Sewer Line Planning: Choosing Optimal Routings

Class Project

for

Math 411

Fall 1996

University of Tennessee, Knoxville

ABSTRACT

The objective of this project is to investigate how alternative sewer line plans might be implemented to best meet the requests of subscribers. This problem is derived from a real situation which arose in the Lyons Bend area of Knox County when the Knoxville Utilities Board (KUB) submitted plans to the community for running sewer lines to various subdivisions within the area.

Several different criteria such as maximization of the return to KUB, maximization of the fraction of satisfied customers, and minimization of the total cost were investigated during the algorithm developing. Finally, a code was created using the second criteria.

The program is written in C code in the UNIX environment. Production runs made indicated that the program gives a reasonable output which satisfy the KUB initial requirements. The program develops and implements methods to decide whether a sewer line should be run down a particular street or not, depending upon the interest of subscribers on that street and the associated costs to KUB and the subscriber for this service.

INITIAL REQUIREMENTS

After contacting KUB, the following information was obtained:

1. Individual subscribers (e.g. households) are free to choose whether they desire sewer line service to their homes or not.
2. However, each household would have to pay a substantial fee to be connected, but if a line was run by their house and they chose not to be connected, they would still be charged a fee, though smaller.
3. All homes that could be connected to a line would be charged monthly bills depending upon water usage, even if they did not use the sewer service.
4. The desire of KUB is to run as many meters of sewer line as possible, even if not everybody along the line wants to be connected, as it would make the connection easily obtainable in the future. At the same time, running any particular line must be profitable for KUB.
5. Initial cost of pipe is covered by people who want this pipe to run to their houses.
6. The cost of lines for the customer is not fixed. It is approximately $20–30 /ft for sandy soil and $50–60 /ft for rocky soil. The cost also varies depending on whether the

line is being run through country roads and cornfields, or city streets and highrise buildings. This cost covers both the cost of materials and excavation.

7. Example: for 20 houses, and 4 do not want service with 1000 ft of $ 50/ ft pipe laid. Therefore, 4 houses would pay $ 1000 while remaining $ 46,000 would be evenly divided by the 16 houses that want the service. Therefore, KUB risks nothing (kind of like the Communist Party in the old Soviet Union). After the pipes are laid, all new income is revenue. But, there is normally a minimum cap set for those who want service, and this is approximately $ 6000. So, in densely populated areas, KUB makes money just by laying the pipes.

8. The main KUB concern is that at least 50 % of the houses must want service before considering laying a new line, though this percentage is viewed here as a variable.

9. The social status of the neighborhood is taken into consideration also, although we do not exactly know how.

Initial problem constraints are quite obvious. First of all, we must run a line to point A before running it to point B (see Figure 1). Then, the cost per meter of running a sewer line is high enough that we restrict consideration to only subdivisions where 50% of households or more are ready to pay for it. The third constraint is the cost of sewer installation in a household.

ALGORYTHM DEVELOPMENT

In the process of developing the algorithm for solving the problem described above, an underlying model framework for analyzing different possibilities was established. We started from defining two categories of customers: satisfied and unsatisfied. The first class were those who wanted the service and got it and those who did not want the service and did not get it. Consequently, the second class would be those who did not want the service but, nevertheless, got it and those who wanted it but did not get it. An unresponsive or apathetic customer is neither satisfied nor unsatisfied, and, therefore, is not considered in the calculation

Then, two obvious possibilities of the algorithm we faced were:

1) to minimize the number of unsatisfied customers;
2) to maximize the number of satisfied customers.

Assumptions of the algorithm are as following:

1. The pipe layout is a tree structure, and contains no loops.
2. Multiple connections to any already existing line are expected to be separate projects. However, the program is

able of handling multiple trees as a single project, if the various trees are connected by uninhabited links to a common root. This requires only a few extra lines in the map data file and does not affect the addressing of the houses.

3. The pipe is laid over the full segment of a link.

3. Due to the fact that the costs involved in the sewer line construction are variable and beyond our ability to predict them, cost considerations are out of the scope of this project.

4. Three possible responses to the survey are:

W = customer wants to be connected.

D = customer does not want to be connected.

N = customer did not respond or does not care.

5. The major criteria of the program is to maximize the customer satisfaction ratio.

THE PROGRAM

The program is designed to run from command line arguments of the form:

UNIX> model mapfilename surveyfilename tresholdratio.

- mapfilename is the name of the required input file containing the description of the tree structure and location of the houses within the tree. The file name can be arbitrarily named.

– surveyfilename is the name of the required input file containing results of the survey. The file name can be arbitrarily named.

tresholdratio is the satisfaction ratio that he model is required to meet in order to consider the generated level of satisfaction. The ratio should be in the form of an integer equivalent to:

```
                         number satisfied
ratio = --------------------------------------- * 100
           number satisfied + number unsatisfied
```

The model takes two input files and generates the best possible map from them, basing its decisions on the following criteria (in order of priority):

1. The final pipe layout must meet or exceed the “threshold satisfaction ratio” specified at run time. If not, the program simply reports the maximum satisfaction ratio that could be achieved, and exits.
2. The final pipe layout should be optimized to maximize the customer satisfaction ratio.
3. Given that two or more different possible pipe layouts will equally produce the maximum possible satisfaction ratio. It is considered desirable for the program to choose from

these layout options the one that specifies the greatest length of pipe.

In actuality, the program chooses the layout that specifies connection to the greatest number. This should be functionally equivalent if empty housing lots are considered “no response” votes, but may not be equivalent if one or more branches of the pipe pass through a region that contains uncharacteristically sparse addresses.

The satisfaction ration is represented as an integer in the range from 0% to 100% which is considered sufficient and acceptable.

Houses are clustered in groups of one or more, and all houses in a common group are considered to be geographically situated such that it is impossible to run pipe to one house in the group without it being available to all of the houses in the group.

The two data files are likely to be generated (or at least maintained) by different individuals. The map data file must be the responsibility of a “project engineer” or some other person with decision making ability, since the grouping of the houses requires a large number of judgment calls and is order dependent. The survey data file can be generated by a data entry person without knowledge of the map structure, since it is simply a tabulation of addresses and responses, without a large degree of required ordering.

Once this “best” map has been generated, the final, overall, satisfaction ratio is compared to the threshold value. If the threshold value has been met (or hopefully exceeded), then the actual satisfaction ratio is output, followed by the text description of the “best” map. No graphics is included as we assume people in the real world do not like graphics.

TESTING

To test the program comprehensively, three different street maps have been created (see the Appendix A). The results of the testing are presented in the Appendix B in table form, as well as on Figure 2. From the graphs of Fig. 2 we can say that the code is working properly for randomly generated maps and, therefore, is correct. The results of runs for all three maps demonstrate that as the percent of those who wanted the service increases, the percent of satisfied customers increases also, which testifies that KUB is reaching its goal of satisfying its clients.

POSSIBLE DIFFERENT ALGORITHMS

Other possibilities for the programming algorithm that were discussed and ruled out during the algorithm development are:

- minimizing laying pipe to those who do not want it;
- minimizing the number of unsatisfied customers;
- maximizing the length of the pipe layout in the highly populated areas in order to increase the future possible income.

The ratio of satisfaction can be also changed in several different ways:

- # satisfied / # unsatisfied ;
- # unsatisfied / # satisfied ;
- # satisfied / # of total customers.

For all the cases above various assumptions and limitations apply. Let us shortly describe each of the possibilities and the reasons they were not accepted.

1) Minimization of laying pipe to those who do not want it is, in fact, one of the main priorities of KUB which, not surprisingly, is not interested in losing its money. However, we thought it would not be fully representative for our goal. Also, mathematically it would be too easy just to

minimize a map geometrically. Nevertheless, if we did utilize this criteria, the way to do it would be to rule out all the ends inhabited by people who do not want the service.

2) Minimization of the number of unsatisfied customers was ruled out because, to our mind, KUB does not have this goal as the primary one; therefore, we did not want to create a somewhat unrealistic scheme. However, the way to do it is pretty much the same as we use for our actual task of maximizing the number of satisfied customers, only that the ratio to minimize would be as following: # unsatisfied / (# satisfied + # unsatisfied).

3) Maximization of the pipe length was an interesting problem as we would have to consider the minimum density of population that would make running the line still profitable for KUB with the initial requirements (considered as limitations) listed previously. However, it still would not be as challenging as maximization of the satisfaction ratio. Anyway ,in developing the algorithm for this case, the optimal minimum population density criteria should be established, and the pipe cost per meter for different geological conditions should serve as a limiting factor.

CONCLUSIONS

As a results of the joint effort, a program to choose an optimal routine for sewer line planning was created and tested. The algorithm is based on calculating the satisfaction ratio, i.e. the ratio of satisfied customers to the total number of customers in a particular living area. Testing of the program has proved that the algorithm is correct, and the program maximizes the satisfaction ratio.

APPENDIX

map 0-20%	w&g	dw&g	w&dg	dw&dg	%sat			map 0-40 %	w&g	dw&g	w&dg	dw&dg	%sat
0	0	0	14	56	0			0	3	1	25	40	75
1	0	0	14	53	0			1	5	5	23	37	50
2	0	0	14	55	0			2	9	5	19	36	64
3	0	0	14	55	0			3	6	3	22	39	66
4	0	0	14	55	0			4	2	2	26	39	50
5	0	0	14	53	0			5	7	4	21	38	63
6	0	0	14	55	0			6	1	1	27	39	50
7	0	0	14	45	0			7	6	2	22	29	75
8	0	0	14	53	0			8	10	8	18	34	55
9	0	0	14	46	0			9	18	15	10	27	54
10	1	1	13	42	50			10	6	5	22	37	55
11	2	2	12	53	50			11	18	16	10	25	52
12	0	0	14	55	0			12	13	12	15	30	52
13	1	1	13	55	50			13	19	14	9	27	57
14	0	0	14	53	0			14	0	0	28	42	0
15	1	1	13	52	50			15	5	1	23	40	83
16	0	0	14	35	0			16	16	13	12	29	55
17	0	0	14	55	0			17	14	10	14	31	58
18	0	0	14	55	0			18	2	0	26	39	100
19	0	0	14	55	0			19	10	8	18	33	55

map 0-60 %	w&g	dw&g	w&dg	dw&dg	%sat			map 0-80 %	w&g	dw&g	w&dg	dw&dg	%sat
0	21	10	21	17	67			0	36	4	20	9	90
1	17	5	25	22	77			1	33	2	23	12	94
2	26	8	16	19	76			2	28	7	28	7	80
3	17	9	25	18	65			3	29	6	27	8	82
4	31	15	11	12	67			4	31	4	25	10	88
5	20	14	22	14	58			5	38	10	18	4	79
6	24	12	18	15	66			6	27	8	29	6	77
7	17	9	25	19	65			7	44	5	12	9	89
8	20	4	22	23	83			8	28	3	28	11	90
9	27	11	15	17	71			9	35	9	21	5	79
10	25	7	17	21	78			10	42	6	14	8	87
11	26	6	16	22	81			11	48	7	8	7	87
12	37	22	5	6	62			12	39	5	17	9	88
13	18	7	24	21	72			13	29	4	27	10	87
14	15	7	27	21	68			14	31	4	25	10	88
15	22	5	20	23	81			15	39	3	17	11	92
16	27	8	15	20	77			16	36	4	20	10	90
17	20	10	22	18	66			17	46	8	10	6	85
18	27	12	15	16	69			18	43	3	13	10	93
19	37	23	5	5	61			19	35	7	21	7	83

map 1-20%	w&g	dw&g	w&dg	dw&dg	%sat
0	0	0	13	45	0
1	1	1	12	44	50
2	0	0	13	49	0
3	1	1	12	44	50
4	0	0	13	52	0
5	0	0	13	42	0
6	1	1	12	44	50
7	0	0	13	49	0
8	0	0	13	49	0
9	3	1	10	42	75
10	3	2	10	43	60
11	0	0	13	42	0
12	2	2	11	50	50
13	0	0	13	42	0
14	0	0	13	48	0
15	0	0	13	39	0
16	1	1	12	45	50
17	0	0	13	52	0
18	0	0	13	48	0
19	0	0	13	48	0

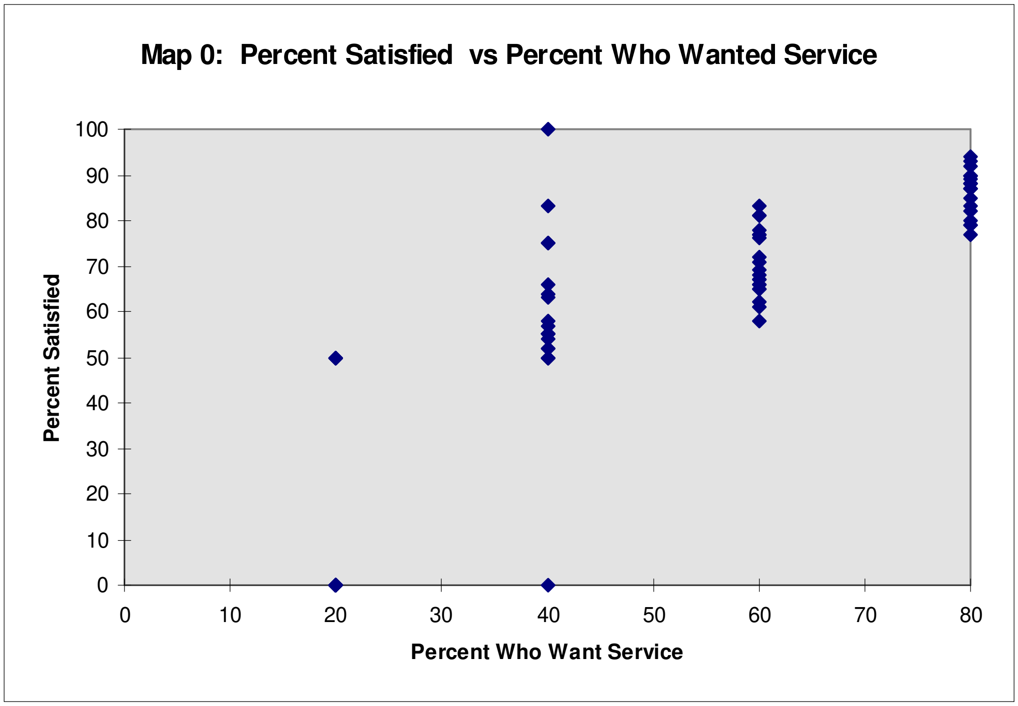
map 1-40 %	w&g	dw&g	w&dg	dw&dg	%sat
0	13	8	13	24	61
1	13	10	13	29	56
2	5	5	21	34	50
3	0	0	26	39	0
4	4	1	22	38	80
5	20	19	6	20	51
6	0	0	26	36	0
7	0	0	26	39	0
8	15	9	11	30	62
9	3	2	23	33	60
10	5	3	21	36	62
11	3	1	23	38	75
12	11	10	15	26	52
13	12	9	15	27	57
14	0	0	26	32	0
15	18	17	8	13	51
16	7	7	19	26	50
17	14	9	12	30	60
18	15	5	11	34	75
19	3	3	23	36	50

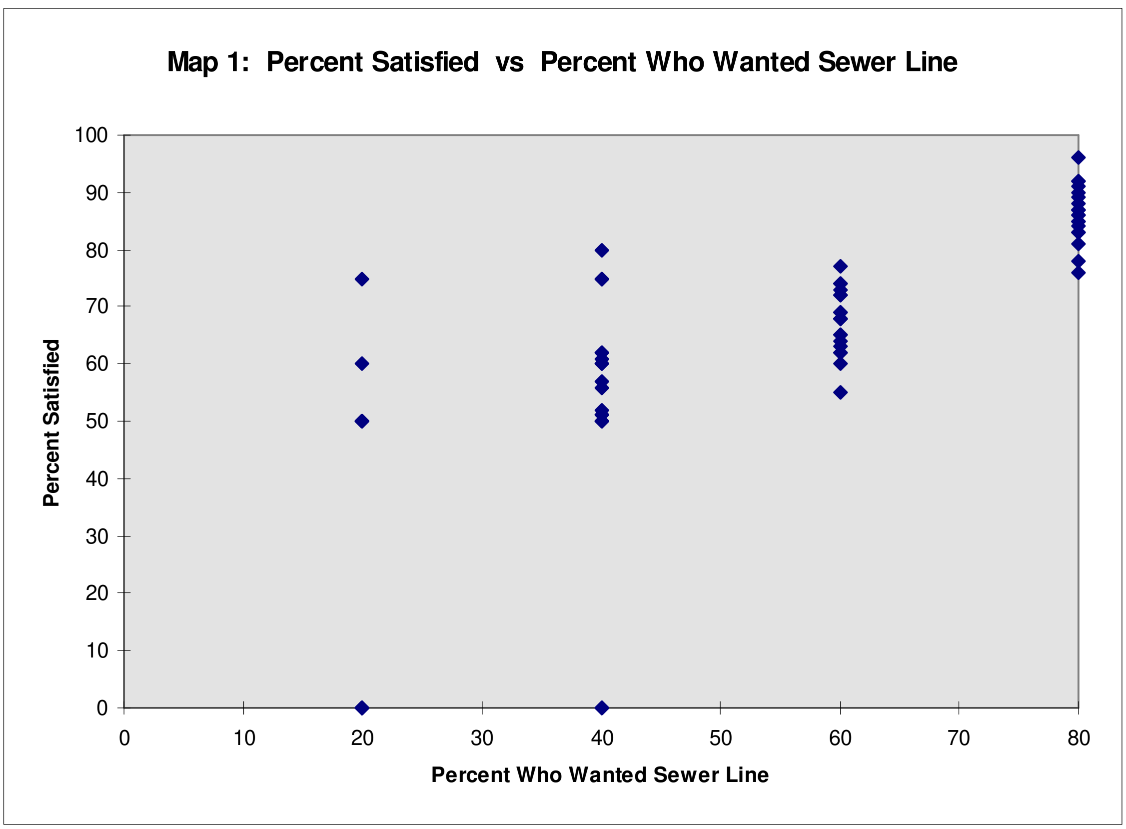
map 1-60 %	w&g	dw&g	w&dg	dw&dg	%sat
0	27	8	12	18	77
1	38	23	1	3	62
2	30	20	9	6	60
3	19	7	20	19	73
4	31	16	8	10	65
5	20	9	19	17	68
6	15	12	24	14	55
7	34	16	5	10	68
8	20	7	19	19	74
9	15	8	24	18	65
10	26	12	13	14	68
11	20	7	19	19	74
12	30	13	9	13	69
13	25	11	14	15	69
14	16	6	23	20	72
15	26	10	13	16	72
16	33	15	6	11	68
17	35	19	4	7	64
18	30	18	9	8	62
19	33	19	6	7	63

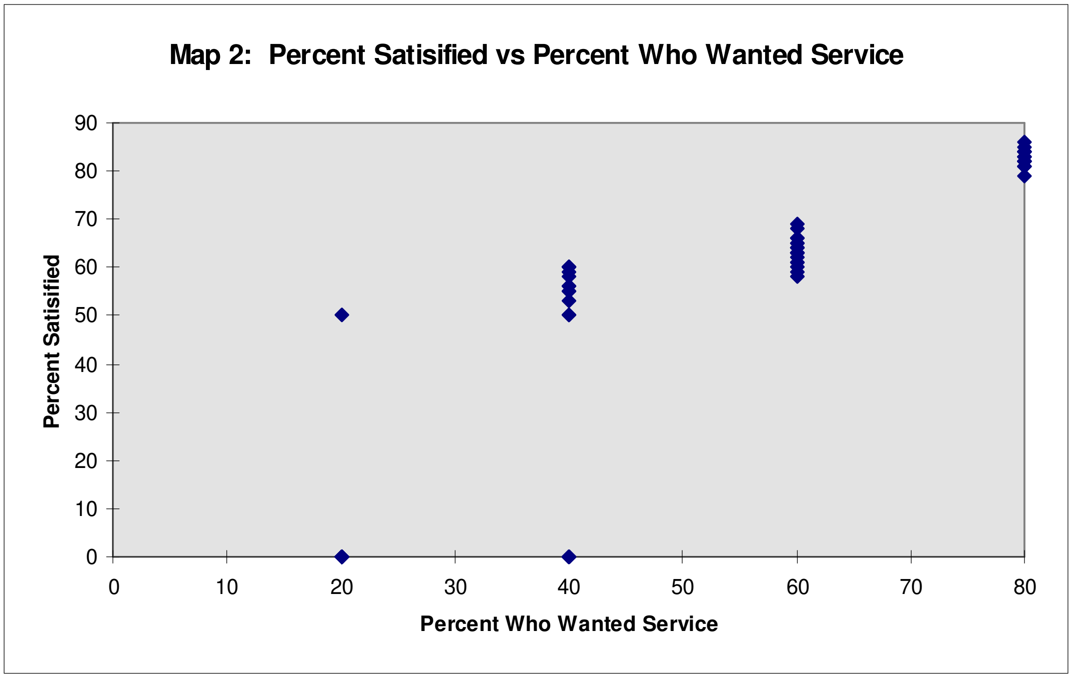
map 1-80 %	w&g	dw&g	w&dg	dw&dg	%sat
0	28	5	24	8	84
1	20	3	32	10	86
2	29	8	23	5	78
3	23	7	29	6	76
4	29	5	23	8	85
5	21	3	31	10	87
6	28	1	24	12	96
7	24	3	28	10	88
8	34	5	18	8	87
9	30	5	22	8	85
10	36	3	16	10	92
11	46	9	6	4	83
12	27	3	25	10	90
13	22	5	30	8	81
14	24	2	28	11	92
15	47	9	5	4	83
16	33	3	19	10	91
17	25	3	27	10	89
18	26	4	26	9	86
19	29	4	23	9	87

map 2-20%	w&g	dw&g	w&dg	dw&dg	%sat			map 2-40 %	w&g	dw&g	w&dg	dw&dg	%sat
0	0	0	15	59	0			0	15	12	16	35	55
1	0	0	15	63	0			1	15	10	16	37	60
2	0	0	15	53	0			2	24	19	7	24	55
3	0	0	15	59	0			3	13	9	18	38	59
4	0	0	15	59	0			4	10	7	21	40	58
5	0	0	15	59	0			5	6	4	25	40	60
6	0	0	15	53	0			6	0	0	31	47	0
7	0	0	15	53	0			7	0	0	31	47	0
8	0	0	15	63	0			8	9	7	22	40	56
9	5	5	10	49	50			9	0	0	31	47	0
10	0	0	15	54	0			10	0	0	31	43	0
11	0	0	15	59	0			11	7	7	24	40	50
12	0	0	15	54	0			12	0	0	31	48	0
13	0	0	15	53	0			13	9	6	22	41	60
14	0	0	15	49	0			14	0	0	31	43	0
15	0	0	15	63	0			15	12	8	19	39	60
16	0	0	15	63	0			16	0	0	31	47	0
17	0	0	15	63	0			17	14	11	17	37	56
18	0	0	15	43	0			18	25	22	6	21	53
19	0	0	15	59	0			19	11	11	20	32	50

map 2-60 %	w&g	dw&g	w&dg	dw&dg	%sat			map 2-80 %	w&g	dw&g	w&dg	dw&dg	%sat
0	44	28	3	3	61			0	56	12	7	4	82
1	46	25	1	3	64			1	51	10	12	5	83
2	41	22	6	9	65			2	55	11	8	5	83
3	40	27	7	5	59			3	59	13	4	3	81
4	40	22	7	9	64			4	53	9	10	7	85
5	37	21	10	10	63			5	56	13	7	2	81
6	39	18	8	13	68			6	55	12	8	4	82
7	43	22	4	9	66			7	48	10	15	5	82
8	34	24	13	7	58			8	58	12	5	3	82
9	31	17	16	14	64			9	58	11	5	4	84
10	43	25	4	6	63			10	50	8	13	8	86
11	35	20	12	11	63			11	53	11	10	5	82
12	37	21	10	11	63			12	62	13	1	2	82
13	34	15	43	16	69			13	63	16	0	0	79
14	38	23	9	9	62			14	56	13	7	2	81
15	42	28	5	4	60			15	56	10	7	5	84
16	45	24	2	7	65			16	56	10	7	6	84
17	36	21	11	11	63			17	53	10	10	5	84
18	36	18	11	14	66			18	55	10	8	6	84
19	43	27	4	5	61			19	46	9	17	6	83


Map 0: Percent Satisfied vs Percent Who Wanted Service
Percent Satisfied
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
Percent Who Want Service


Map 1: Percent Satisfied vs Percent Who Wanted Sewer Line
Percent Satisfied
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
Percent Who Wanted Sewer Line


Map 2: Percent Satisified vs Percent Who Wanted Service
Percent Satisified
Percent Who Wanted Service
0
10
20
30
40
50
60
70
80
90

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Task 3	S. Monty and M. Peek
Task 4	V. Semak and M. Terry
Task 5	Y. Wu and A. Bredikhin

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