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A Tabu Search Based Approach for Work Zone Scheduling

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A Tabu Search Based Approach for Work Zone Scheduling

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Abstract: *This paper introduces a work zone scheduling methodology, which is intended to be used as a decision – aid tool for transportation planners that have to undertake a number of work zones larger than the available number of construction crews during a given time period. Two traffic assignment approaches are used to evaluate the traffic delay caused by work zone combinations and a Tabu Search methodology is employed to select the schedule with the least total traffic delay. The approach is implemented and tested on an example network and on a large-scale realistic network, the Columbus, OH urban network. The results show that substantial network improvements can be obtained by accounting for work zone impacts and implementing appropriate schedules.*

1. INTRODUCTION

The Transportation Efficiency Act for the 21st Century (TEA 21) funds and the aging highway infrastructure have increased the number of construction and rehabilitation work zones; this is only expected to worsen as many highways are approaching the end of their lifecycle. Many transportation planners are increasingly facing the need to schedule simultaneously many on-going work zones in their jurisdictions. As a result, it is common to observe multiple work zones scheduled to start at the same time (or to overlap), causing considerable increase in traffic congestion, delays and environmental hazards. Very little has been done to develop efficient work zone scheduling methodologies that can evaluate the combined effect of work zones on the transportation network.

Existing approaches that aim to evaluate the impact of work zones on the urban street network based on their characteristics and an estimate of the traffic volume can be categorized into benefit/cost analysis and design studies. The benefit/cost approaches (Dudek, 1988 and Jiang, 1999), examine the cost associated with vehicle delays and the negative impact on the environment in terms of air and noise pollution, while design studies (Schrock and Maze, 2000) primarily focus on the alternative work zone traffic management plan to enhance safety and reduce vehicle delay.

These approaches can provide valuable insights into the relationship between the type of work zone and the resulting costs. However, they cannot evaluate the combined impact on the overall system of more than one on-going work zone. For instance, Fwa *et al*. (1998) developed a scheduling methodology that uses genetic algorithms to minimize traffic delay at only one work zone.

The motivation for this paper is the need for quantitative tools to assist in work zone scheduling while accounting for their impact on traffic. This paper introduces a systematic methodology for (i) evaluating the impact of work zone combinations on an urban street network and (ii) selecting the schedule with the least total travel delay on the network.

The proposed scheduling methodology uses a traffic assignment algorithm to evaluate the impact of work zone combinations on the transportation network and a Tabu Search approach to select the work zone schedule with the least total vehicle delay. Tabu Search is a heuristic searching approach that can find “good solutions” for intractable combinatorial optimization problems that are difficult to solve analytically. It offers a framework for computing solutions to the maintenance-scheduling problem, which inherently has an extremely large number of feasible solutions. The methodology is intended to be used as a decision-aid tool for

transportation planners to evaluate the impact of combinations of work zones before construction starts. Quantifying the total traffic delay caused by work zones for the entire construction period would allow transportation planners to develop effective work zone schedules.

This paper is organized as follows: Section 2 discusses the problem formulation and the solution algorithm. Section 3 explains the testing procedure for evaluating the proposed approach, along with the computational results. Section 4 concludes the paper and provides suggestions for future research.

2. PROBLEM FORMULATION

Work zone construction is a complex problem that requires careful planning of the work zone layout, duration of construction, float time, and various other operational constraints. In addition, it requires a thorough coordination among government agencies and construction companies with often conflicting objectives. For example, it might be financially beneficial for the construction company to ask that two closely spaced work zones be scheduled to immediately follow each other in order to minimize the cost of transporting the construction equipment and material from one site to the other. This, however, could be detrimental to the traffic network performance. For simplicity, in this paper we account for only the work zone layout and duration and not for the operational constraints such as float time and cost of transporting the construction equipment.

2.1 Work Zone Scheduling Problem

Scheduling generally aims to reduce the associated operating costs and to improve quality and efficiency. For work zone applications, scheduling consists of the sequence in which work zone

need to be performed in order to minimize the impact of groups of simultaneously on-going work zones on an urban street network. This usually follows when the number of work zones (***w***) to undertake in a given time period exceeds the available number of construction crews (***c***) (*i.e.* ***c***< ***w***), or when performing all the on-going work zones simultaneously is detrimental to the network performance. As a result, only sub-groups of work zones (***c***) can be scheduled to be in progress at the same time. Since one crew can perform only one work zone at any given time, there are $C_c^w = \frac{w!}{(w-c)!c!}$ possible work zone combinations that can be selected in progress. For instance, if nine work zones (A, B, C, D, E, F, G, H, I) need to be undertaken and only three construction crews are available, then there are C_3^9 = 84 work zone combinations, where (A, B, C) is one possible combination among the 84.

The total number of possible schedules (***k***) with (***w***) work zones and (***c***) crews is defined as follows:

$$k = \frac{C_c^w \times C_c^{w-c} \times C_c^{w-2c} \ldots \times C_c^c}{(w/c)!}$$

For example, with nine work zones (A, B, C, D, E, F, G, H, I) and only three construction crews used, the total number of possible work zone schedules is $\frac{C_3^9 \times C_3^6 \times C_3^3}{(9/3)!} = 280$, where {(A, B, C), (D, G, I), (E, F, H)} is one among the 280 possible schedules. It is obvious that as the number of difference between ***c*** and ***w*** increases, the total number of possible schedules quickly becomes very large and intractable to solve without an efficient searching method.

Figure 1 depicts the framework of the proposed methodology. It consists of selecting work zone combinations (*e.g.* (A, B, C)) and use a traffic assignment approach to evaluate their impact on the urban transportation network. Then, a Tabu Search method is employed to select the schedule ***S*** (*e.g.* {(A, B, C), (D, G, I), (E, F, H)}) among the ***k*** possible ones with the least total travel delay. The total travel delay of a schedule is the sum of total travel delay of each of its work zone combinations. The following sections introduce the traffic assignment models and Tabu Search approache used in this paper to solve the work zone scheduling problem.

2.2 Traffic Assignment Models

Work zones typically reduce the available capacity of the roadways, which inherently increase the total traffic delay. It is well known that after a few days into work zone operation, motorists adjust to the new traffic conditions by changing their paths. Any traffic assignment methodology (*i.e.* static, dynamic or simulation-based) could be used to evaluate the increase in total traffic delay under each work zone combination. Static traffic assignment approaches are commonly used in planning applications. Currently, static assignment models are widely used by agencies for planning application: from infrastructure structure improvement to traffic maintenance and congestion management. The major limitation, however, is that they cannot capture traffic phenomena such as the propagation of shockwaves and queue spillovers. This could be important, especially if closely spaced on-and-off ramps precede the work zones.

In this paper, the dynamic traffic assignment (DTA) methodology introduced by Ziliaskopoulos (2000) is employed to evaluate the total travel time of work zone combinations. We intend to evaluate the effect of work zones during periods of rush hour, because it is assumed that the greatest impact on the network occurs when almost all of the facility capacity is used.

The time-dependent demand of the approach can be set to adequately reproduce the rush hour traffic conditions. We also use an All or Nothing (AON) static traffic assignment model to evaluate an actual urban network.

2.3 Tabu Search Methodology

Heuristic search methodologies in general do not guarantee optimality as they may converge at a local optimum solution. This is the case, quite often, when using local searching procedures. In order to "escape" from local optimum and explore a larger portion of the feasible region, a Tabu Search heuristic methodology is used in this paper.

Tabu Search was first introduced by Glover (1989) and has since been used to solve many practical applications such as the vehicle routing problem (VRP) (Gendreau, Hertz and Laporte, 1994), network design problem (Mouskos, 1992), the job shop scheduling problem (Dell'Amico and Trubian, 1993), and many other combinatorial optimization problems. As opposed to classical local search procedures, Tabu Search does not stop at the first local optimum when no improvement is possible. The best solution in the neighborhood is always selected, even if it is worse than the current solution. This allows it to explore more solutions from the feasible region.

In the proposed methodologies, a Tabu Search module is used as part of an iterative process, where in each iteration a potential schedule is evaluated. The number of iterations (I) is arbitrarily set. It starts by selecting a feasible schedule to be the initial schedule (*e.g.* {(A, B, C), (D, G, I), (E, F, H)}), and proceeds by selecting feasible schedules from the ***neighborhood*** of that initial selection. The schedule with the lowest total travel time among the new set of candidate schedules is selected as the next schedule to move to. The design of the ***neighborhood***

is a key element in the formulation of the proposed Tabu Search method as it may considerably increase the computational and searching efficiency. In this paper, the neighborhood is defined as performing a single adjacent work zone pair interchange. For instance, if the initial schedule of work zones is (*e.g.* {(A, B, C), (D, G, I), (E, F, H)}) then the new candidate schedule could be {(A, B, D), (C, G, I), (E, F, H)} by interchanging the work zone pair (C, D).

To avoid cycling, a Tabu List is used to store solutions that cannot be considered at the next iteration. Typically, the Tabu List cannot contain all of the previously visited solutions, because of the computational requirements. Instead, an arbitrary Tabu List size ***n*** is defined. If ***n*** is too small, cycling may occur; if it is too large, the search may be computationally prohibited.

The Tabu List contains work zone pairs that were swapped during the previous iterations and which cannot be swapped again during the current iteration. Initially, the Tabu List is empty. Every time an interchange is made to the current schedule, the new work zone pair interchange is entered at the top of the Tabu List; all previous pair entries are pushed down by one position, and the most bottom pair entry is deleted.

3. COMPUTATIONAL RESULTS

3.1 Test Networks

The proposed methodology is evaluated on a test network with DTA model and on an actual urban network, 1990 Mid-Ohio Regional Planning Commission (MORPC) Columbus, OH network, with static assignment model.

DTA approach was evaluated on a network, which consists of one freeway and two arterial roads connected with a number of ramps and cross streets as depicted in Figure 2. In this example, three freeway work zones F_1, F_2, F_3 and three arterial street work zones A_1, A_2, A_3 are

considered, while only two construction crews are available at any given time. Freeway work zones experience a one-lane reduction and a new speed limit of 50 ft/sec down from 100 ft/sec; the arterial street work zones undergo a half-lane closure and a new speed limit of 40 ft/sec down from 50 ft/sec. All work zones are assumed to have identical construction duration.

The MORPC Columbus, OH network currently in use by the Ohio Department of Transportation consists of 12,658 arcs, 5,441 nodes and 978 centroids. A graphical representation of this network is shown in Figure 3. Current OD demand used for planning on the Columbus Network was used to evaluate the impact of arbitrary selected work zone in this paper. Work zones were placed on the most heavily traveled links. As a result, the six most used links within the densest OD pairs were selected with two available construction crews. To capture the effect of work zone, the capacity of the six selected links was reduced half. All work zones are assumed to have the same construction duration.

3.2 Methodology Performance with test network

We start by heuristically selecting the initial base work zone schedule, which consists of sequence $\boldsymbol{S_1}$ = {(F_1, A_1), (F_3, F_2), (A_2, A_3)}. Table 1 shows the system total travel time of the three respective combinations of the base work zone sequence as reported by the DTA approach.

Table 1. Total travel time with each work zone combination

Work Zone Combinations	Total System Travel Time (sec.)
(F_1, A_1)	5,506
(F_3, F_2)	**7,938**
(A_2, A_3)	5,040

Table 1 shows that the greatest impact is incurred when the two closely spaced freeway work zones (*i.e.* F_2 and F_3) are scheduled to be in progress at the same time. Besides, the total travel time of the initial base work zone sequence $\boldsymbol{S_1}$ is equal to 18,610 seconds.

Next, the Tabu Search heuristics proceeds to interchange work zone pair for $\boldsymbol{S_1}$. There are four candidate schedules in the neighborhood of $\boldsymbol{S_1}$ and their respective total travel time is shown in Table 2.

Table 2. The candidate schedules of $\boldsymbol{S_1}$

Candidate Schedule	Total Travel Time (Sec.)
{(F_1, F_3) (A_1, F_2) (A_2, A_3)}	**18,356**
{(F_3, A_1) (F_1, F_2) (A_2, A_3)}	18,610
{(F_1, A_1) (F_3, A_2) (F_2, A_3)}	18,484
{(F_1, A_1) (A_2, F_2) (F_3, A_3)}	18,484

The schedule with the smallest total travel time corresponds to sequence $\boldsymbol{S_2}$ = {(F_1, F_3) (A_1, F_2) (A_2, A_3)}. The aspiration criterion is changed from 18,610 seconds to 18,356 seconds. The Tabu List is updated and now contains the work zone pair {(A_1, F_3). At the next iteration, there are four candidate schedules in the neighborhood of $\boldsymbol{S_2}$, as shown in Table 3.

Note that the first candidate sequence is Tabu, because the work zone pair (A_1, F_3)) is already in the Tabu List and cannot be swapped during the current iteration. Even if that candidate schedule had the lowest total travel time, it is still would have been rejected. The best non-Tabu sequence is $\boldsymbol{S_3}$ = {(F_1, F_3) (A_1, A_2) (F_2, A_3)} with a total travel time of 18,018 seconds. The Tabu List is updated and now contains the work zone pairs (A_1, F_3) and (F_2, A_2).

Table 3. The candidate schedule of S_2

Candidate Schedule	Total Travel Time (Sec.)
$\{(F_1, A_1)(F_3, F_2)(A_2, A_3)\}$	18,484
$\{(A_1, F_3)(F_1, F_2)(A_2, A_3)\}$	18,610
$\{(F_1, F_3)(A_1, A_2)(F_2, A_3)\}$	**18,018**
$\{(F_1, F_3)(A_2, F_2)(A_1, A_3)\}$	18,356

In this example, the optimum schedule $\{(F_1, F_3)(A_1, A_2)(F_2, A_3)\}$ is found after only two iterations. That schedule reduces the total traffic delay by 3.91% compared to the initially heuristically selected base schedule. However, it results in 5.31% total delay reduction when compared to the worst possible schedule. These are computed using ratio (1) and the results are reported in Table 4.

$$\text{Percent Change} = [\frac{(\text{TTT WZ - TTT NWZ})}{\text{TTT NWZ}}]x100\% \qquad \text{Ratio (1)}$$

where:

TTT WZ: System total travel time with work zone combinations

TTT NWZ: System total travel time without work zones

Table 4. The Impact of work zone schedules

	Schedule	Impact
No Work Zones		0
Initial	{(F_1, A_1) (F_3, F_2) (A_2, A_3)}	23.08%
Optimum	**{(F_1, F_3) (A_1, A_2) (F_2, A_3)}**	**19.17%**
Worst	{(F_1, A_1) (F_3, A_2) (F_2, A_3)} {(F_1, A_2) (F_3, A_1) (F_2, A_3)} {(F_1, A_2) (F_3, A_3) (F_2, A_1)}	24.48%

In addition Table 4 shows that the worst schedule always occur when the freeway work zones (*i.e.*F_1, F_2, and F_3) are in different combination. In other words, if the freeway is undergoing construction at all times then the traffic delays are at their highest. It is recommended, instead, to get done with the freeway work zones as quickly as possible by scheduling as many as possible of them to be in progress at the same time. Without any constraint on the number of construction crew, the optimum would consist of scheduling all freeway work zone at the same time. For example, the total travel time of the schedule {(F_1, F_2, F_3) (A_1, A_3) (A_2)} would consist of only 19.16% increase in total travel delay.

3.3 Methodology Performance with Columbus network

The proposed methodology was also applied to the Columbus network with static assignment model. In this example, six most used links 9344,9840,9352,9326,9486,9581 within densest OD pairs were selected as work zones, while only two construction crews are available at any given time. We start by heuristically selecting the initial base work zone schedule, which consists of sequence $\boldsymbol{S_1}$ = {(9344, 9840), (9352, 9326), (9486, 9581)} with 2,167,094 minutes total system

travel time. In this example, the optimum schedule {(9352, 9840), (9486, 9326), (9344, 9581)} with 21,64,961 minutes total system travel time is found after only three iterations. That schedule reduces the total traffic delay by 0.1% compared to the initially heuristically selected base schedule. However, it results in 0.12% total delay reduction when compared to the worst possible schedule. These are computed using ratio (1) and the results are reported in Table 5. While the optimum schedule does appear to lower down the total system travel time, the total travel time differences are rather small.

Table 5. The Impact of work zone schedules

	Schedule	Impact
No Work Zones		0
Initial	{(9344, 9840), (9352, 9326), (9486, 9581)}	0.37%
Optimum	**{(9352, 9840), (9486, 9326), (9344, 9581)}**	**0.27%**
Worst	{(9486, 9840), (9352, 9344), (9326, 9581)}	0.39%

The scheduling methodology lead to similar results as those presented above, that is, a schedule with better network performance than the empirically selected one.

4. CONCLUSIONS AND FUTURE RESEARCH

This paper has introduced a work zone scheduling methodology. The approach uses both dynamic traffic assignment and static traffic assignment approaches to evaluate the impact on transportation networks of work zone combinations and employs a Tabu Search methodology to find the work zone schedule with the least total travel delay. With the “best” work zone schedule, total traffic delay and environmental impacts could be reduced. The computational

results obtained in a simulated environment show that the proposed methodology is effective at finding the work zone schedule with substantial improvements in total traffic delay, compared to heuristically or empirically selecting it.

The methodology could be expanded to design a better neighborhood criterion for more efficient swapping. Furthermore, it is necessary to address more complex issues related to work zone scheduling such as work zone float time and resource allocation.

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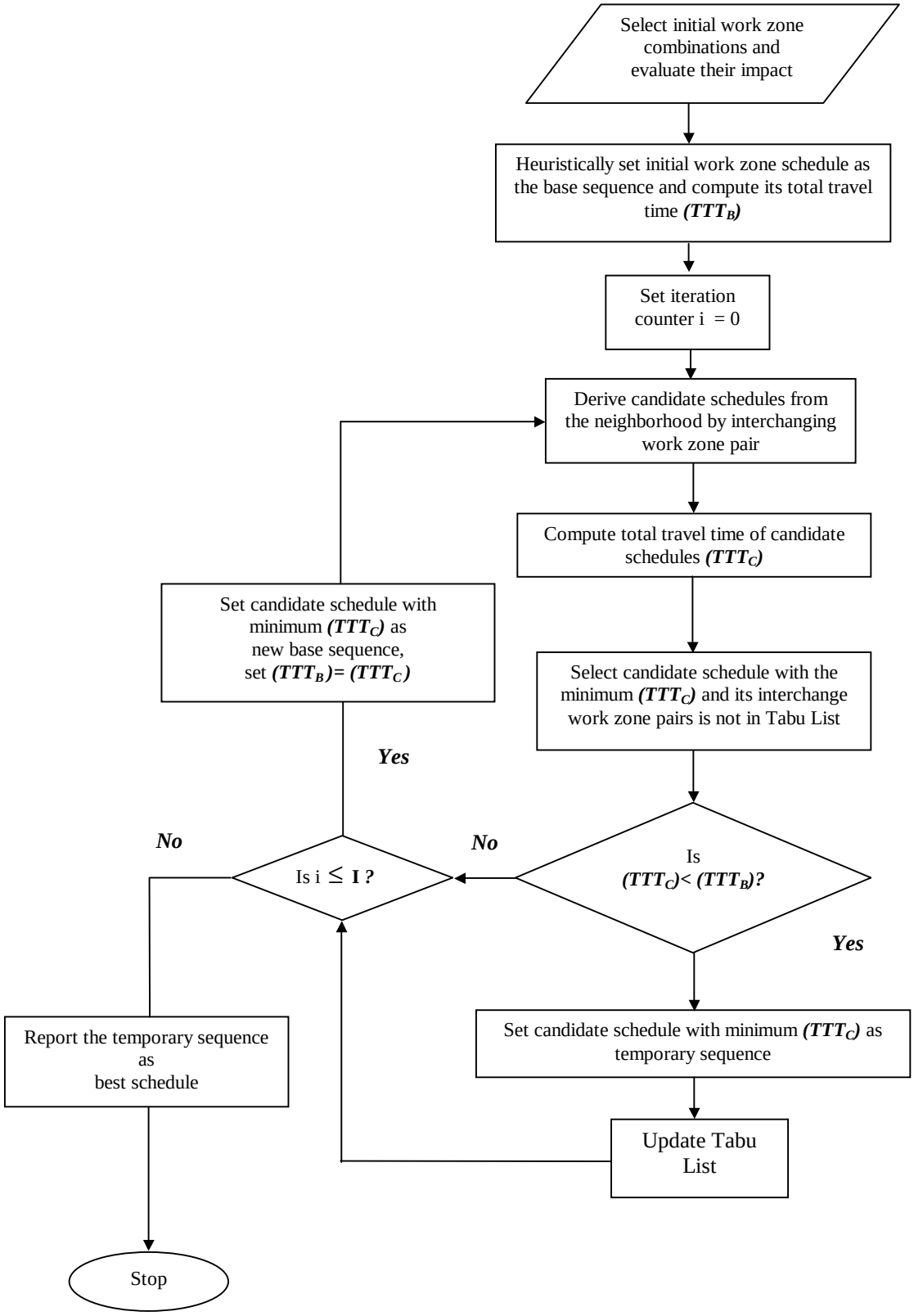

Figure 1. Solution Algorithm

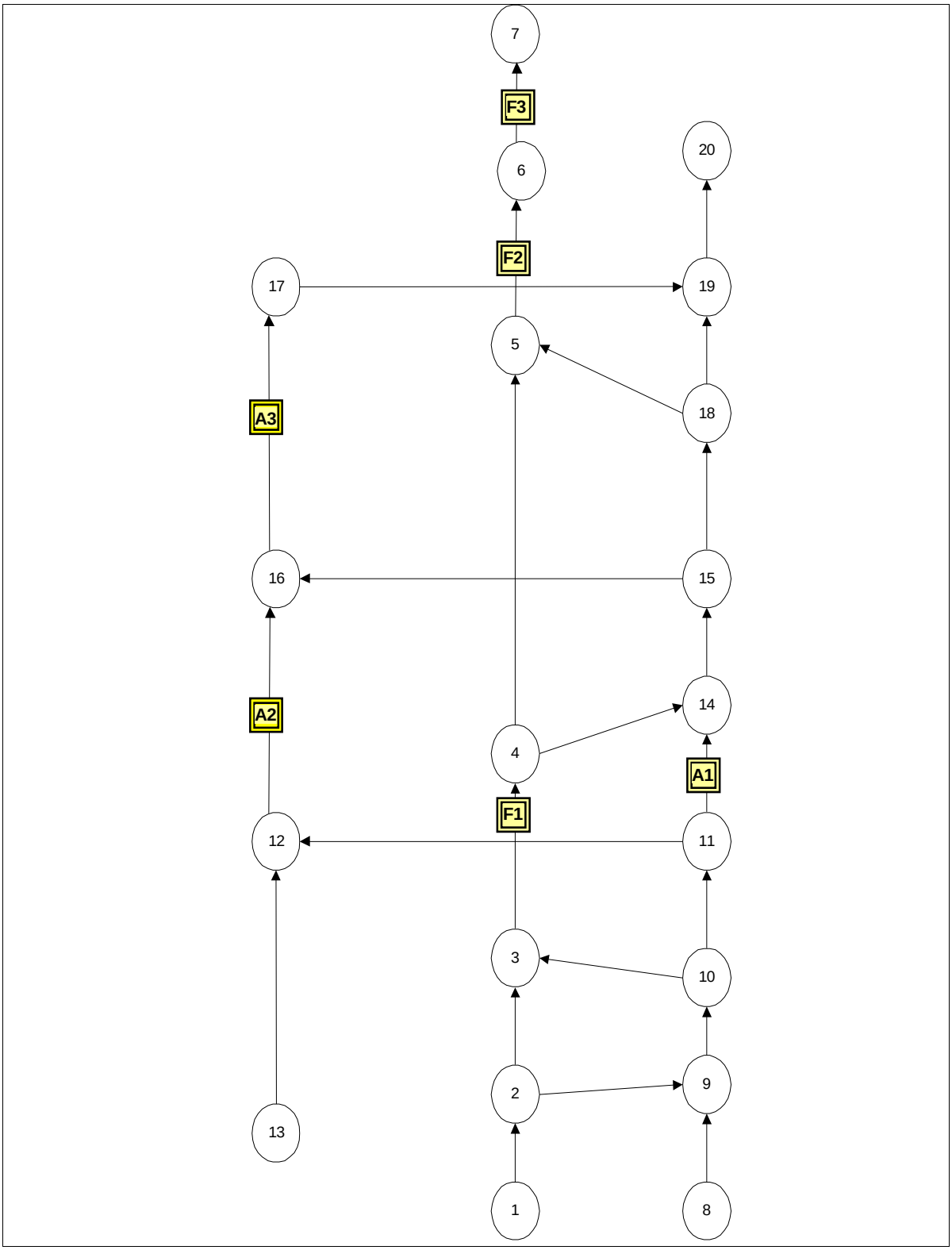

Figure 2. The Test Network

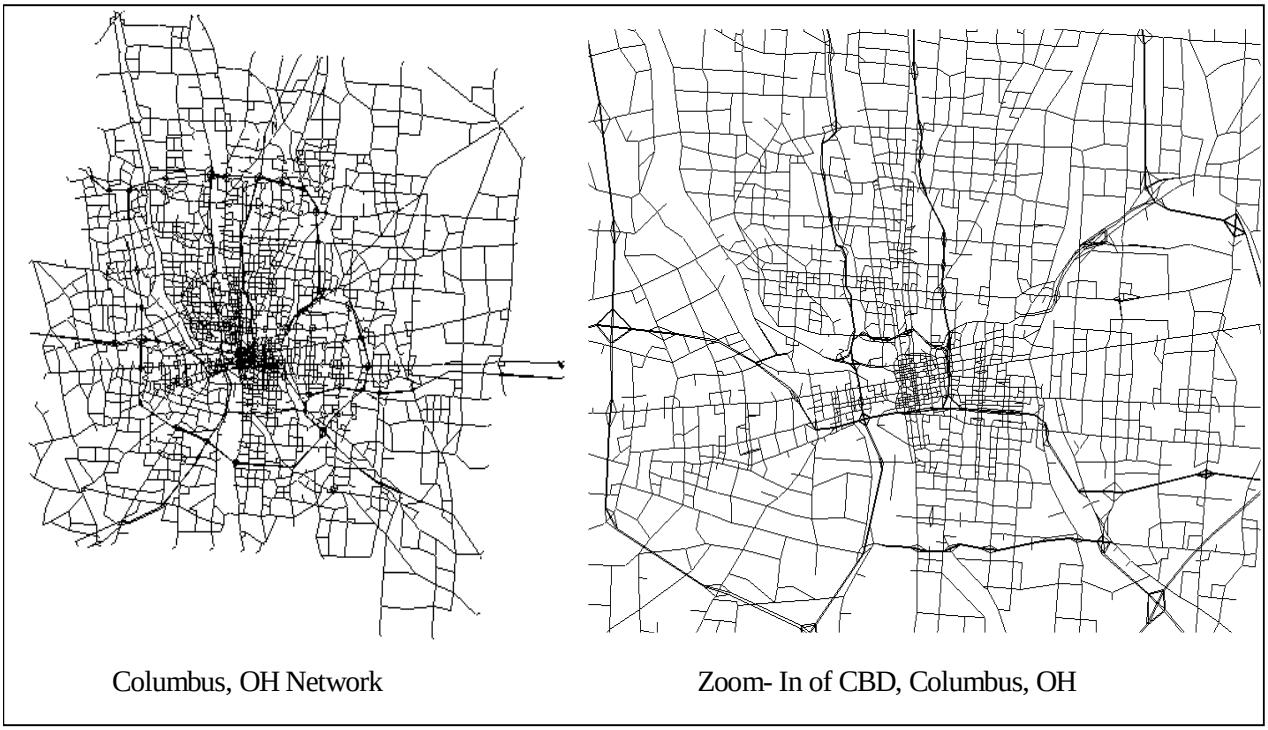

Figure 3. Columbus Network