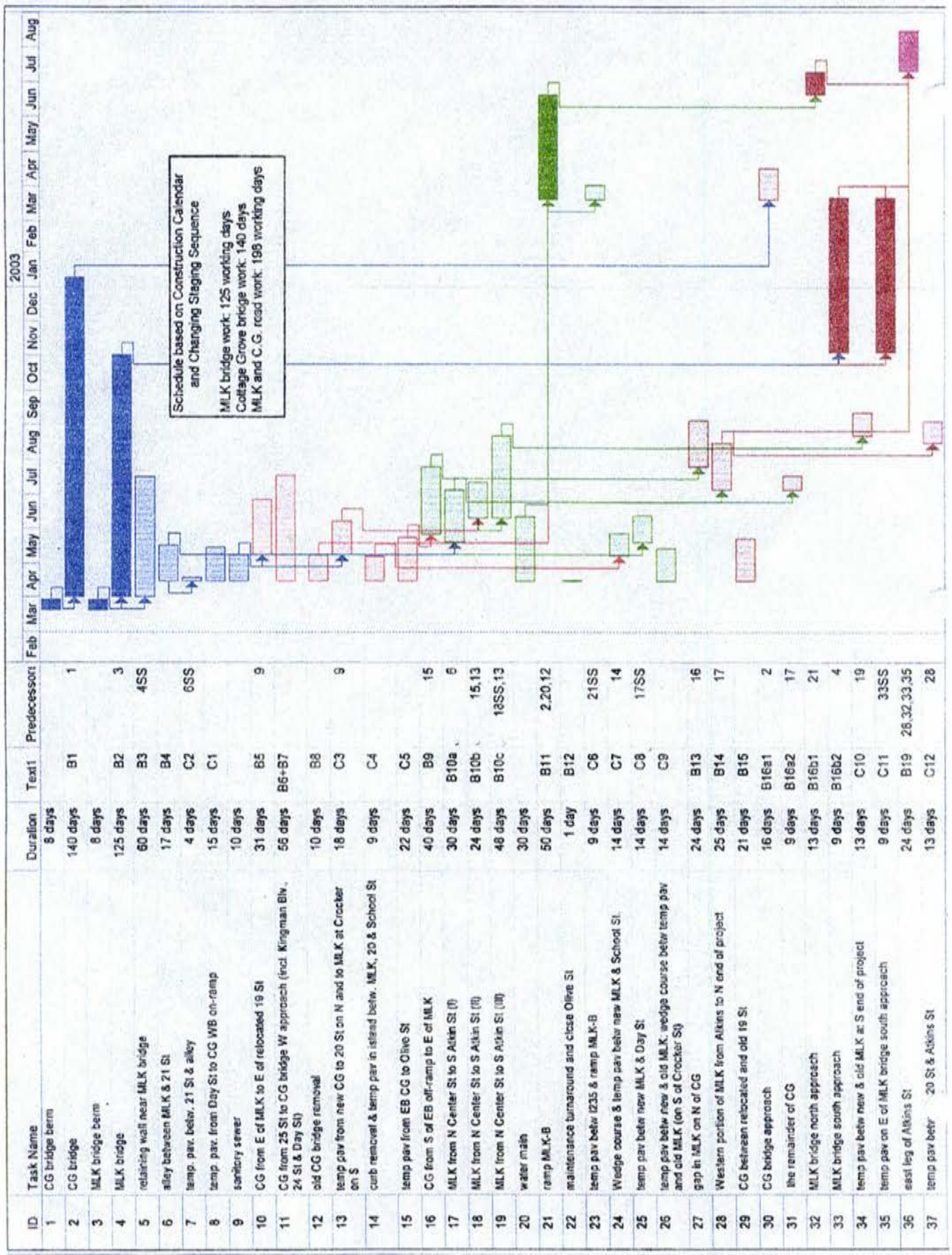

Figure 10: MLK and Cottage Grove Schedule Based on Accelerated Staging with Construction Calendars

5.2 MEASURE II: IMPROVING PRODUCTION RATES

It is convenient to use scheduling software to determine the maximum allowable duration for critical activities necessary to guarantee the required project completion date. This may be done by adjusting the activity durations along the critical path.

In Critical Path I, the total working days are 235 days (148 days for bridgework and 87 days for roadwork). According to the road and bridge construction calendars set up by ISU researchers, which are the same from March to November, the last working day in November 2002 is November 13. Therefore, if the project starts on March 20, 2002 and finishes on November 13, 2002, there are only 141 working days available.

We assume that on the same critical path, every activity's acceleration rate is the same, which is 40% ((235 - 141)/235 = 40%). Based on this assumption, an acceleration calculation form for Critical Path I is created as shown in Table 11.

Table 11: Acceleration Calculation for Critical Path I

Activity Description	Code	Standard Duration (days)	Acceleration Rate	Required Duration (days)
CG bridge berm		8	40%	5
CG bridge	B1	140	40%	84
Ramp MLK-B	B11	50	40%	30
MLK bridge north approach	B16b1	13	40%	8
East leg of Atkins Street	B19	24	40%	14
Total		**235**		**141**

Required duration = Standard duration * (1 - Acceleration rate) = Standard duration * 60%

Using the same method, an acceleration calculation form for Critical Path II is created as shown in Table 12.

Table 12: Acceleration Calculation for Critical Path II

Activity Description	Code	Standard Duration (days)	Acceleration Rate	Required Duration (days)
MLK bridge berm		8	10.56%	7
MLK bridge	B2	125	10.56%	112
MLK bridge south approach (or Temporary pavement on E of MLK bridge south approach)	B16b2 (or C11)	9	10.56%	8
East leg of Atkins Street	B19	24	40.00%	14
Total		**166**		**141**

Required duration = Standard duration * (1 - Acceleration rate)

Based on the acceleration calculations for Critical Paths I and II, an accelerated schedule, indicated in Figure 11, is created that can satisfy the requirement of project completion date.

When adopting Measure II, the main concern is whether the acceleration rates are possible in real construction.

According to Tables 11 and 12, the highest acceleration rates for bridgework and roadwork are both 40%. It is necessary for ISU researchers to find out whether this acceleration rate is possible or not in real construction.

ID	Task Name	Duration	Text1	Predecessors
1	CG bridge berm-calculated 8 days	5 days		
2	CG bridge-calculated 140 days	84 days	B1	1
3	MLK bridge berm-calculated 8 days	7 days		
4	MLK bridge-calculated 125 days	112 days	B2	3
5	retaining wall near MLK bridge	60 days	B3	4SS
6	alley between MLK & 21 St	17 days	B4	
7	temp. pav. betw. 21 St & alley	4 days	C2	6SS
8	temp. pav. from Day St to CG WB on-ramp	15 days	C1	
9	sanitory sewer	10 days		
10	CG from E of MLK to E of relocated 19 St	31 days	B5	9
11	CG from 25 St to CG bridge W approach (incl. Kingman Blv., 24 St & Day St)	56 days	B6+B7	
12	old CG bridge removal	10 days	B8	
13	temp pav from new CG to 20 St on N and to MLK at Crocker on S	18 days	C3	9
14	curb removal & temp pav in island betw. MLK. 20 & School St	9 days	C4	
15	temp pav from EB CG to Olive St	22 days	C5	
16	CG from S of EB off-ramp to E of MLK	40 days	B9	15
17	MLK from N Center St to S Atkin St (I)	30 days	B10a	6
18	MLK from N Center St to S Atkin St (II)	24 days	B10b	15,13
19	MLK from N Center St to S Atkin St (III)	48 days	B10c	18SS,13
20	water main	30 days		
21	ramp MLK-B-clculated 50 days	30 days	B11	2,20,12
22	maintenance turnaround and close Olive St	1 day	B12	
23	temp pav betw I235 & ramp MLK-B	9 days	C6	21SS
24	Wedge course & temp pav betw new MLK & School St	14 days	C7	14
25	temp pav betw new MLK & Day St	14 days	C8	17SS
26	temp pav betw new & old MLK; wedge course betw temp pav and old MLK (on S of Crocker St)	14 days	C9	
27	gap in MLK on N of CG	24 days	B13	16
28	Western portion of MLK from Atkins to N end of project	25 days	B14	17
29	CG between relocated and old 19 St	21 days	B15	
30	CG bridge approach	16 days	B16a1	2
31	the remainder of CG	9 days	B16a2	17
32	MLK bridge north approach -calculated 13 days	8 days	B16b1	21
33	MLK bridge south approach -calculated 9 days	8 days	B16b2	4
34	temp pav betw new & old MLK at S end of project	13 days	C10	19
35	temp pav on E of MLK bridge south approach-calculated 9 days	8 days	C11	33SS
36	east leg of Atkins St-calculated 24 days	14 days	B19	28,32,33,35
37	temp pav betwe[illegible] St & Atkins St	13 days	C12	28

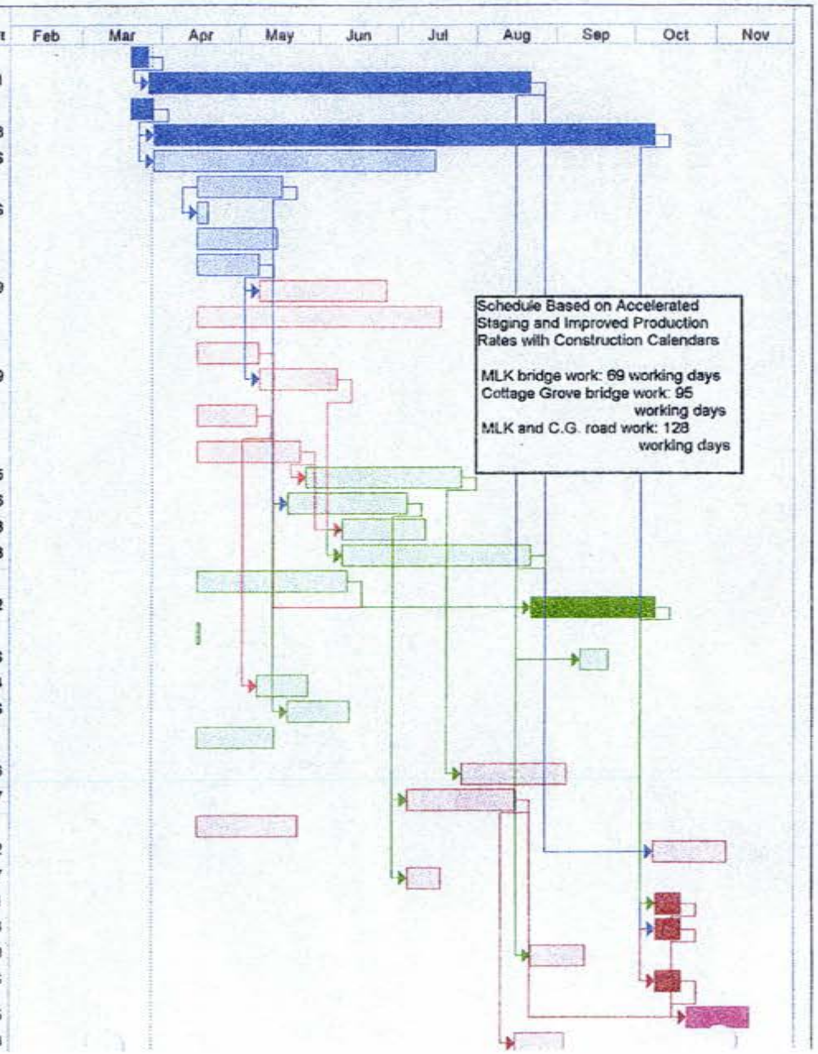

Figure 11: MLK and Cottage Grove Schedule Based on Accelerated Staging and Improved Production Rates with Construction Calendars

There are three steps for the acceleration possibility analysis:

1. Step I: Possibility of improving the DOT's standard production rates in real construction.

   One reason for this is that the DOT's standard production rates are comparatively lower than the average of actual production rates. The DOT's standard production rates are used mainly to determine contract durations. They are kept lower to attract as many as possible contractors to bid projects, or else less competent contractors will not be qualified to bid the projects.

   Another reason is that when the DOT's standard production rates are used to determine contract durations, the overlapping of different operations is not considered. Highway projects are linear, which means one activity follows another sequentially, and those activities must be performed continually over the duration of the entire project. Usually, a road construction project involves operations of clearing, grubbing, grading, base course, and paving. Each of these operations will be conducted from one end of the project to the other. It is rare that each operation will only start after its predecessor has been finished from one end of the project to the other. The more actual situation is each operation starts after its predecessor is somewhere midway in its construction, so long as the principle is satisfied that no two operations can happen at the same time in the same place. For example, the paving operation can start at the starting point of the project while its predecessor, base course operation, is still being conducted somewhere but has not reached the end point of the project. This is called time overlapping of operations. This construction method can save time, but requires more crews.

2. Step II: Finding the actual production rates and their distribution

ISU researchers collected daily production rate data from some highway projects in Iowa, processed them with a statistical analysis program, and then obtained the statistical distribution of those production rates. The projects from which those daily production rate data were collected are recent urban or rural highway projects in Iowa. So they have similar construction conditions to Project I235. Daily production rate data were collected for each operation and processed by a statistical program named SAS. For each operation we can obtain a histogram and various percentiles.

A Pth Percentile is the value that has at most P% of the data below it and at most (100-P)% above it. It can be used to value a certain datum's occurring possibility in a set of data. Table 13 shows the rank of Iowa DOT standard production rates and the accelerated production rates in the daily production rate data collected from Iowa DOT highway projects. From this table, it is indicated that most of the DOT standard production rates are less than their corresponding 50th percentiles. Histograms show the distribution of the data. They can be used as another tool to value a certain datum's occurring possibility in a set of data. Figure 12 is an example of the distribution histogram of production rate data of PCC paving collected from Iowa DOT highway projects.

A detailed statistical analysis of production rate data is described in Appendix B.

Table 13: the Comparison of Iowa DOT Standard Production Rates and the Production Rates from Iowa DOT Highway Projects

Operation Description	Mean	50th Percentile	75th Percentile	80th Percentile	90th Percentile	DOT Standard Production Rate	Percentile of DOT Standard Production Rates	Accelerated Production Rate in MLK & C.G. Projects	Percentile of Accelerated Production Rate in MLK & C.G. Projects
ACC paving (ton/day)	2,133	1,632	3,640	4,277	4,460	1,300	46th	1,820	52nd
PCC paving (m^3/day)	1,340	987	2,062	2,338	2,890	550	40th	770	44th
Excavation CL10 (m^3/day)	5,538	3,079	7,825	10,298	13,544	4,000	48th	5,600	63rd
Excavation CL12 (m^3/day)	3,369	2,326	3,764	4,550	5,804	75	11th	105	11th
Clearing & grubbing (unit/day)	5,45	142	1,177	1,301	1,551	400	56th	560	59th
Drainage/subdrain (m/day)	1,840	1,564	2,871	3,019	3,877	1,000	34th	1,400	46th
Embankment-in-place (m^3/day)	12,673	10,110	18,961	21,624	28,263	700	20th	980	23rd
Pavement removal (m^2/day)	4,640	1,650	4,646	5,309	9,509	3,400	65th	4,760	76th

* The acceleration rates are 40%.

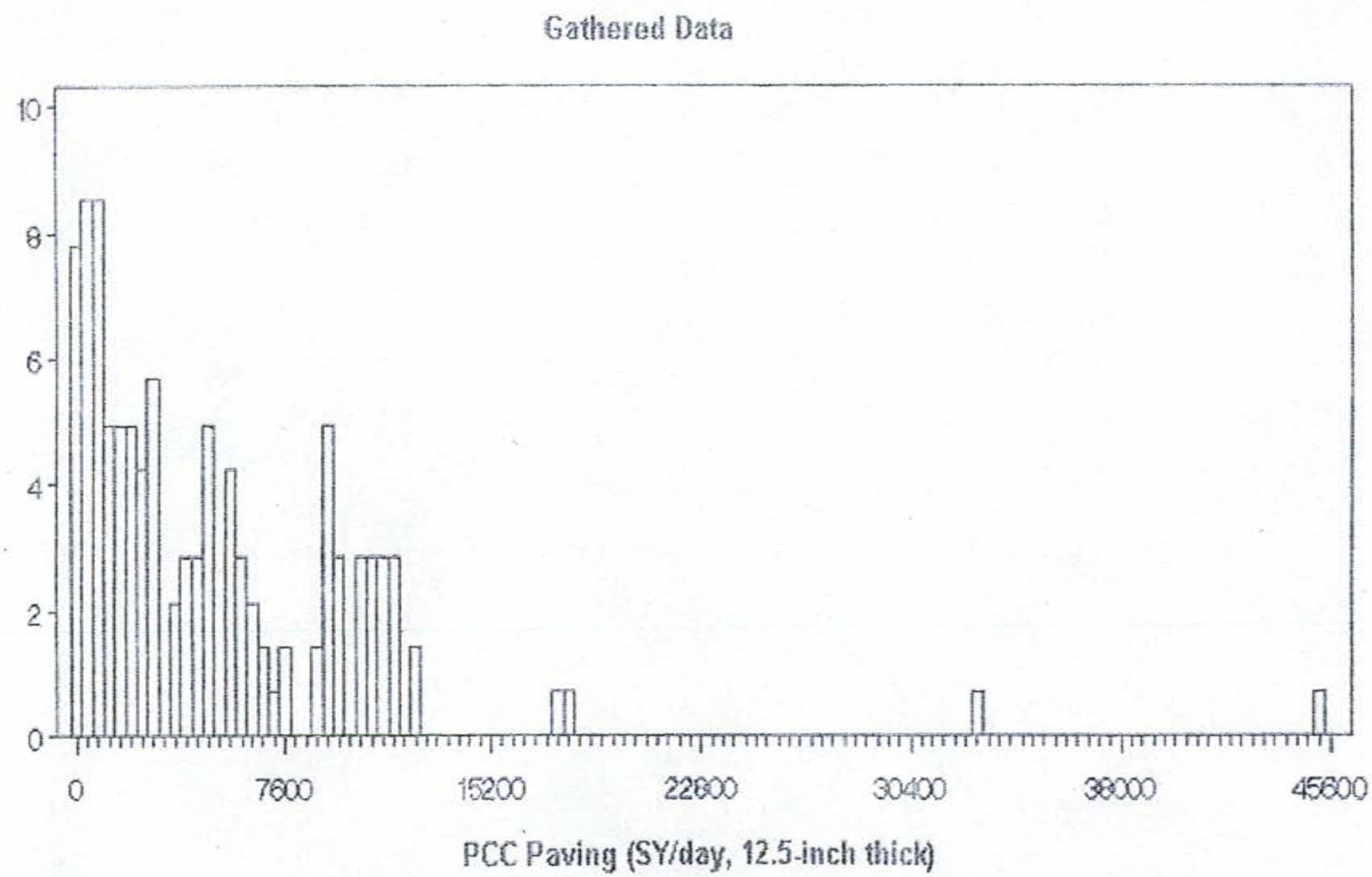

Figure 12: Distribution Histogram of Daily Production Rates Data of PCC Paving from Iowa DOT Projects

3. Step III: Finding out the possibility of accelerated production rates in real construction

   The possibility of an accelerated production rate in real construction can be measured by finding its corresponding percentile and its location in the histogram. For example, to find out the possibility of an accelerated production rate for PCC paving (770 m^3/day, or 2425 SY/day, 12.5-inch thick), from Table 13, we can see its corresponding percentile is 44^{th}, which means in the real construction, there are at most 44% of the production rate data below it and at most 56% above it. The histogram in Figure 12 shows that the required accelerated production rate of PCC paving in the MLK and Cottage Grove projects, 2,425 SY/day, 12.5-inch thick, has a comparatively high occurring frequency in the distribution histogram. So it seems that the required production rate of 770 m^3/day (or 2,425 SY/day, 12.5-inch thick), can be easily obtained in the actual construction. However, the data gathered to compose Table 13 and Figure 12, are mostly from rural projects, in which production rates are usually higher than those in urban projects. Therefore, the possibility of production rate acceleration in an urban project, like the corridor I235, needs further investigation if production data from more urban projects are available.

Measure II is commonly used to accelerate projects. However, increasing production rates usually means increasing cost because of the increase of labor, material, and equipment. And sometimes, if the required acceleration rate is too high, this measure is not very practical.

5.3 MEASURE III: USING CONSTRUCTION ALTERNATIVE

Another measure to accelerate projects is to adjust the logical relationship between critical activities, decrease the number of critical activities on the same critical path, then try to accelerate projects with the fewest production rates improving. A main point of this measure is using existing roads as long as possible, then switching to new roads without using detours.

This measure requires larger changes to the original staging when compared with Measure I and Measure II. It changes logical relationships between activities and may lead to adding new activities or deleting old activities.

Usually this measure can decrease acceleration cost, because the requirement for production rate improvement is decreased.

However, this measure is not practical at just any time, because on some occasions there is only one possible staging solution.

In the MLK and Cottage Grove projects, the original Iowa DOT construction staging indicated that the bridgework and roadwork are both involved in the same critical path, and that is the main reason why the projects cannot be finished on the required project completion date based on DOT standard production rates.

By adopting a different traffic control strategy, ISU researchers devised another staging for the MLK and Cottage Grove projects (we call it proposed staging from ISU), in which some logical relationships and activities' staging sequences are changed. Figure 13 shows the proposed staging plan, and Figure 14 is the corresponding schedule based on ISU's proposal.

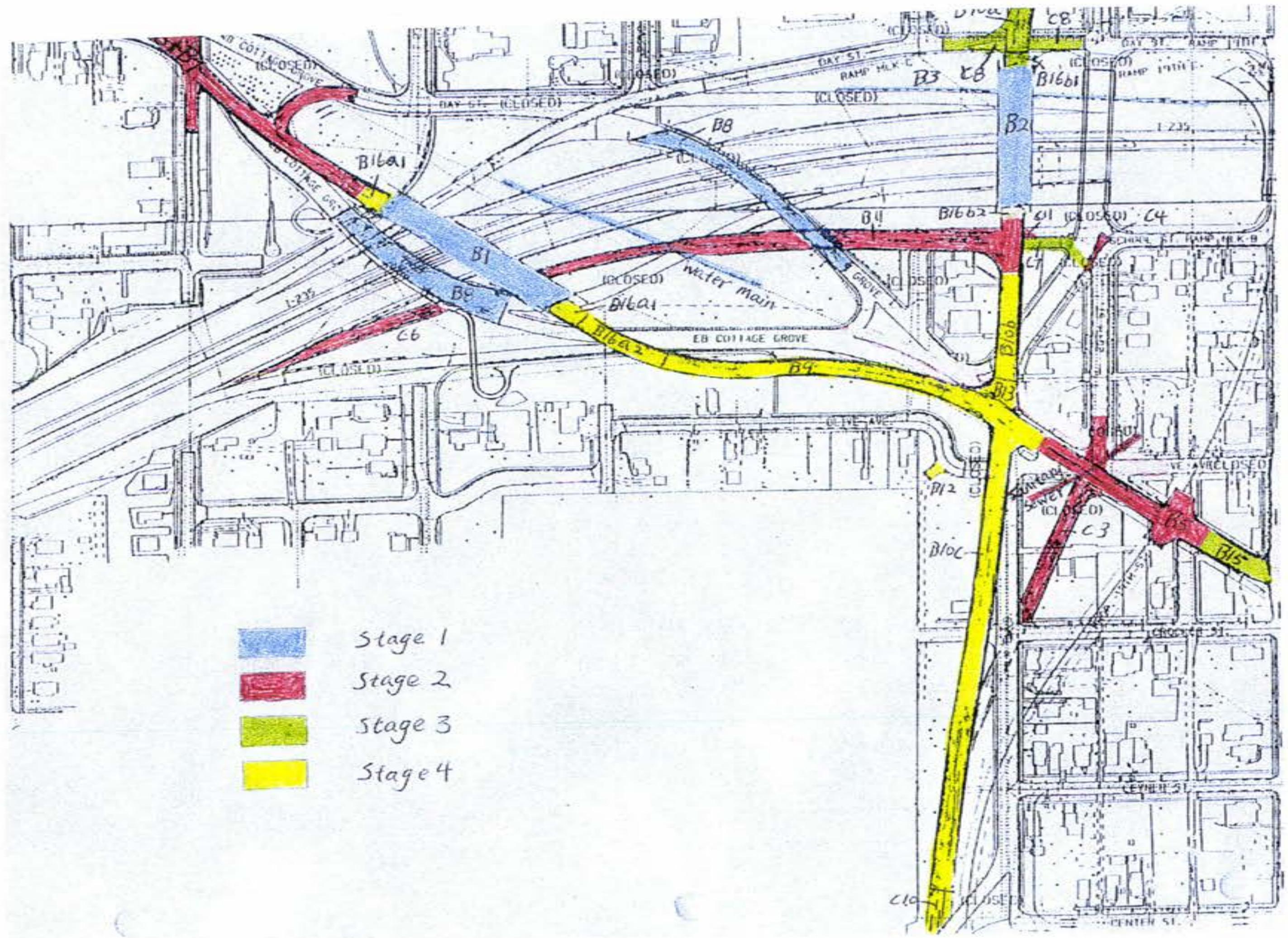

Figure 13: Staging Map of MLK and Cottage Grove Projects from ISU Proposal

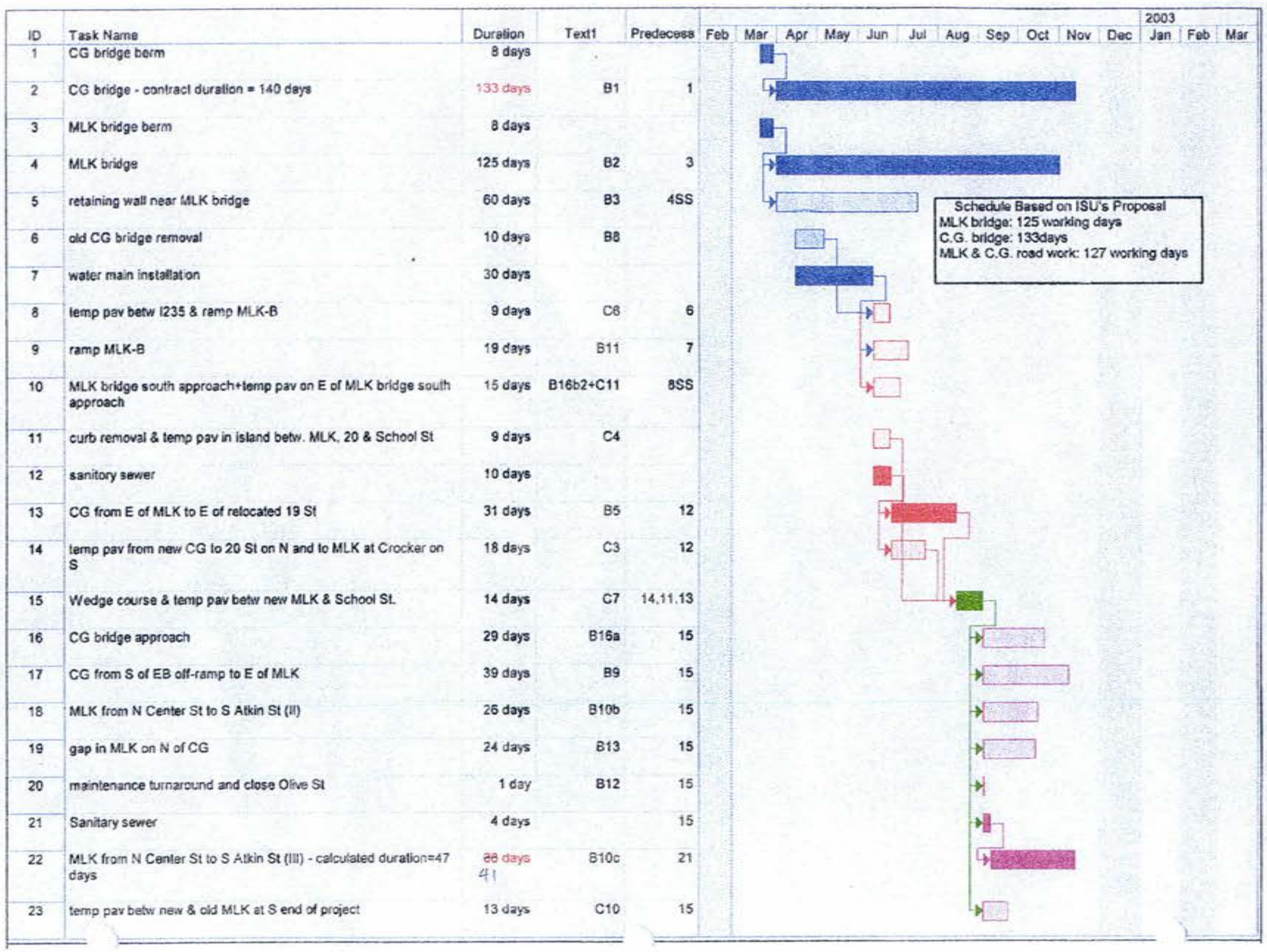

Figure 14: MLK and Cottage Grove Schedule Based on the Construction Alternative and Improved Production Rates with Construction Calendars

We can see some changes from the original staging by using the proposed staging from ISU:

1. The number of total activities decreases.

   By using the proposed traffic control strategy, some temporary pavements (activities C1, C2, C5, and C9) and an alley (B4), which are used to provide public traffic during the construction, are unnecessary and can be deleted. The deletion of these activities can save time and cost for the projects.

2. There are changes in critical paths.

   By using the proposal from ISU, it is observed that the critical paths for the projects have been changed from two critical paths into 3 critical paths.

   Critical paths in ISU proposal:

   Proposed Critical Path I: CG bridge berm → CG bridge

   Proposed Critical Path II: MLK bridge berm → MLK bridge

   Proposed Critical Path III: Water main installation → sanitary sewer → CG from east of MLK to east of relocated 19th Street (B5) → Wedge course & temporary pavement between new MLK and School Street (C7) → Sanitary sewer → MLK from N Center Street to S Atkin Street (III) (B10c).

   Original Critical Path I: CG bridge berm → CG bridge (B1) → ramp MLK-B (B11) → MLK bridge north approach (B16b1) → east leg of Atkins Street (B19).

Original Critical Path II: MLK bridge berm → MLK bridge (B2) → MLK bridge south approach (B16b2) and temporary pavement on east of MLK bridge south approach (C11) → east leg of Atkins Street (B19).

It is very clear that in the original critical paths, both bridgework and roadwork are included in the same critical path, which is the main reason for keeping the total project duration long. In contrast, in ISU's proposal, Proposed Critical Paths I and II only include bridgework, and Proposed Critical Path III only includes roadwork, which prevents the influence of bridgework and roadwork on each other.

3. Production rate acceleration is reduced.

   Based on ISU's proposal, to satisfy the project completion date of November 2002, the MLK bridge project needs no acceleration, the Cottage Grove bridge project only needs to be accelerated from 140 days to 133 days (acceleration rate 5%), and roadwork only need be accelerated from 133 days to 127 days (acceleration rate 4.5%).

By using Measure III in this case, the MLK bridge project, Cottage Grove bridge project, and the road project are independent from each other. All these three projects can be completed by November 2002 with the least acceleration.

By consulting an experienced DOT construction engineer, this acceleration proposal from ISU can probably save $50,000 of direct costs for reduced detour construction, which does not include the indirect cost savings yet.

Therefore, by comparing the constructability and economization, Measure III is suggested as the best method to accelerate the projects.

Actually, in this case, all three acceleration measures have been used, while Measure III is the most efficient acceleration method. By using Measure III, a new construction staging plan is created. In this new plan, every activity will start as early as possible, which is the essence of Measure I. And by using Measure II (5% acceleration rate for the Cottage Grove bridge project and 4.5% acceleration rate for roadwork), the required project completion date can be satisfied.

CHAPTER 6: SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

The corridor I235 includes reconstruction of more than 80 bridges and 20 interchanges. These projects may have relationships with each other and will influence each other's construction. Therefore it is very important to identify the acceleration need in one project as soon as possible and adopt certain acceleration measures to guarantee its on-time project completion and prevent the delay of other projects caused by it.

This thesis describes the process of creating schedules, identifies the need of acceleration, and recommends different acceleration measures for urban freeway interchange reconstruction projects, with the example of the MLK and Cottage Grove projects in the corridor I235.

The process of identifying the need of acceleration includes the following steps: finding out the logical relationship among activities; calculating standard durations of activities; creating Gantt chart schedules; and assigning construction calendars on activities.

The standard durations of activities are calculated by using Iowa DOT standard production rates, which are used by the Iowa DOT to decide contract durations. The standard production rates are usually lower than the average project production rates to attract more contractors to bid projects. Therefore, it is possible to have project acceleration in the real construction. In the step of calculating standard durations of activities, if DOT standard production rates are not available for some operations, like hand paving, it is a good method to consult experienced construction experts for solutions.

Construction calendars are very critical in changing a working-day schedule into a calendar-day schedule, which is more useful than the working-day schedule in schedule creating, tracking, changing, and updating. ISU researchers interviewed some experienced contractors in Iowa and Iowa DOT construction engineers, analyzed daily production rate data from projects of the Iowa DOT, and created some construction calendars that can be used in Project I235. By using Microsoft Project, these construction calendars can be easily assigned to the working-day schedules.

There are three possible acceleration measures that can be considered to accelerate projects: changing staging sequence (Measure I), improving production rates (Measure II), and using a construction alternative (Measure III).

When using Measure I to accelerate projects, the sufficient material, equipment, and labor must be guaranteed. Usually, using this method alone cannot satisfy acceleration requirements, because this measure can seldom have influence on critical paths. However, this measure can help to prevent noncritical activities from becoming critical and hindering the required project completion date while other measures are adopted. So this measure is often combined with other measures as listed above to accelerate the project schedule.

When adopting Measure II, the main concern is whether the acceleration rates are possible in real construction, which can be proved by the acceleration possibility analysis. Measure II is commonly used to accelerate projects. However, increasing production rates usually means increasing cost because of the increase of labor, material, and equipment. And sometimes, if the required acceleration rate is too high, this measure is not very practical.

Measure III is a comparatively bigger change of the original staging than Measure I and Measure II. It changes logical relationships between activities and may lead to adding new activities or deleting old activities. Usually, it can decrease acceleration costs, because the requirement for production rate improvement is decreased. However, this measure is not practical at just any time, because on some occasions there is only one possible staging solution.

It is suggested that in the acceleration process, these three measures be considered and compared with each other, and the most economical and practical measure be adopted. The measures can be used separately or in a combined way.

6.2 RECOMMENDATIONS

Here are some recommendations for future research:

1. In this study, it is found that some of the Iowa DOT standard production rates are too low. Further study on their practicality in contract duration determination, schedule creating, and other processes is suggested.
2. Construction calendars for more detailed work are encouraged to create more accurate construction schedules.
3. Further investigation into construction acceleration measures is encouraged to realize project acceleration economically and practically.

APPENDIX A. PROJECT MANAGEMENT SOFTWARE

INTRODUCTION

Project management software plays a very important role in project management work. There are quite a few project management software products available on market, and each of them has its own abilities, limitations, and application situations. Choosing the appropriate project management software is critical for the efficiency and success of project management work.

PROJECT MANAGEMENT SOFTWARE USED IN THE CORRIDOR I235

In the beginning, the ISU researchers used Microsoft Project 98, a project management software, to schedule and track project and resource information for the corridor I235. As shown in Figure 15, all required activities were listed and their predicted durations were calculated. For example, it was necessary to know how many days were required to place all of the selected backfill in activity "ML EB Widening." When the volume of selected backfill became known, that volume was divided by the DOT standard production rate for selected backfill, shown in Table 2, and a duration for the selected backfill could be derived. The duration of an activity is shown by the length of the bar on the right part of Figure 15, which represents this activity.

After calculating durations for various activities, all the activities were connected by their logical relationships. All the logically connected activities comprise a bar chart (a.k.a. Gantt chart), through which potential time and resource sharing problems and the influence of the delay or advancement of an activity can be determined. For example, if Activity 10 (42nd Street, West Des Moines water) is postponed from June 1, 2001, to June 1, 2002, then Activity 20 (42nd Street, West Des Moines bridge and approaches) must be deferred until

January 15, 2005, which is one year later than originally scheduled. Therefore, Activity 10 must be accelerated to guarantee the timely completion of Activity 20.

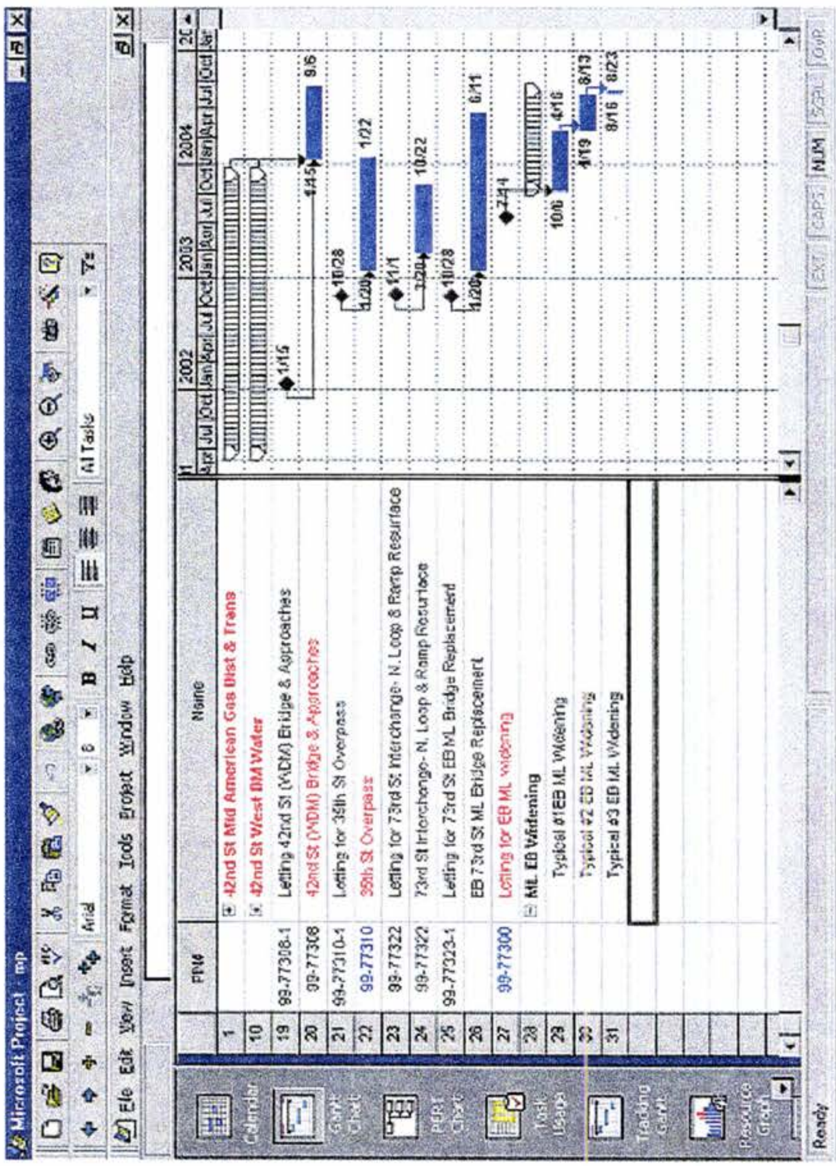

Figure 15: A Simplified Typical Microsoft Project 98 File Used by ISU to Do Scheduling Work

CURRENT PROJECT MANAGEMENT SOFTWARE PRODUCTS

The most popular project planning and scheduling software products used in the construction area are Microsoft Project and Primavera Project Planner (P3). Each product offers similar Web-based project management functionality, but they differ significantly in ease of installation and configuration, ease of access, collaboration capabilities, and price. These two software products have their own features and areas of application, so it is important to understand the size and characteristics of the project when making the choice of appropriate management software.

P3 offers more functionality than Microsoft Project does. In addition, its new solution for project management – Primavera Enterprise (P3e) – can enable an organization to prioritize its projects throughout the entire project life cycle and throughout the entire project team. Some advantages of P3 when compared with Microsoft project are as follows:

1. In P3, one can move a Work Breakdown Structure (WBS) element without erasing its activities, and P3e further offers the option of merging the activities into other WBS elements. The WBS breaks the project down into successive elements of data. More details and more levels are developed until the desired amount of control is established.
2. P3 provides four types of activities (duration types): task-dependent, resource-dependent, level of effort, and milestone. However, Microsoft Project has only two: milestone and normal.
3. Compared with P3, Microsoft Project's resource hierarchy is less flexible and has limited meta-data for each resource. Meta-data maintain links between software artifacts, such as transformation definitions or database columns, to keep track of all the parts of a data warehouse system.
4. P3 is multi-user, and Microsoft Project is not.

5. P3e offers increased style activity codes and enhances hierarchical control of the code structure.

A project situation in which P3 should be considered as an appropriate management tool may be as follows: the project is very large, 2,000 tasks or more, and the organization needs to manage multiple projects simultaneously, which means they want to prioritize those projects and optimize resource allocation between projects.

While Microsoft Project is less powerful than P3, it has its own advantages:

1. It is much less expensive than P3. Microsoft Project products cost between $300 and $500, while P3 products cost between $1,000 and $2,000.
2. Microsoft Project is much easier to learn and more user-friendly.

   However, Suretrak Project Manager 3.0, a Primavera product released in 2000, is a simplified version, and easier to use than the previous Primavera products.
3. Microsoft Project can be easily linked with other Microsoft files, such as Excel, for automatic data updating. Considering the wide application of Microsoft Software products, this is a very valuable characteristic.
4. The introduction of Microsoft Project Central, which gives project collaborative capabilities, is a most welcomed enhancement. Microsoft Project Central is the Web companion to Microsoft Project, facilitating team collaboration and communication. Todd Rooke, chief technology architect of Rainier Technology, said, "Microsoft Project Central accommodates the manager as well as the individual task owners. It can often be difficult to delegate tasks in an efficient manner, especially in the larger teams. This platform provides a central view of

current project status for the entire team, and also allows team members to understand the dependencies of their own tasks." (Microsoft Corporation, 2001)

Therefore, when the project has less than 2,000 activities, the organization's emphasis is not on multiple projects, and other Microsoft applications are being employed, Microsoft Project would be an ideal management tool.

Basically, the project management software chosen should integrate with existing systems, facilitate use through simple interfaces, and be cost-effective.

FORMAT CONVERSION BETWEEN PROJECT MANAGEMENT SOFTWARE PRODUCTS

Sometimes, the need may occur to convert the format of a file between Primavera and Microsoft Project. The conversation can be very easily realized through a utility (program) called Primavera MPX Convert, an effective and user-friendly tool. Once the Primavera MPX Convert program is started by clicking on the "MPX Conversion" item in the Primavera program, the "Primavera MPX Convert" window is displayed as seen in Figure 16.

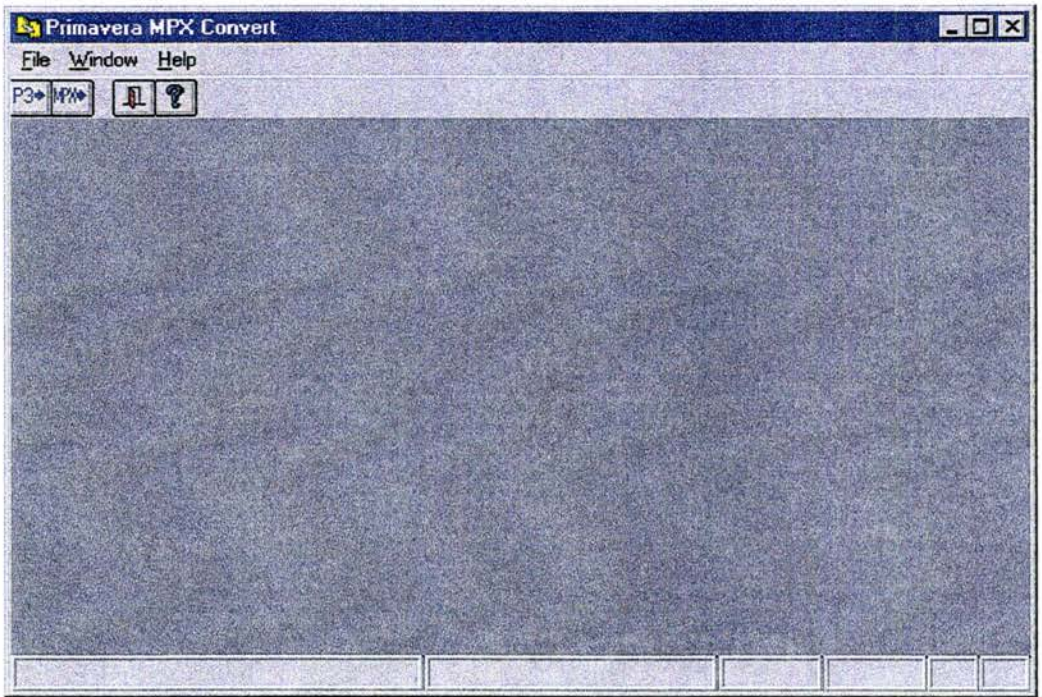

Figure 16: First Screen for the Utility that Converts Microsoft Project to Primavera

To convert a Microsoft Project file into a P3 file, click on the "file" button, then click "convert a MPX project to P3 project" (or click the second icon in the tool bar directly). Then the "Convert Project Form" window is displayed, as seen in Figure 17. Use the "Browse" button to select the Microsoft Project file, then click "OK." The "Convert Project To" window is displayed as seen in Figure 18. At that point, use the "Browse" button to select the appropriate folder and enter a name in the "Project name" box (this will then become the Primavera file name) and click "OK." The conversion from a Microsoft Project file to a P3 file is now complete.

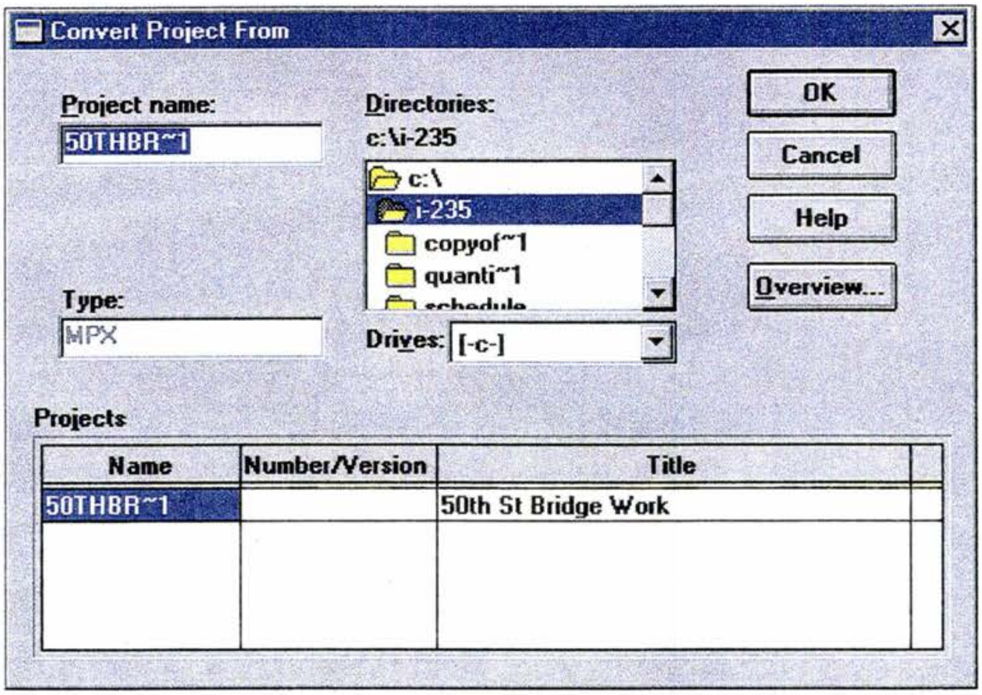

Figure 17: Second Screen for the Utility that Converts Microsoft Project to Primavera

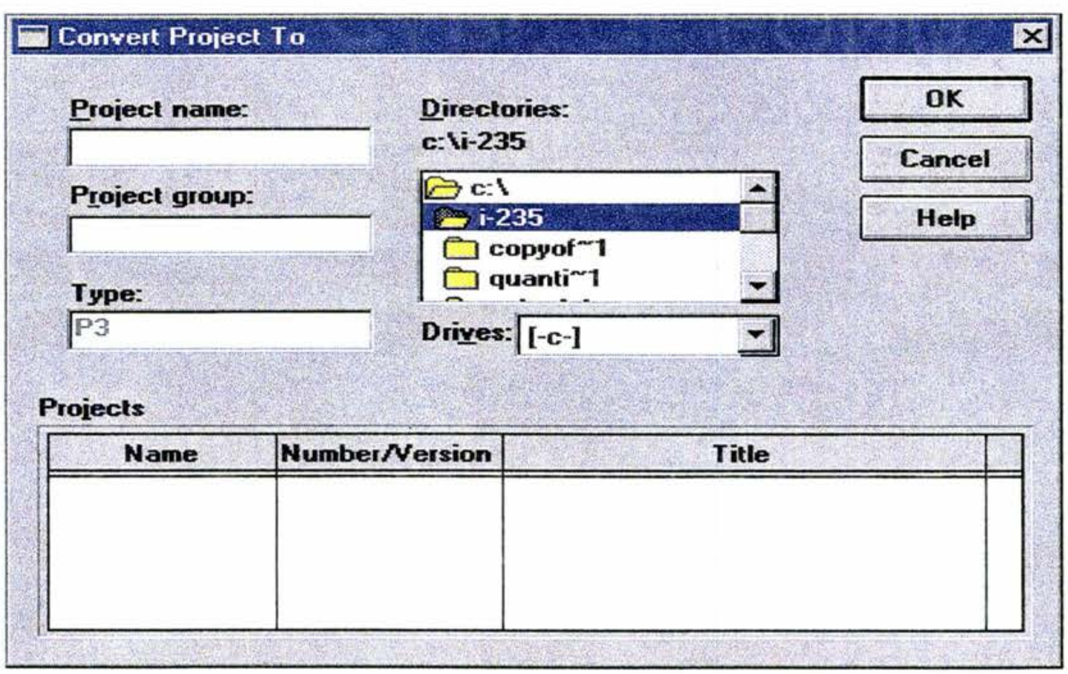

Figure 18: Third Screen for the Utility that Converts Microsoft Project to Primavera

To convert a P3 file to a Microsoft Project file, click on the "file" button, then click "convert a P3 project to MPX project" (or you can click the first icon in the tool bar directly). The remaining steps are the same as those for converting a Microsoft Project file to a Primavera file.

During the conversion, there are special issues that should be considered:

1. This conversion program is designed for a one-time P3 file to Microsoft Project file conversion or vice versa. It is not intended for an ongoing data exchange between these two formats.
2. This conversion program works with Microsoft Project files created with Versions 3.0, 4.0, or 4.1 and P3 files created with versions 1.0, 1.1, or 2.0.

In general, the format conversion between Microsoft Project files and P3 files can be easily realized by Primavera MPX Convert.

APPENDIX B. STATISTICAL ANALYSIS OF PRODUCTION RATE DATA

During the preconstruction project engineering and management phase, timely and accurate scheduling inputs will ensure that the final design, timing, and cost of the work are totally consistent with the project objectives. They can identify potential delays, conflicts, acceleration possibilities, and so on, and realize savings at the earliest possible opportunity.

In the scheduling work, production rate plays a very important role.

Production rate is a ratio relating some volume of output to the quantity of time used.

Production rate = output (units of product) / time (usually days)

Production rates can be used to determine contract durations, predict project durations in preconstruction phase to expect possible delays, identify the acceleration possibility, and so on.

However, construction is such a diversified industry that production rates will be influenced by various factors like weather, geographical location, the availability of material and labor, and so on. The United States is a vast country with various weather and geographic conditions. Therefore, uniform construction production rates for nationwide use are not available.

For a specific construction project (assume it is called Target project), how to find appropriate production rates is a critical issue. There are various sources for production rates: contractors, government agencies, research institutes, and so on.

The following will describe a method to derive appropriate production rates for different usages. This method has been adopted by the Iowa Department of Transportation and researchers from Iowa State University. This method can help to determine production rates for a specific construction project when no ready-made production rates are available.

The essence of the method is to analyze production rate data and derive appropriate production rates. It includes three steps: data gathering, data analysis, and result reporting.

STEP I: DATA GATHERING

The data analyzed are daily production rate data from similar projects.

As described above, production rates will be influenced by weather, geographical location, the availability of material and labor, and so on. Similar projects are expected to have similar production rates. Therefore, the expected production rates would be derived by analyzing similar projects.

Similar project conditions mean similar weather, geographical locations, materials, equipment, labor, construction methods, management styles, and so on.

Table 14 shows an example of daily production rate data of special backfill from a construction site.

STEP II: DATA ANALYSIS

The gathered data compose a data sample from a population. We are interested in the percentiles and histograms of the sample.

A Pth Percentile is the value that has at most P% of the data below it and at most (100-P)% above it. It can be used to value a certain datum's occurring possibility in a set of data.

Histograms show the distribution of the data, as indicated in Figure 12. They can be used as another tool to help estimate the likelihood of a certain datum occurring in a set of data.

Percentiles and histograms can be obtained through processing the data by a statistical program named SAS or Microsoft Excel.

Table 14: Daily Production Rate Data of Special Backfill

Entry No. (1)	Date (2)	Sta From (3)	Sta To (4)	Side (5)	Placed (MG) (6)
1	8/27/99	159+00	149+00	WBL	1683.699
2	8/30/99	159+00	156+00	EBL	356.415
3	8/31/99	145+55	148+70	WBL	124.638
4	9/1/99	1540+50	1545+55		649.299
5	9/2/99	3541+19	3542+74		185.605
6	9/3/99	148+70	159+00	EBL	1292.92
7	9/6/99	126+12	127+72	WBL	267.3
8	9/7/99	126+28	127+78	EBL	267.3
9	9/8/99	137+05	137+47	WBL	94.256
10	9/9/99	136+15	137+05	WBL	184.181
11	9/10/99	136+14	137+55	EBL	251.262
12	9/13/99	145+55	148+70	WBL	713.8
13	9/14/99	140+87	145+55	WBL	379.494
14	9/15/99	140+87	148+70	WBL	776.214
15	9/16/99	148+70	143+50	EBL	757.154
16	9/17/99	148+70	143+50	EBL	383.703
17	9/20/99	148+70	159+00	E&WBL	619.634
18	9/21/99	1540+40	1545+55	RAMP A	127.351
19	9/22/99	127+72	132+19	WBL	575.289
20	9/23/99	132+19	136+15	WBL	509.652
21	9/24/99	140+94	148+70	EBL	570.915
22	9/27/99	148+70	159+00	E&WBL	130.103
23	9/28/99	127+72	132+19	WBL	309.771
24	9/29/99	132+19	136+15	WBL	274.428
25	9/30/99	126+12	127+72	WBL	29.7
26	10/1/99	126+28	167+78	EBL	29.7
27	10/4/99	137+05	137+47	WBL	10.473
28	10/5/99	136+15	137+05	WBL	20.465
29	10/6/99	136+14	137+55	EBL	27.918
30	10/7/99	127+78	132+19	EBL	873.18
31	10/8/99	132+19	134+10	EBL	378.18
32	10/11/99	134+10	136+14	EBL	607.248
33	10/12/99	134+10	136+14	EBL	64.023
34	10/13/99	2536+14	2537+88	RAMPB	243.938
35	10/14/99	2538+87	2541+50	RAMPB	413.938
36	10/15/99	126+12	132+19	E&WBL	355.487
37	10/18/99	4538+25	4539+72	RAMPB	231.25

STEP III: RESULT APPLICATION

The statistical analyzing results can be used in various aspects.

1. Standard production rates of government agencies

   In the Iowa DOT, the standard production rates are used mainly to determine contract durations. In some cases, they should be kept lower to produce a large contract duration, which can attract as many as possible contractors to bid projects. Therefore, a production rate that is less than the 50th percentile, will be adopted as standard production rates. As shown in Table 12, most of the Iowa DOT standard production rates are less than the 50th percentiles of the data collected from previous Iowa DOT highway projects.

2. Predicted actual production rates under normal project conditions

   Usually, the 50th percentile will be regarded as predicted actual production rate under normal project conditions. It can be used to identify the need for acceleration if the duration calculated by using it is longer than required.

3. Possibility of accelerated production rates

   By finding out the percentile rank of a proposed accelerated production rate (i.e., its corresponding percentile, as shown in Table 14), we will know the degree of difficulty to achieve it during the actual construction. The higher the percentile, the more difficult it is to achieve it. Such information can assist in estimating the difficulty of acceleration. That can provide contractors with a rough idea to help in their efforts to accelerate projects.

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