ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

Title: A Signal Interconnection Case

Course: EMGT 540/640
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Author(s): R. Shannon, K. Al Kahtani and S. Alalyanm

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Abstract: Uses linear programming to develop an alternate automobile signal (traffic lights) scheme to minimize cost.

A Signal Interconnection Case

R. Shannon, K. Al-Kahtani, S Al Alalyan

EMP-9702

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A SIGNAL INTERCONNECTION CASE

ENGINEERING MANAGEMENT 540

OPERATION RESEARCH

MARCH 19,1997

PREPARED

FOR

Dr. TIM ANDERSON

TEAM MEMBERS

RANDALL C. SHANNON

KHALID AL KAHTANI

SALEH ALALYAN

23	0.0000000E+00	0.0000000E+00
24	0.0000000E+00	0.0000000E+00
25	0.0000000E+00	0.0000000E+00
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33	0.0000000E+00	0.0000000E+00
34	0.0000000E+00	0.0000000E+00
35	2.000000	0.0000000E+00
36	1.000000	0.0000000E+00
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38	0.0000000E+00	0.0000000E+00
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43	0.0000000E+00	0.0000000E+00
44	3.000000	0.0000000E+00
45	1.000000	0.0000000E+00
46	1.000000	0.0000000E+00
47	0.0000000E+00	0.0000000E+00
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49	0.0000000E+00	1.500000
50	0.0000000E+00	4.000000
51	0.0000000E+00	0.0000000E+00
52	0.0000000E+00	2.000000
53	0.0000000E+00	4.000000
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57	1.000000	0.0000000E+00
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59	0.0000000E+00	0.0000000E+00

OVERVIEW

Multnomah County is the smallest county in the state of Oregon by land area. But it has the largest population. This is due to the city of Portland, the largest city in the state, which occupies the center of the county. The east side of the county has the fourth largest city in the state, Gresham, and three smaller cities, Troutdale, Fairview and Woodvilliage. This area has experienced tremendous growth in the last ten years. Due to that growth it now has traffic problems.

Portland has done all of the road maintenance within its city limits since the early eighties. Multhomah County Transportation is responsible for maintaining only the arterials in east county. This is a recent change. Until 1994 the county maintained all roads in east Multnomah County. At that time the local road maintenance was turned over to the Cities. This was a political compromise resulting from many hours of hot debate between the County and Gresham.

Historically Multnomah County maintained primarily rural roads. Due to the growth and the political compromise the Transportation Division now finds itself responsible for a heavily traveled urban arterial system. The traffic section has not been proactive in upgrading the system to improve traffic flows. In response to this Gresham applied for and received a Federal grant to install the first phase of a signal interconnect project. Once approved the County Transportation Division took over the engineering and contracting of the project since it was for signals that are County Maintained.

The County has executed a intergovernmental agreement with the City of Portland to use its traffic control center and computers to coordinate the signals in East Multnomah County. This saved the cost of installing a whole new center. This left the problem of transmitting the information from downtown Portland to the signals. This was accomplished by installing communication relays that would transmit using Paragon's cable system.This first phase of the project is nearly complete and the next phase is now being planned. This is what our project proposes to help plan the next phase.

Purpose of study

Most people today usually use automobiles, and it is very clear that any body who is using a car is wishing to move from one place to the other by the fastest and most convenient way, this of course make the traffic is heavier in some streets than the others. As Multnomah County which is a small county but with a high population it is one of our responsibility to respond to that kind of need. We of course can't reply to all those kind

BUILD(4)	0.0000000E+00	0.0000000E+00
BUILD(5)	0.0000000E+00	-8.000000
BUILD(6)	0.0000000E+00	-5.500000
BUILD(7)	0.0000000E+00	-9.500000
BUILD(8)	0.0000000E+00	-9.000000
BUILD(9)	0.0000000E+00	-5.500000
BUILD(10)	1.000000	-5.000000
BUILD(11)	0.0000000E+00	0.0000000E+00
BUILD(12)	1.000000	0.0000000E+00
BUILD(13)	1.000000	0.0000000E+00
BUILD(14)	0.0000000E+00	0.0000000E+00
BUILD(15)	1.000000	0.0000000E+00
BUILD(16)	1.000000	0.0000000E+00
ADT(1)	0.0000000E+00	0.0000000E+00
ADT(2)	1.000000	0.0000000E+00
ADT(3)	1.500000	0.0000000E+00
ADT(4)	4.000000	0.0000000E+00
ADT(5)	0.0000000E+00	0.0000000E+00
ADT(6)	2.000000	0.0000000E+00
ADT(7)	4.000000	0.0000000E+00
ADT(8)	5.000000	0.0000000E+00
ADT(9)	0.0000000E+00	0.0000000E+00
ADT(10)	3.000000	0.0000000E+00
ADT(11)	2.500000	0.0000000E+00
ADT(12)	5.000000	0.0000000E+00
ADT(13)	0.0000000E+00	0.0000000E+00
NC(1)	1.000000	0.0000000E+00
NC(2)	0.0000000E+00	0.0000000E+00
NC(3)	0.0000000E+00	0.0000000E+00
NC(4)	0.0000000E+00	0.0000000E+00
NC(5)	1.000000	0.0000000E+00
NC(6)	0.0000000E+00	0.0000000E+00
NC(7)	0.0000000E+00	0.0000000E+00
NC(8)	1.000000	0.0000000E+00
NC(9)	1.000000	0.0000000E+00
NC(10)	1.000000	-3.000000
NC(11)	1.000000	-2.500000
NC(12)	1.000000	-5.000000
NC(13)	1.000000	0.0000000E+00

Row	Slack or Surplus	Dual Price
1	15.50000	1.000000
2	2660.000	0.0000000E+00
3	0.0000000E+00	0.0000000E+00
4	0.0000000E+00	0.0000000E+00
5	1.000000	0.0000000E+00
6	1.000000	0.0000000E+00
7	0.0000000E+00	0.0000000E+00
8	0.0000000E+00	0.0000000E+00
9	0.0000000E+00	0.0000000E+00
10	0.0000000E+00	0.0000000E+00
11	0.0000000E+00	0.0000000E+00
12	0.0000000E+00	0.0000000E+00
13	0.0000000E+00	0.0000000E+00
14	0.0000000E+00	3.500000
15	0.0000000E+00	0.0000000E+00
16	0.0000000E+00	0.0000000E+00
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19	0.0000000E+00	0.0000000E+00
20	1.000000	0.0000000E+00
21	1.000000	0.0000000E+00
22	0.0000000E+00	0.0000000E+00

of needs without considering the amount of money that would limit our movement. That is why this need for the minimization of the overall system cost.

In order to plan for future adequate streets for the area of expanding population and traffic it is very much needed to have a reasonable cost for the future solutions. The problem that we are dealing with is a problem that could lead to more complicated traffic problems if the planers did not anticipate and provide solutions in advance to avoid that kind of complication.

In this report we are intending the present results that could be used to serve the present traffic needs, moreover we are presenting the results of the solutions that would be needed in the future considering the future change that are going to create new and different kind of needs , we try to make our projection as accurate as possible based on the possible information that we could have in regard of the future planes for the traffic are we are analyzing in this paper.

OBJECTIVES

Cost minimization of the overall system is an objective of our class project. The cost minimization can also be applied to future projects which are a subset of the construction of the whole signal interconnection program. This was achieved by modeling the whole system and then modeling subsets of the system, for future projects

Prioritization of future projects was a second objective of this project. The decision process of which signals to interconnect first has been done on a route basis in the past. This results in a suboptimum interconnection of the whole system. While this may be a valid method of selecting the signals to be interconnected, it is not a optimum method of selecting the route by which the signals are to be interconnected.

METHODS

Minimum spanning tree:

Suppose that each arc (i,j) in a network has a length associated with it and that arc (i,j) represents a way of connecting node I to node j. A spanning tree of minimum length in a network is a minimum spanning tree. In figure 1, the spanning tree consisting of arcs (1,3) and (2,3) is the unique minimum spanning tree.

The following method (MST algorithm) may be used to find a minimum spanning tree.

Step 1 Begin at any node I, and join node I to the node in the network (call it node j) that is closest to node I. The tow nodes I and j now from a connected set of nodes

```
Rows=      57 Vars=      27 No. integer vars=      27  ( all are linear)
Nonzeros=     191 Constraint nonz=   169(   155 are +- 1) Density=0.120
Smallest and largest elements in absolute value=     1.00000        20000.0
No. < :  55 No. =:    0 No. > :    1, Obj=MAX, GUBs <=  15
Single cols=    0

Optimal solution found at step:         424
Objective value:                   15.50000
Branch count:                            34

                          Variable           Value        Reduced Cost
                            BUDGET        20000.00        0.0000000E+00
                         NODEA( 1)        1.000000        0.0000000E+00
                         NODEA( 2)        2.000000        0.0000000E+00
                         NODEA( 3)        3.000000        0.0000000E+00
                         NODEA( 4)        3.000000        0.0000000E+00
                         NODEA( 5)        4.000000        0.0000000E+00
                         NODEA( 6)        5.000000        0.0000000E+00
                         NODEA( 7)        6.000000        0.0000000E+00
                         NODEA( 8)        7.000000        0.0000000E+00
                         NODEA( 9)        6.000000        0.0000000E+00
                        NODEA( 10)        8.000000        0.0000000E+00
                        NODEA( 11)        9.000000        0.0000000E+00
                        NODEA( 12)        10.00000        0.0000000E+00
                        NODEA( 13)        11.00000        0.0000000E+00
                        NODEA( 14)        12.00000        0.0000000E+00
                        NODEA( 15)        1.000000        0.0000000E+00
                        NODEA( 16)        5.000000        0.0000000E+00
                         NODEB( 1)        2.000000        0.0000000E+00
                         NODEB( 2)        3.000000        0.0000000E+00
                         NODEB( 3)        4.000000        0.0000000E+00
                         NODEB( 4)        6.000000        0.0000000E+00
                         NODEB( 5)        7.000000        0.0000000E+00
                         NODEB( 6)        6.000000        0.0000000E+00
                         NODEB( 7)        7.000000        0.0000000E+00
                         NODEB( 8)        8.000000        0.0000000E+00
                         NODEB( 9)        10.00000        0.0000000E+00
                        NODEB( 10)        12.00000        0.0000000E+00
                        NODEB( 11)        10.00000        0.0000000E+00
                        NODEB( 12)        11.00000        0.0000000E+00
                        NODEB( 13)        12.00000        0.0000000E+00
                        NODEB( 14)        13.00000        0.0000000E+00
                        NODEB( 15)        9.000000        0.0000000E+00
                        NODEB( 16)        13.00000        0.0000000E+00
                          COST( 1)        5000.000        0.0000000E+00
                          COST( 2)        4600.000        0.0000000E+00
                          COST( 3)        6672.000        0.0000000E+00
                          COST( 4)        4562.000        0.0000000E+00
                          COST( 5)        9800.000        0.0000000E+00
                          COST( 6)        9720.000        0.0000000E+00
                          COST( 7)        5500.000        0.0000000E+00
                          COST( 8)        9000.000        0.0000000E+00
                          COST( 9)        5491.000        0.0000000E+00
                         COST( 10)        6400.000        0.0000000E+00
                         COST( 11)        6250.000        0.0000000E+00
                         COST( 12)        5280.000        0.0000000E+00
                         COST( 13)        5660.000        0.0000000E+00
                         COST( 14)        6832.000        0.0000000E+00
                         COST( 15)   0.0000000E+00        0.0000000E+00
                         COST( 16)   0.0000000E+00        0.0000000E+00
                         BUILD( 1)   0.0000000E+00        -1.000000
                         BUILD( 2)   0.0000000E+00        -6.000000
                         BUILD( 3)   0.0000000E+00        -9.000000
```

C = {i,j}, and arc (i,j) will be in the minimum spanning tree. The remaining nodes in the network (call them C') are referred to as the unconnected set of nodes.

Step 2 Now choose a member of C' (call it n) that is closest to some node in C. Let m represent the node in C that is closest to n. Then the arc (m,n) will be in the minimum spanning tree. Now update C and C'. Since n is now connected to {i,j}, C now equals {i,j,n} and we must eliminate node n from C'.

Step 3 Repeat this process until a minimum spanning tree is found. Ties for closest node and arc to be included in the minimum spanning tree may be broken arbitrarily.(1)

LP FORMULATION

A LP formulation was created when it was found difficult to relate the value of connecting a node with the cost of building a link. It is possible to do this in the spreadsheet formulation but we selected to use Lingo instead of Excel.

The formulation maximizes the total ADTs of the signalized intersections connected. A maximum budget variable was introduced that limited the amount spent on the interconnections. A constraint that set the build variable to zero if neither of a links nodes are connected is used. This in conjunction with a node connected binary variable that can only be set if a link is connected to it are the heart of this program. Setting the node connected variable increases the objective function by the value of the intersection ADT. The building of the link that connects the node spends part of the budget. The balancing of these two provides the desired result.

In testing of this formulation it was found possible that islands of connected nodes could be created. This was especially evident as the budget was reduced in the model. The results need to be examined for these islands. If they are present additional constraints can be added to break them up. The constraint would set the number of links connected to the nodes in question equal to the number of nodes in question. Since each link after the first link connects one additional node this will insure that these nodes are all connected. This constraint can be added for the total number of originally unconnected nodes equaling the number of built links. This will not eliminate the problem as it can force multiple connections in a path of nodes. however, It will reduce the probability of islands in most cases.

(1)*A minimum spanning tree algorithm was used. This algorithm is on page 443 from Operations Research Applications and Algorithms 3rd Edition by Wayne L. Winston. This algorithm was applied using an Excel spreadsheet.*

```
!Minimum Spanning Tree with Knapsack on node values;

sets:
link / 1..16 / : nodea,nodeb,cost,build ;
nodes / 1..13 / :adt,nc ;
endsets

data:
budget=20000;
adt=0,1,1.5,4,0,2,4,5,0,3,2.5,5,0;                        !Input the value of a node;
nodea=1,2,3,3,4,5,6,7,6,8,9,10,11,12,1,5;                 !Input the first node # on eac
nodeb=2,3,4,6,7,6,7,8,10,12,10,11,12,13,9,13;             !Input the second node # on ea
cost=5000,4600,6672,4562,9800,9720,5500,9000,5491
     ,6400,6250,5280,5660,6832,0,0;                       !Input the cost of a arc;
enddata

max=@sum(nodes(i):nc(i)*adt(i));                   !Maximize value of nodes connected;
budget>@sum(link(j):cost(j)*build(j));             !Budget Constraint;
@for(link(l)|l#gt#14:build(l)=1);                  !Set existing links to built;


@for(link(l)|l#le#14:                              !Loop for all links except those buil
     build(l)<@sum(link(k)|k#ne#l#and#nodea(k)#eq#nodeb(l):build(k))+
              @sum(link(m)|m#ne#l#and#nodea(m)#eq#nodea(l):build(m))+
              @sum(link(n)|n#ne#l#and#nodeb(n)#eq#nodea(l):build(n))+
              @sum(link(p)|p#ne#l#and#nodeb(p)#eq#nodeb(l):build(p));
    ! Sets build status to less than sum of adjacent links.  Build will equal 0
    ! no adjacent links are built;
     build(l)<nc(nodea(l));
     build(l)<nc(nodeb(l));                         !Build constraints;
     @bin(build(l)));                               !Declare build status binary;



@for(nodes(i):@bin(nc(i)));                         !Declare node connetion status binar
@for(nodes(i):
     nc(i)< @sum(link(m)|nodea(m)#eq#i:build(m))+
            @sum(link(n)|nodeb(n)#eq#i:build(n)));     !Set nodes connected statu
end

  ! NOTE:  Check results for "islands" of links. (ie two or more links not conne
  !        main set of links.  If found add a new constraint to eliminate the is
```

ASSUMPTIONS The main assumption that we have made is that similar methods of communication will be used on future phases of this project as on the first phase. There has been the release of some new technology that would allow using line of sight radio to transmit the information. This is probably too progressive for Multnomah County especially after so much has been invested in a hardwire architecture.

Another assumption is that the links must go along the street grid. This is a constraint imposed by the cost and difficulty in getting easements to go across private property. This changes the problem from a Traveling Salesman Problem to a Minimum Spanning Tree Problem.

Along with this we have assumed that if there is conduit underground the wire will be installed in it not overhead. In some cases both options are available. The cost of maintenance of an underground system is lower after it is once installed. While this will not justify the cost of installing conduit it will justify the extra cost of pulling wire in the conduit.

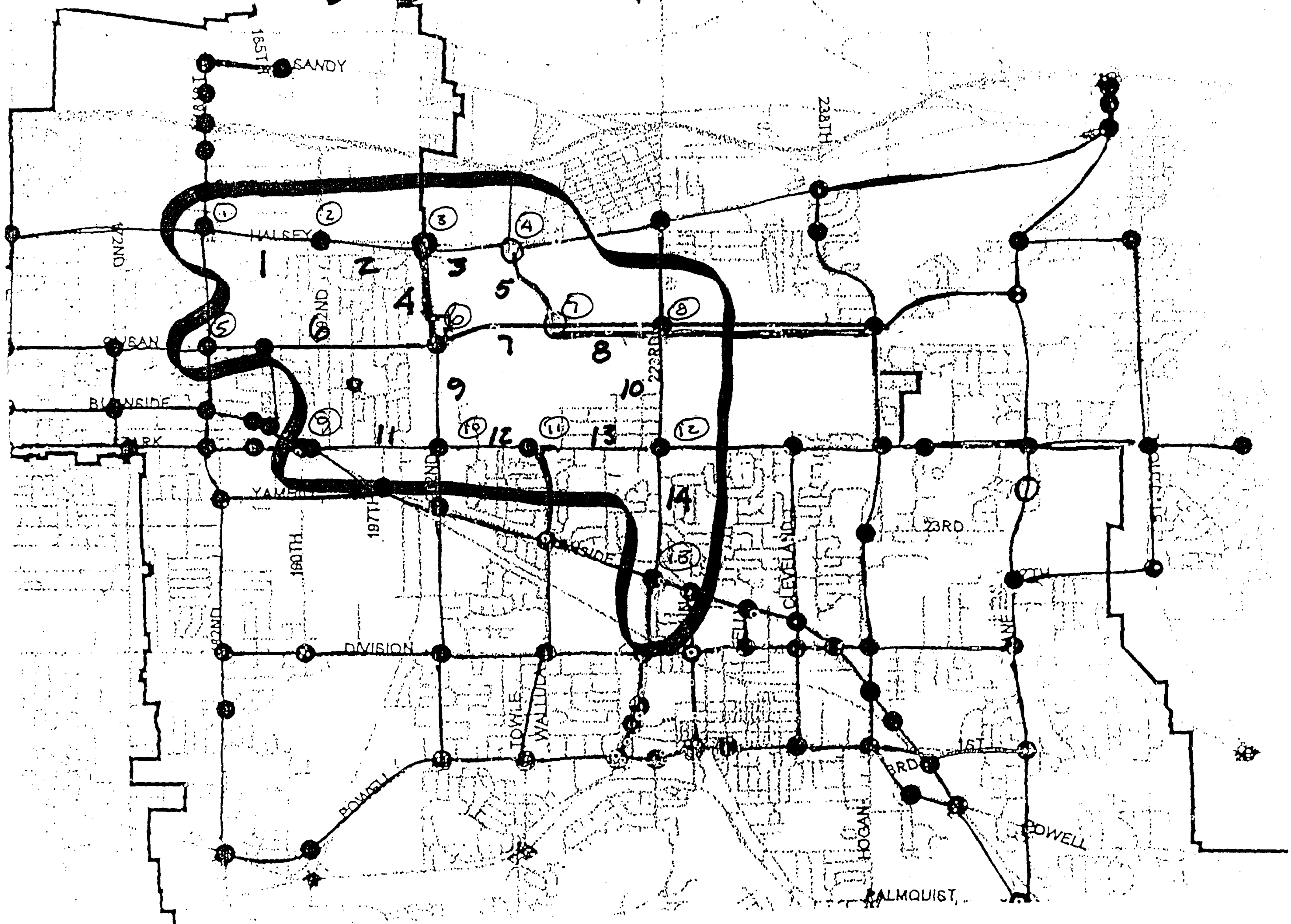
The value of connecting a signal was assumed to be proportional to the traffic flow through the signal. This assumption may no be valid. The value of connecting a signal may be more related to the number of consecutive signals connected along the travel route. The late date of this realization and the difficulty in modeling this relationship prevented us from revising our model.

DATA SOURCES

The costs from the first phase of construction of the signal interconnect project were used to provide a simplified cost per lineal foot of road for wiring. The connection costs at each controller cabinet were ignored. Also ignored were the costs of the signal controller upgrades needed to add communication capabilities. These costs are fixed and will not effect the results. But the cost/ foot prices will give an overall project cost that is low compared to actual total project costs.

There were two communication relays installed as part of the first phase. These relay the data from the network to a control center in downtown Portland. The cost of these were ignored. The number of these communications relays installed will effect the results of the spanning tree problem. Every communication relay installed eliminates the need for one link. Since the cost of these relays is much greater that the cost of any individual link there is no cost saving by installing more. When the program was run assuming phase 1 work completed one link along Burnside between Wallula and 223 was eliminated due to the extra communication relay already installed.

SOLUTION 4 DATA SET



The two methods of installation are overhead wire and wire in conduit. The conduit option is only used where the power has been underground. In anticipation of this the county has been installing conduit for the interconnect project whenever there has been an undergrounding project. Therefore the cost of $4.00 per foot for wire in conduit doesn't include the cost of the conduit. This was done by dividing the traffic control and other miscellaneous costs between the road or link lengths were taken from the Multnomah County Integrated Road List data base. This data base has the length of each section of road from intersection to intersection. The total of these between signals gives us the feet of wire needed to connect the signals.

The possible link routes were selected by reviewing the existing conduit locations with the signal electricians and as built plans. The overhead routes were selected by quick drive by reviews of power pole routes. The routes following the arterials were usually selected.

Multnomah County annually has the traffic counted on most arterials at several locations annually. This data is collected by mechanical or electrical counters temporarily installed on the roads. This data is called the ADTs for Average Daily Traffic. These counts were used to generate most of the ADT data in the LP formulation. This data was also adjusted due to anticipated opening of a new road. The new section of road, 207th from Halsey to Glisan, will be opened in early 1998. The data was also adjusted due to planned closing of freeway entrances during reconstruction of highway 84. These adjustments were only rough projections of what the changes in traffic will be. The magnitude of the changes is limited by the capacity of the existing roads.

Results

When the minimum spanning tree was run on the system assuming no prior construction the attached map shows the results. The cost calculated was almost identical to the cost of the system with the phase I construction installed. This was due to the costs of the extra communications relay not being included. The cost of the signal relay is almost double the cost of any single link. Therefore there is no potential savings by adding more relays. The costs for both systems was about $259,000. This shows that not much potential for a minimum cost system has been lost by the route selection method used for the initial project.

The results of the minimum spanning tree and knapsack LP formulation are attached. The heighten map shows the reduced area modeled due to the student version limitations. The big black line is the limits of the area modeled. The green highlights are

TRAFFI	STREET	BUILD	LINK#	LENGT	COST/FT	COST	NODE#	NODE#	
17300	GLISAN	0	120	3500	$2.00	7000	79	16	0
18410	DIVISION	0	46	3564	$2.00	7128	41	54	0
?	BURNSIDE	0	52	1820	$4.00	7280	84	14	0
12500	HOGON/242	7357.8	71	3678.9	$2.00	7358	44	45	0
?	Eastman/223	0	39	1863.8	$4.00	7455	24	25	0
?	182nd	7529.5	1	3764.76	$2.00	7530	1	2	0
18,590	KANE	7550	85	3775	$2.00	7550	57	58	0
?	202nd	0	21	3843.8	$2.00	7688	13	14	0
7540	Eastman/223	0	41	1980	$4.00	7920	25	26	0
23210	182nd	0	5	4012.8	$2.00	8026	3	4	0
6330	KANE	0	75	4028.6	$2.00	8057	52	53	0
18000	KANE	8194	87	4097	$2.00	8194	58	63	0
?	HOGON/242	0	65	4107.8	$2.00	8216	41	42	0
?	POWELL	0	4	4314	$2.00	8628	11	12	0
?	TOWEL	0	31	4371.8	$2.00	8744	19	20	0
	TOWEL	0	33	4440.5	$2.00	8881	20	21	0
?	GLISAN	0	223	2250	$4.00	9000	100	28	0
?	POWELL	0	20	2400	$4.00	9600	36	48	0
	CLEVELAND	0	59	4899.8	$2.00	9800	38	39	0
16520	207TH	0	200	2450	$4.00	9800	99	100	0
15300	HALSEY	0	130	5100	$2.00	10200	70	8	0
?	STARK	10560	98	5280	$2.00	10560	56	61	0
6850	POWELL	0	18	2650	$4.00	10600	35	36	0
19190	HALSEY	0	138	5400	$2.00	10800	29	46	0
11640	Troutdale	0	89	5471	$2.00	10942	61	62	0
13000	GLISAN	0	122	5500	$2.00	11000	16	28	0
7500	POWELL	0	16	2800	$4.00	11200	32	35	0
9710	GLISAN	0	124	5600	$2.00	11200	28	44	0
?	HALSEY	0	136	5600	$2.00	11200	17	29	0
6200	HALSEY	0	140	7900	$2.00	15800	46	63	0
?	TROUTDALE	0	91	8543	$2.00	17086	59	61	0
	HALSEY	0	237	4277	$4.00	17108	99	29	0

the resulting minimum spanning tree. This has a very close relation to the spreadsheet minimum spanning tree solution. The differences are caused by the selections of which nodes are included in the data set.

Future work

The models used can be expand and refined. One refinement would be to change the maximization function in the LP formulation to maximize the totaled ADT of the as traveled routes between the signals interconnected. This is a better approximation of the value of connecting signals. The expansion of the LP formulation to include the whole system may be of limited value since much of it is already built. The formulation should be expanded to encompass all of the system that is north of Division street. This is were most of the unconnected signals are left.

The results of this study must be considered as preliminary estimates to be revised and refined as more traffic studies and information become available. The traffic counts will vary greatly over time. Future change depends on so many different factors the greatest of which is the politics of East Multnomah County.

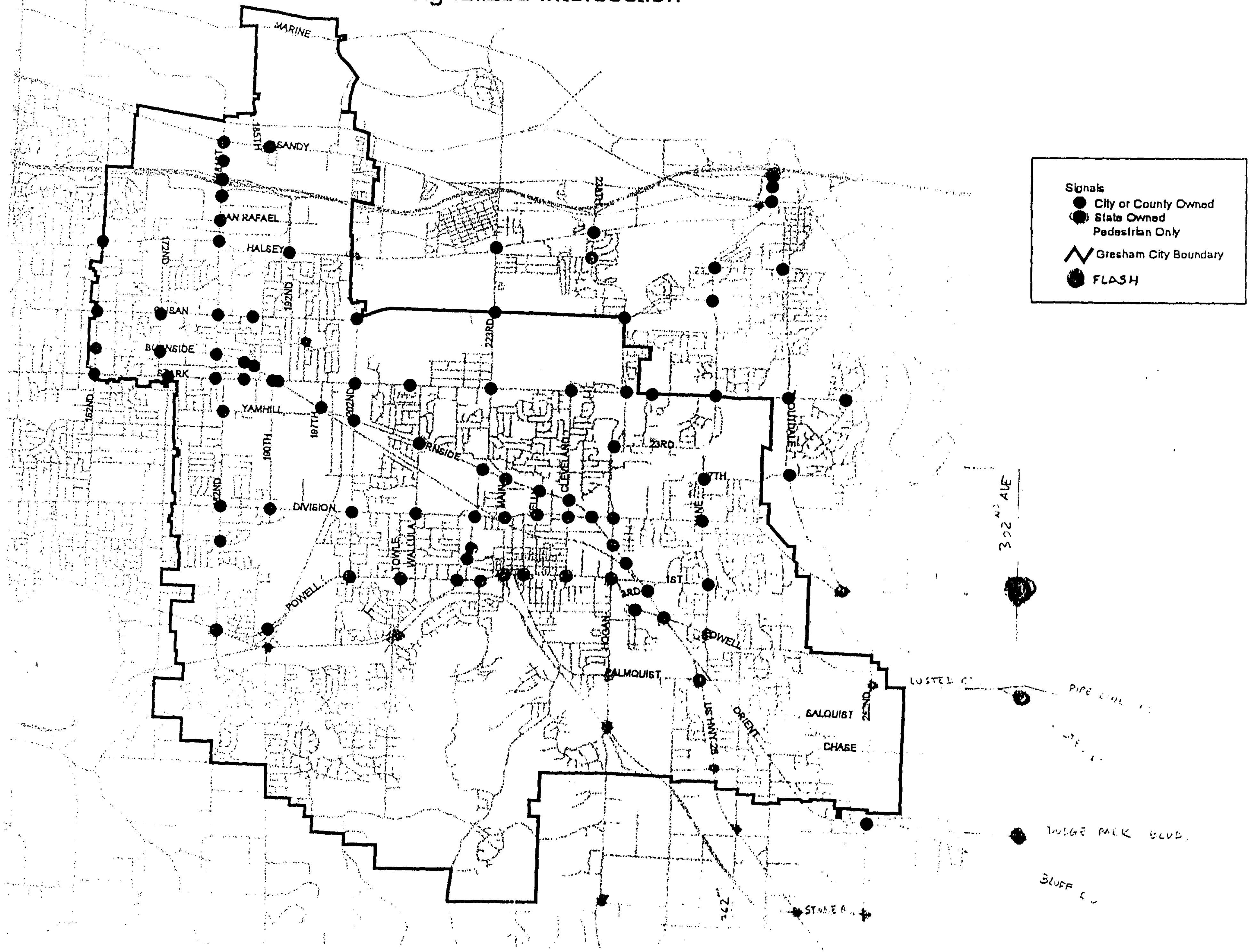
TRAFFI	STREET	BUILD	LINK#	LENGT	COST/FT	COST	NODE#	NODE#	
	HALSEY	4600	134	2300	$2.00	4600	80	17	0
?	STARK	4604	78	2302	$2.00	4604	66	5	0
?	BURNSIDE	0	104	2302	$2.00	4604	81	6	0
14500	GLISAN	0	116	2310	$2.00	4620	78	7	0
?	POWELL	4660	24	2330	$2.00	4660	36	51	0
?	BURNSIDE	0	72	1175	$4.00	4700	40	47	0
22590	POWELL	4800	8	2400	$2.00	4800	18	22	0
14220	BURNSIDE	0	66	1220	$4.00	4880	77	40	0
?	COCHRANE	4900	48	2450	$2.00	4900	55	59	0
10480	HALSEY	5000	132	2500	$2.00	5000	8	80	0
?	STARK	5005.4	92	2502.7	$2.00	5005	39	43	0
14870	BURNSIDE	0	60	1290	$4.00	5160	34	37	0
9680	BURNSIDE	5216	58	1304	$4.00	5216	26	34	0
11721	STARK	5280	86	2640	$2.00	5280	15	21	0
?	Eastman/223	5290	47	2645	$2.00	5290	28	29	0
?	STARK	5301	76	2650.5	$2.00	5301	67	66	0
?	BURNSIDE	0	102	2651	$2.00	5302	68	81	0
?	GLISAN	0	114	2652	$2.00	5304	69	78	0
12300	202nd	5417.2	19	2708.6	$2.00	5417	12	13	0
18280	TOWEL	0	29	2708.6	$2.00	5417	18	19	0
?	MAIN	5417.2	49	2708.6	$2.00	5417	31	33	0
?	CLEVELAND	5417.2	55	2708.6	$2.00	5417	35	73	0
8900	STARK	5417.2	100	2708.6	$2.00	5417	61	60	0
1203	202nd	5491.2	25	2745.6	$2.00	5491	15	16	0
5650	GLISAN	5500	222	2750	$2.00	5500	16	100	0
?	KANE	5607.4	83	2803.7	$2.00	5607	56	57	0
?		5620	128	2810	$2.00	5620	58	62	0
?	STARK	5660	88	2830	$2.00	5660	21	27	0
14100	KANE	5839.6	77	2919.8	$2.00	5840	53	54	0
10800	STARK	5945	90	2972.5	$2.00	5945	27	39	0
	STARK	5966	96	2983	$2.00	5966	74	56	0
?	DIVISION	5987.6	28	2993.8	$2.00	5988	3	71	0
4003	POWELL	6000	22	3000	$2.00	6000	48	53	0
1775	Yamhill	0	50	3000	$2.00	6000	4	84	0
14100	BURNSIDE	6020	74	3010	$2.00	6020	52	50	0
19190	DIVISION	0	34	3014.9	$2.00	6030	19	25	0
16220	BURNSIDE	6040	54	3020	$2.00	6040	14	20	0
?	181st	6072	13	3036	$2.00	6072	7	8	0
	162	6072	129	3036	$2.00	6072	69	70	0
15020	BURNSIDE	6180	56	3090	$2.00	6180	20	26	0
16810	POWELL	6200	2	3100	$2.00	6200	1	11	0
	STARK	0	84	3125	$2.00	6250	76	15	0
19850	HOGON/242	6399.4	69	3199.7	$2.00	6399	43	44	0
?	Eastman/223	6400	45	3200	$2.00	6400	27	28	0
?	CHERY P	0	126	3300	$2.00	6600	44	57	0
?	DIVISION	6642	30	3321	$2.00	6642	71	13	0
15980	HALSEY	6672	236	1668	$4.00	6672	17	99	0
5000	HOGON/242	6769	67	3384.5	$2.00	6769	42	43	0
	Eastman/223	0	43	3416	$2.00	6832	26	27	0
?	KANE	0	81	3421.5	$2.00	6843	55	56	0

ATTACHMENTS

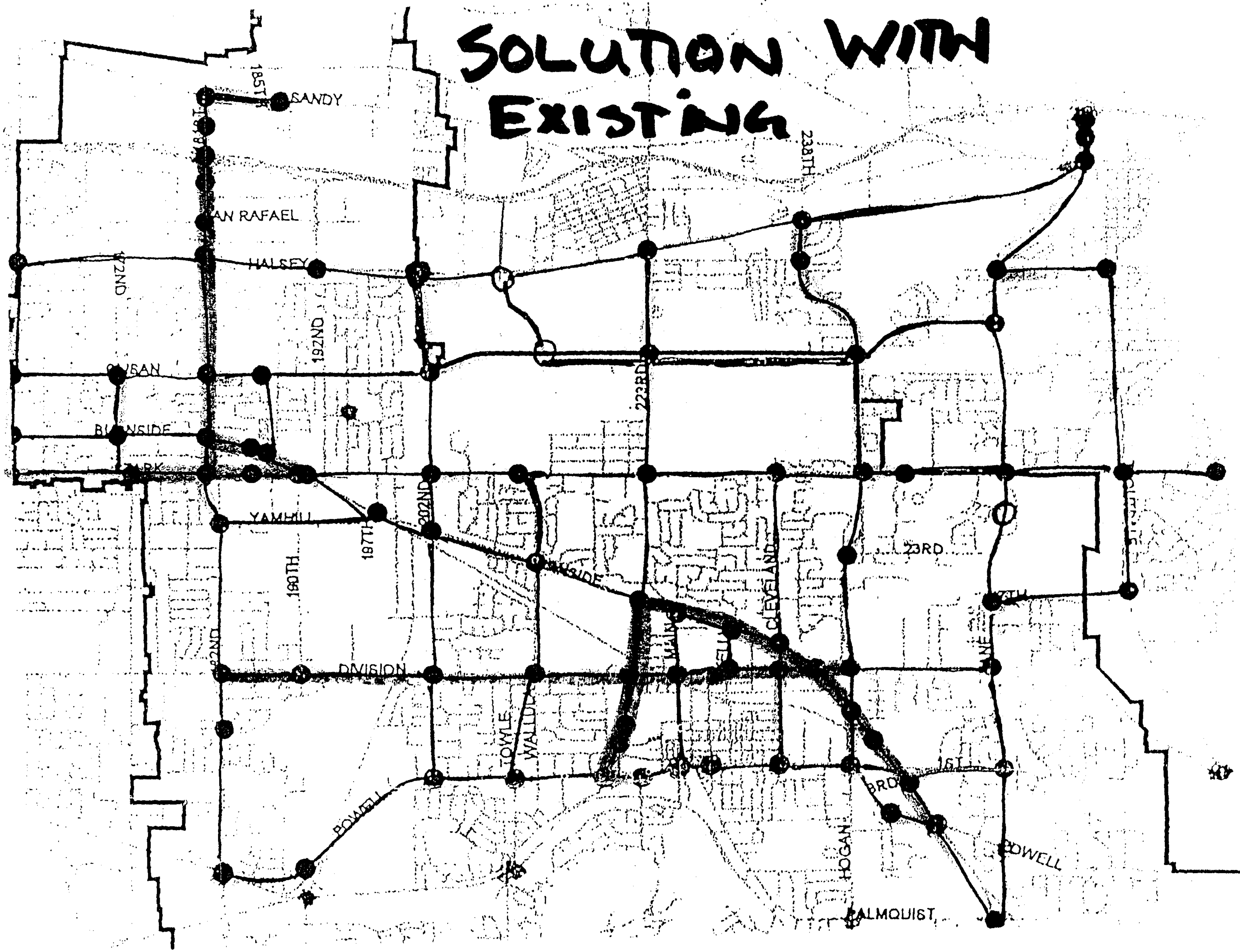
- SIGNALIZED INTERSECTION
- AN ARTICLE ABOUT THE PROBLEM
- UNDERGROUND CONDUIT
- MINIMUM SPANNING TREE SOLVER
- LINK NUMBERS
- NODE NUMBERS
- SOLUTION 1
- SOLUTION WITH EXISTING
- DATA SPREADSHEETS
- SOLUTION AND DATA SET
- L P SOLUTION
- SAMPLE OF DATA

		359577	5					1	2
			5	111	6	2		0	6
TRAFFI	STREET	BUILD	LINK#	LENGT	COST/FT	COST	NODE#	NODE#	
			0			0	0	6	6
26530	BURNSIDE	600	108	300	$2.00	600	82	83	0
33100	HALSEY	800	142	400	$2.00	800	63	64	0
35630	CLEVELAND	992.6	57	496.3	$2.00	992.6	73	38	0
40600	HALSEY	1020	144	510	$2.00	1020	64	65	0
39400	Eastman/223	1204	37	301	$4.00	1204	23	24	0
2640	DIVISION	1320	44	660	$2.00	1320	77	41	0
2541	181st	1689.6	17	844.8	$2.00	1690	9	10	0
21940	HOGON/242	1689.6	63	844.8	$2.00	1690	40	41	0
22610	DIVISION	1721.2	42	860.6	$2.00	1721	73	77	0
?	STARK	1721.2	94	860.6	$2.00	1721	43	74	0
22550	181st	1774.2	15	887.1	$2.00	1774	8	9	0
?	KELLY	1980	53	990	$2.00	1980	72	37	0
22550	POWELL	2040	14	510	$4.00	2040	31	32	0
?	181st	2090.8	9	1045.4	$2.00	2091	5	6	0
?	162	2092	127	1046	$2.00	2092	67	68	0
?	172	2092	133	1046	$2.00	2092	66	81	0
?	STARK	2333.8	80	1166.9	$2.00	2334	5	75	0
?	BURNSIDE	2420	110	1210	$2.00	2420	83	76	0
21460	DIVISION	2429	36	1214.5	$2.00	2429	25	33	0
20200	BURNSIDE	2440	106	1220	$2.00	2440	6	82	0
19710	DIVISION	2608.4	38	1304.2	$2.00	2608	33	72	0
19519	GLISAN	2720	118	1360	$2.00	2720	7	79	0
18020	STARK	0	82	1365	$2.00	2730	75	76	0
17910	Eastman/223	2745.6	35	686.4	$4.00	2746	22	23	0
199900	181st	2777.2	7	1388.6	$2.00	2777	4	5	0
20500	DIVISION	2777.2	40	1388.6	$2.00	2777	72	73	0
?	182nd	2893.4	3	1446.7	$2.00	2893	2	3	0
?	MAIN	2904	51	1452	$2.00	2904	33	34	0
?	202nd	3030	23	1515	$2.00	3030	14	15	0
10220	162	3220	131	1610	$2.00	3220	68	69	0
16160	172	3220	135	1610	$2.00	3220	81	78	0
15900	181st	3220.8	11	1610.4	$2.00	3221	6	7	0
5901	POWELL	3480	10	870	$4.00	3480	22	30	0
?	POWELL	3560	12	890	$4.00	3560	30	31	0
5500	BURNSIDE	3576	68	894	$4.00	3576	47	48	0
16560	HOGON/242	3727.6	61	1863.8	$2.00	3728	36	40	0
?	HOGON/242	3727.6	73	1863.8	$2.00	3728	45	46	0
?	DIVISION	3917.8	32	1958.9	$2.00	3918	13	19	0
	BURNSIDE	0	64	990	$4.00	3960	38	77	0
	KANE	3960	79	1980	$2.00	3960	54	55	0
13870	BURNSIDE	0	62	1050	$4.00	4200	37	38	0
24610	BURNSIDE	4200	112	2100	$2.00	4200	76	84	0
18590	POWELL	4500	26	2250	$2.00	4500	51	50	0
?	202nd	4561.8	27	2280.9	$2.00	4562	16	17	0
4710	POWELL	4600	6	2300	$2.00	4600	12	18	0
	BURNSIDE	4600	70	1150	$4.00	4600	48	50	0

Signalized Intersection



SOLUTION WITH EXISTING



METROEAST

News of Gresham, east Portla Troutdale, Sandy, Fairview, Wo Village and other communities east Multnomah County a north Clackamas Coun

N.E. 181st: the slowest drive in east

■ Drivers trying to make a left turn on the arterial also are a source of many accidents, a problem concerning officials

By KARA BRIGGS
of The Oregonian staff

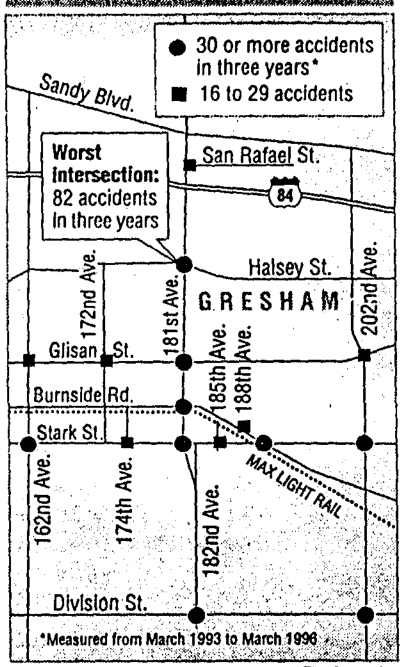
It's not your imagination if the seconds seem to turn into minutes as you wait for the light to change at an intersection on Northeast 181st Avenue. During rush hour a motorist can wait through two or three red lights to get through one of those intersections.

Traffic engineers say Northeast 181st Avenue is the most heavily traveled arterial in east Multnomah County. Not only is it the street that most Portland residents take to get to Mount Hood and the primary truck route, it is also the primary route to Interstate 84 for most of east Multnomah County.

With 44,000 vehicles driving it every day, 181st has double the traffic of the next most busy street east of Portland — Northeast 242nd Avenue.

"It's not just a congestion issue, but a safety issue," said Dave Rouse, transportation manager for Gresham. "If you're waiting beyond 40 seconds at a red light you start to get antsy. You start to take chances and you start to dart out into traffic."

BAD INTERSECTIONS



The Oregonian

Five of the 10 worst intersections in Gresham, based on number of traffic accidents, are on 181st Avenue. The worst is 181st and Halsey Street, followed by Stark, Division, Burnside and Glisan.

In the last three years there have been 329 accidents on the arterial, many stemming from left turns on or off 181st Avenue.

The left turns also force traffic to stop. Signals slow traffic even more. During the evening commute southbound traffic on 181st frequently backs up onto the exit ramp of Interstate 84 and onto the freeway.

The avenue gets a D for how easily traffic flows on 181st, Rouse said. For people who want to turn left on or off 181st without a traffic signal, the avenue gets an F.

Despite the miserable traffic jam, business and industry along the avenue are clamoring to expand or build outlets. Albertsons Food and Drug and Trailblazer Food Products have expanded; Henningsen Cold Storage Co. has built a distribution center in the Banfield Corporate Park. A McDonald's restaurant and two hotels are planned.

Business owners want to tap into the market of people trapped in their cars on 181st Avenue and the 64,900 passing by on Interstate 84.

The owners of the Burger King and Holiday Inn Express on Northeast 181st near Interstate 84 want Gresham to delay issuing permits for new construction until the city thoroughly studies ways to improve traffic flow on 181st Avenue.

Holiday Inn Express staff urge guests to reach 181st Avenue by driving south on Northeast 178th to San Rafael Street, which has a traffic light on 181st Avenue.

"We have some moral concerns and I think the city needs to have some serious moral concerns," said Don Gale, the regional manager for Hospitality Association, which owns the Holiday Inn Express.

City officials have talked about installing a median on 181st Avenue to block left turns, forcing drivers to turn at traffic signals.

Gale and Larry Lazar of the Westwind Group, which owns Burger King, oppose that plan and have offered to pay for a more complete traffic study than they think the city has done. They have asked the city to install a traffic light at the entrance to their businesses; they say a median would hurt access.

Rouse said another traffic lig would probably back traffic up ev farther on to Interstate 84 by ma ing 181st even slower.

The city has begun coordinati the traffic signals to improve flow.

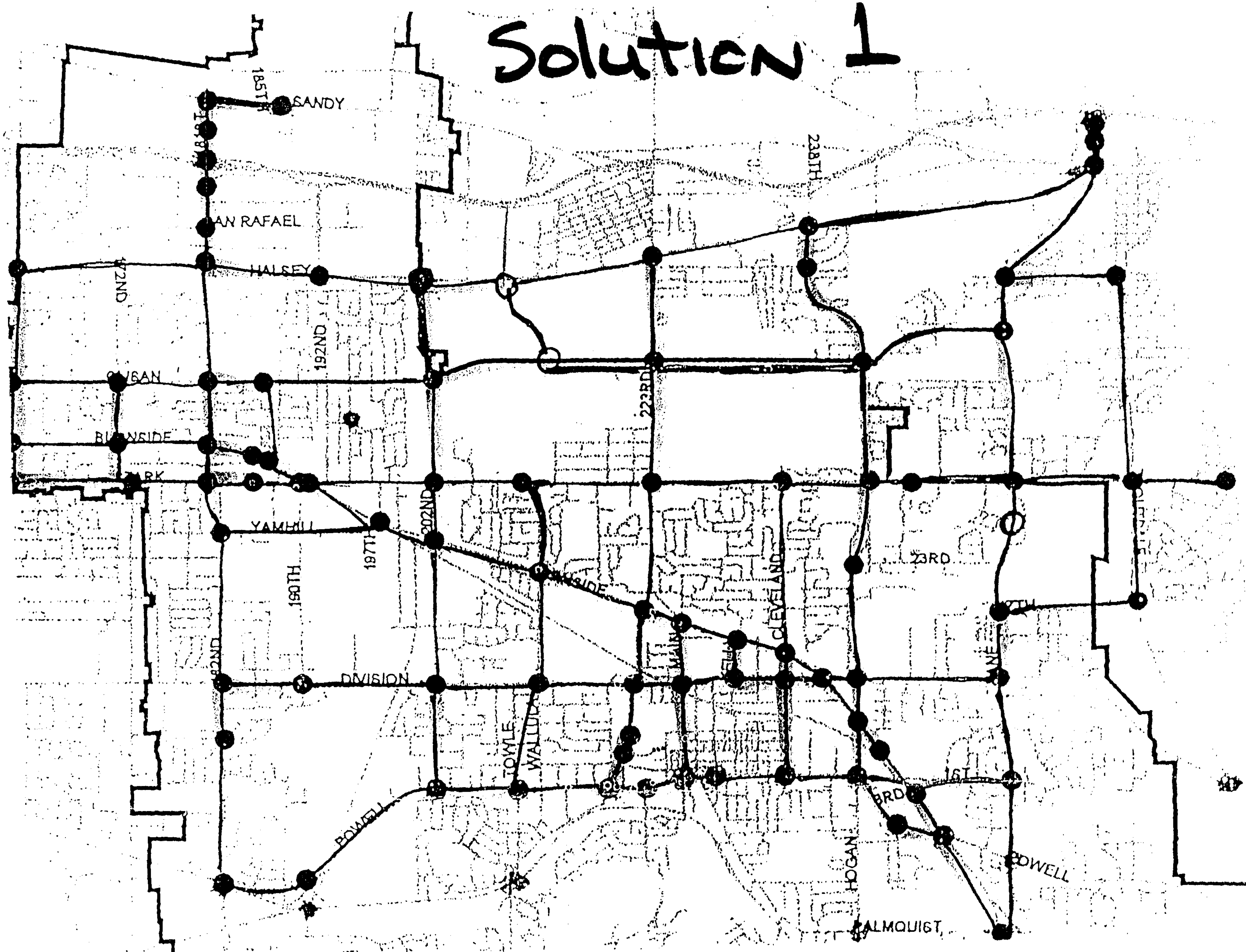
Ultimately, Rouse said that 18 needs two more lanes and a left tu lane to keep traffic from getti backed up. But he said the city capital improvement budget is bei spent on repairs to arterials.

Traffic experts disagree abo how much the new Northeast 207 Avenue interchange on Interstate will alleviate traffic on 181st.

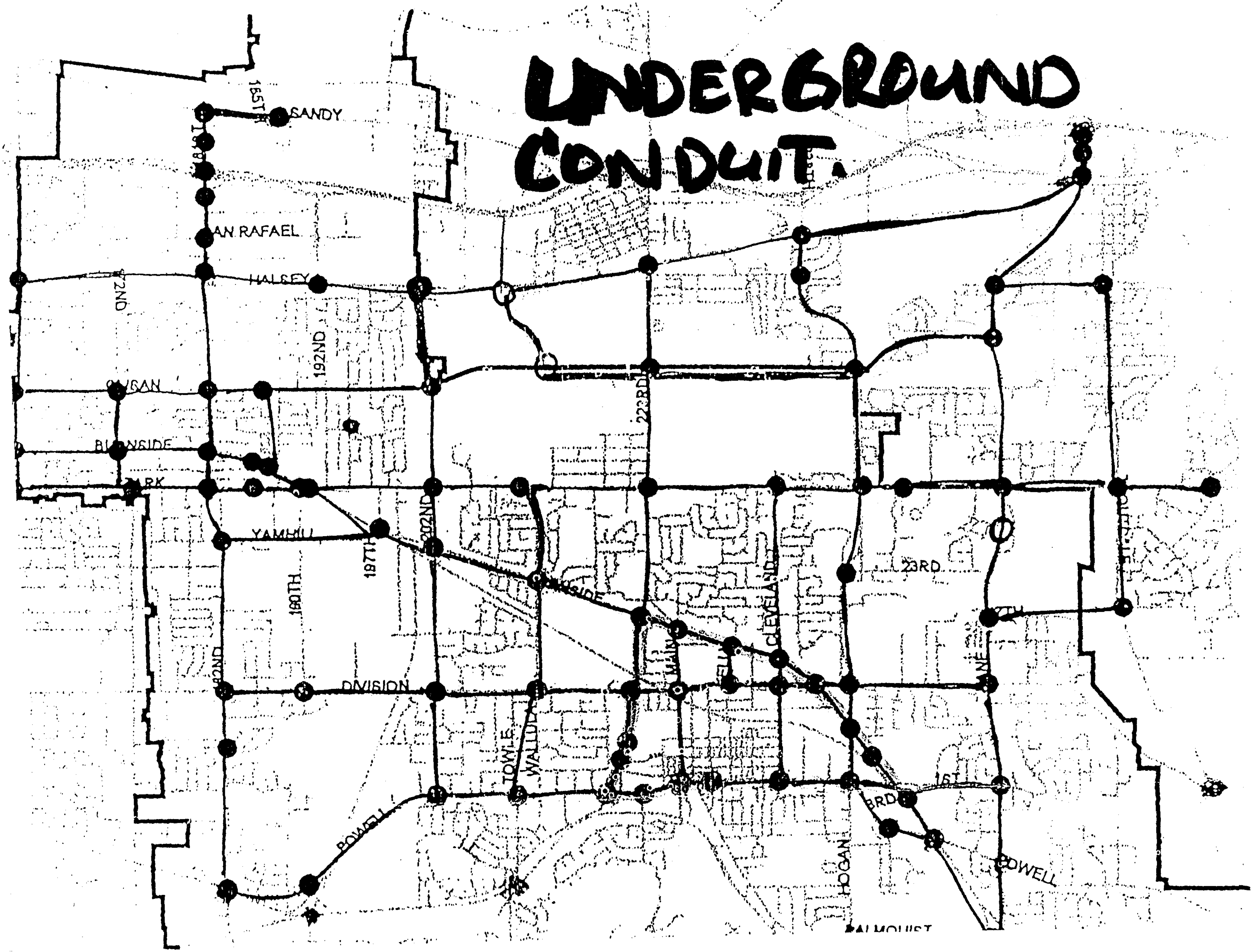
Rouse thinks it will temporari reduce traffic. But in the long ru new construction in the Columb South Shore and Northeast Airpo Way will return the traffic to 181 Avenue.

Traffic from other sources is on likely to increase the cars ar trucks on 181st Avenue. Metro pro ects the population of the four ea Multnomah County cities projecte to grow by 38,681 people in the ne 20 years. And with most of the pr fessional jobs still in downtow Portland, and 51 percent of the ne jobs in Washington County, mo drivers will soon be driving 181 Avenue to Interstate 84.

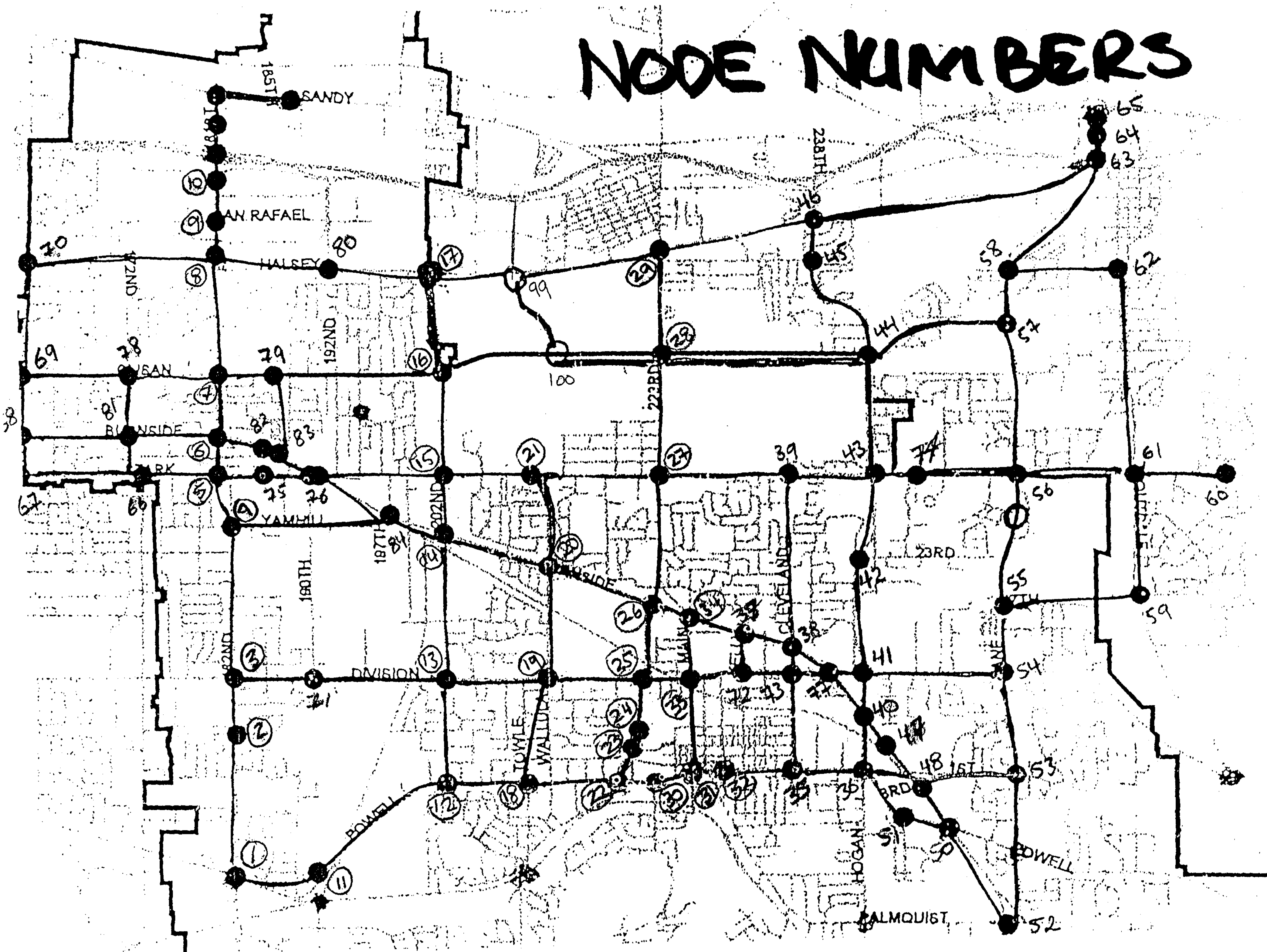
Solution 1


SANDY
185TH
AN RAFAEL
HALSEY
172ND
192ND
BURNSIDE
YAMHILL
197TH
202ND
223RD
238TH
23RD
DIVISION
TOWLE
WALLULA
CLEVELAND
MAIN
HOGAN
POWELL
POWELL
1ST
3RD
ALMQUIST

UNDERGROUND CONDUIT.



NODE NUMBERS



Minimum Spanning Tree Solver

ARC #	BUILD	COST	NODE#	NODE#					
				1	2	5	3	6	0
1	YES	10	1	2	0	0	0	0	0
2	YES	30	2	5	0	5	0	0	0
3	YES	59	3	5	0	0	3	0	0
4		62	1	5	0	0	0	0	0
5	YES	75	2	6	0	0	0	6	0

Sum of Column below except first two which are just the first two nodes

Arc Descriptor

results

Input Data sorted from cheapest or shortest arc to longest arc

zeros

The formula shown below is in G5 and should be copied to all cells in the box.

```
"=IF(AND(SUM($F5:F5)=0,SUM(G$4:G4)=0),
IF(ISERROR(MATCH($D5,$E$2:F$2,0)),
IF(ISERROR(MATCH($E5,$E$2:F$2,0)),0,$D5),
IF(ISERROR(MATCH($E5,$E$2:F$2,0)),$E5,0)),0)
```

ALGORITHM

Step 1 Select shortest arc connecting two nodes.

Step 2 Select shortest arc connecting a node to any node already connected.

Step 3 Repeat Step 2 until all nodes are connected.

Note: Any ties in length are broken by entry order.

LINK NUMBERS