ORGANIZING UTILITY SERVICES IN TRANSPORTATION CORRIDORS

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ABSTRACT

Utility facilities are frequently located underground within transportation corridors to deliver services (gas, water, electric, telecom, drainage, etc) to customers. Accommodation of such installations can be complicated by the available right-of-way, restrictions on facility placement and concern for traffic hazards, along with other issues. Disorganized and inefficient occupancy of the corridor is the usual result of a progressive series of installations, each in turn picking the most favorable location available, without regard to overall occupancy.

This paper is concerned with the development of a realistic planning model for organizing utilities in the subterranean right-of-way. A program has been constructed to accomplish the task of identifying acceptable configurations while seeking to minimize the total societal costs of corridor development. Issues of efficiency (utilization of resources in congested corridors), flexibility (gauging the potential to extend occupancy) and balance (even distribution of costs) were explored for typical examples. It is anticipated that eventually this research could result in better management and decision making when new corridors are developed, as well as for the addition or relocation of facilities in existing corridors.

KEY WORDS

utility facilities, transportation corridors, optimal placement, right-of-way, planning

INTRODUCTION

Along with roads, utilities are granted equal access to the transportation right-of-way and by law must be accommodated. Without some degree of control however, evolutionary development of the available corridor (“first come–first served”) is prevalent. The resulting configuration is not likely to be efficient in terms of the best use for corridor resources however, and expansion of corridor capacity, either through roadway widening or the addition of new utility facilities, soon becomes extremely difficult. Furthermore, activities associated with the installation and maintenance of existing facilities become inconvenient, unsafe and disruptive to traffic flow.

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Agencies representing roadway development - often the state transportation department or a corresponding local entity - can exert some degree of control over this process, but without specific direction, little is usually accomplished. This paper presents a methodology for planning to configure the available utility corridor in an efficient manner, oriented towards new construction in urban areas where space is typically quite limited. An optimization of the configuration of the subterranean corridor, obtained by minimizing the total societal cost is suggested. To attain this goal, the constraints governing the organization of the corridor, along with this total cost function, are incorporated into a heuristic model for application of optimization. After introducing simplifying assumptions a programming strategy is developed to carry out the extensive calculations required. One main objective is to investigate how preplanning for the later addition of some facilities could affect the placement of the facilities initially installed. The model requires a large body of design information (including for example, the location of pre-existing facilities, if any), much of which may be uncertain or not easily available, due to proprietary and security concerns.

In constructing a model for the optimization process, it is recognized that a diverse group of stakeholders participate in the planning for corridor development, including utilities, engineering and construction firms, regulatory agencies and the public. All have specific objectives and consequently value the components of the total cost of development in different ways. The intent of this investigation is to develop a model for corridor configuration that will facilitate the decision making process to choose an efficient and functional arrangement benefiting all stakeholders, while taking into account a diverse set of requirements. Ultimately, the goal is automated planning and design for facilities, with particular emphasis on effectively managing crowded urban corridors.

Although the problems associated with utility accommodation have been widely discussed elsewhere, as summarized by Kuhn, et al. (2002) and models for management of data regarding the nature and placement of facilities in the corridor have been proposed by Quiroga and Pina (2003), the concept of applying optimization techniques to corridor configurations has apparently received little attention. Previous work by Collier and Kranc (2006) discussed optimization for additions to corridors with existing facilities. Relocation and pavement renovation are both issues that are a part of the overall problem of utility placement, but not directly treated here. Methods similar to those presented could be utilized however, to apply optimization to these important problems.

GOALS FOR OPTIMIZATION

For purposes of this investigation the total societal cost, comprised of all location dependent costs, has been chosen as a target for optimization. The total cost of any particular corridor configuration (denoted by i) is the weighted sum of the individual composite costs C_j, for n facilities, individually positioned at $x_{i,j}$, $y_{i,j}$:

$$TC_i = \sum_{j=1}^{n} W_j \, P_j C_j (x_{i,j}, y_{i,j}) \tag{1}$$

where W_j represent an importance weighting factor for the j^{th} facility (assumed here to be unity), and P_j represents the probability that the j^{th} utility facility will be installed (expressed as a decimal). In this manner, future events may be factored into planning with an effective weighting equal to the probability of occurrence.

The total societal cost may be compared to economic models used to make capital investment decisions, which include not only installation costs but also ongoing costs such as maintenance. Most, if not all cost factors bearing on the placement location of a particular facility can be reduced to a present value by defining a fixed study period, or service life. In order to preserve a degree of adaptability, the possibility of weighting any individual component of the cost or the influence of any one facility has been retained. The choice of total cost as a target for optimization is a logical possibility and defensible, but certainly other choices could be made.

To facilitate cost comparisons between alternative configurations, a non-dimensional efficiency ratio is introduced. For any configuration i, a ratio comparing the actual cost to the absolute minimum total cost MTC, can be formed

$$Q_{eff,i} = \frac{MTC}{TC_i} \qquad (2)$$

where the MTC is defined in the same way as the TC, but for the sum of the absolute minimum individual cost functions, MC_j, (the smallest cost of placement somewhere in corridor without regard to other constraints). Thus, determining the smallest value TC_{opt} results in the most efficient corridor configuration, wherein each facility is placed near a point of total minimal cost ($Q_{eff,\ opt}$ approaches 100%). In many practical situations it may not be possible to configure the corridor so that the absolute minimum cost for each facility is obtained and a limited efficiency results, which may be interpreted as an indication of a crowded corridor. Other factors that could help to characterize particular solutions and influence final planning decisions will be discussed later.

EXAMPLE

In this paper, an example illustrating planning for a new corridor is explored, as a means of introducing the decision making process developed in this research. Consider a situation where it is desired to install four utilities initially and one additional facility is likely to be installed in five years. The available corridor in this example is small (2.13 m horizontally and 1.37 m vertically) so that planning for this corridor is a relatively complex situation without an obvious solution. Congestion will force some utilities to be installed at a deeper location than would normally be desirable. Table 1 summarizes the data to be input regarding the corridor and Table 2 specifies the individual facilities (the selection of parameters is representative but arbitrary)

Table 1. Corridor Data

R/W Width	5.78 m	**Design Speed**	88.43 km/h
Cover	0.91 m	**Service Life**	20 yr
Max Depth	2.28 m	**Design Year**	10 yr
Lanes	2 lanes-2 way	**Ave Volume**	20 k/day
Lane Width	3.65 m	**Growth Rate**	10%

Table 2: Facility specifications

Facility	Diameter (m)	Freq (#/km/yr)	AGF Diameter (m)	AGF (#/km)
Gas Distribution	0.13	1.9	None	0
Potable	0.20	6.2	None	0
Telecom	0.18	0.6	0.6	12.4
Power Distribtution	0.20	3.1	None	0
Reclaimed	0.15	0.6	None	0

Note that only one installation (power distribution) involves above ground facilities (AGF). Other than utility types and sizes, the main difference between the facilities lies in the number of access events, (units of events per year/km). The four initial installations will be by open trench. The utility added later will be installed by either open trench or trenchless methods depending on location. The proposed addition (Table 2) is a reclaimed water line without above ground facilities. This utility is estimated to have a probability of installation of 50% during the fifth year after the initial installations. Y_j is the total service life in years for the individual facilities (equal to 20 years for all facilities except the reclaimed water which will be 15 years, if this facility is installed).

MODELING ASSUMPTIONS

The organizational model developed here is based on a two dimensional local cross section of the corridor, assumed to remain constant. Changes in facility arrangement along the corridor can be accounted for by subdivision of the entire installation into sectors with constant configuration, each handled separately. The occupancy constraints bounding the corridor include the horizontal extent, here taken to be the distance from the centerline of the pavement to the edge of the right-of-way (i.e. one-half of the total corridor), and the vertical extent, here taken to start at a required ground cover depth and extending to a limit of installation, usually governed by local geology or the method of installation (see Figure 1, below). Curvature of the right-of-way is neglected. In the interest of maintaining a tractable model the following assumptions are additionally imposed, and other assumptions will be introduced as needed.

- Intersections, medians, sidewalks, or lateral connections are not considered.
- Equal weighting is applied to the importance of each of the installed utilities and associated cost components.
- Installation under pavement is not permitted.
- Complex interrelationships among factors have been generally ignored (for example, possibility of common trenching as a means of installation).

Additionally, each installing facility is required to maintain specified clearance with adjacent facilities and there are often rules pertaining to the vertical stacking of facilities as well as installation beneath pavement. Requirements for clearance between facilities are dependent on regulatory requirements, method of installation, environmental concerns as well as other factors. Here it is assumed that a bounding box (where placement of installing facility is excluded) surrounds any installed facility to facilitate the computational search process for feasible solutions. In general this clearance depends strongly on the nature of the facilities. For simplicity, here it is assumed that the conduit wall-to-wall dimensions for constructing the bounding box are all fixed at 0.61 m in each direction, to which the diameter of the installed facility must be added.

COST MODELS

For a particular configuration (subscript i) the societal cost C_j for facility j placed at location $x_{i,j}$, $y_{i,j}$ as the sum of m component costs c_k

$$C_j = \sum_{k=1}^{m} w_k c_k (x_{ij}, y_{ij}) \tag{3}$$

where w_k is a weighting factor (taken here to be unity) introduced to establish the relative importance of each of the cost components, as mentioned previously. Each of the cost components is expressed as a unit cost (cost per kilometer along the corridor). It is assumed for simplicity that price inflation exactly equals the time value of investment over the service life of the corridor, so that all costs can be converted from an annualized to present value basis without considering interest charges. For annually recurring components, the cost is multiplied by the service life of facility j. A tacit assumption of this work is that the final configuration chosen will be constructible, that is to say there will be no important cost factors associated with the order of construction or the spatial relationships between facilities. For the present discussion the following cost factors have been considered:

1. Installation - Placement of a facility is a non recurring event, with costs dependent on the installation method utilized. Here, the reclaimed facility to be added will be installed by trenchless methods and all other facilities are to be installed by open trench burial with shoring or other trench protection as required. A simplified, aggregate cost for burial (including excavation, shoring, bedding, backfill, maintenance of traffic and pavement, etc.) has been constructed from examination of the compilation of installation costs by Zhao and Ranjani (2002), agency maintained records and commercial estimation techniques, as for example, Spencer (2005). As a first approximation, data available has been fitted to a linear model:

$$c_{1,j}(x_{i,j}, y_{i,j}) = [127.5 y_{i,j} + 186.4] \tag{4}$$

   where the depth, $y_{i,j}$, is expressed in meters. All cost components given here are given in thousands of $US/km. In general, the intercept will be a function of horizontal location of the facility ($x_{i,j}$). In this example however, the placement of facilities is restricted to an unpaved region by assumption, so that the intercept is taken as a simple constant. Trenchless methods do not usually depend strongly on position (but do depend on conduit diameter), but for valid comparisons a charge must be attributed to this installation method, here taken to be 2.0 k$/km per mm of pipe diameter, according to Zhao and Ranjani (2002).

2. Access – Access to the installed facility after burial (for repairs or connections, etc.) was assumed to take place via a trench excavation (as discussed under item 1 above), shored on both sides and extending for a distance L_{eq}, taken here to be 9.14 m overall, for the present modeling effort. Access is a recurring event (variable with facility), with an annual rate f_{acc} along the roadway

$$c_{2,j}(x_{i,j}, y_{i,j}) = [127.5y_{i,j} + 186.4]\, L_{eq} f_{acc} Y_j \tag{5}$$

where Y_j is the service life of the j^{th} facility.

3. Regulatory surcharge – At present, regulatory agencies managing the rights-of-way have relatively little power to direct specific placement of individual facilities (except for imposing clear zones), but consider facility installation close to the pavement undesirable. As a means of introducing a position dependent factor to assist in encouraging selective placement, an additive regulatory surcharge has been included in the present model. Thus, if a facility is installed within some specified distance of the pavement, a "cost" is attributed to this installation. No actual funds need to be exchanged to impose this charge (nor is equal application to all facilities a requirement), but the total cost function can be biased by adjustment of the surcharge parameter S. Since maintenance of traffic is affected by an ongoing series of access events, this surcharge will be treated similarly as a recurring expense and therefore must be multiplied by the number of years of service expected for the utility, Y_j.

$$c_{3,j}(x_{i,j}) = \begin{cases} SY_j & 3.7\,\text{m} < x_{i,j} < 4.27\,\text{m} \\ 0 & \text{elsewhere} \end{cases} \tag{6}$$

where the surcharge zone begins at the edge of the pavement (here 3.7 m from centerline) and the cost coefficient must be multiplied by the years of service, Y_j. This charge has been included for purposes of model exploration and should be considered as speculative, since authority for such charges may not exist at present.

4. Vehicular crashes with above ground facilities (AGF) - A comprehensive, probabilistic model for crash analysis with AGF has been presented in the Roadside Design Guide (1996). The intended purpose for this model is to make benefit/cost decisions regarding possible relocations of aboveground facilities. For the present analysis, this package is utilized directly to generate a deterministic point function describing the recurring cost (in appropriate units) imputed to a specific AGF as a function of horizontal offset from the pavement. In the interest of brevity, a complete explanation of the model will not be given, however the function depends on the traffic volume along road over the corridor service life, the design speed and the product of a parameter describing the number of encroachments per year per [vehicles per day] per distance along the corridor. Additionally, the importance of imposing a possible "clear zone" (where installation of above ground facilities is forbidden) in overall planning is acknowledged but not considered here.

Other location dependent factors could be easily included in the total cost, as for example a term to account for damage to other facilities during installation or access events.

Unfortunately, only limited information regarding the true cost of such damage exists. In regard to uncertain information, it is most important to remember that the total cost is simply a target for optimization, thus maintaining the proper relative component costs is perhaps more important than having absolute cost data.

OPTIMIZATION METHODS

Various optimization strategies might be employed to find a solution to the problem as posed here. Exhaustive search involves an examination of all feasible configurations to identify a configuration that has the smallest total cost (highest efficiency) while satisfying all constraints imposed. Unfortunately, for many cases of interest, such a strategy is computationally intensive. The basis of an alternative search strategy employed in this investigation is the observation that the edge of the right-of-way at minimum depth tends to be the point of minimum total cost for individual facilities. Initially an arbitrary order for installation of the facilities is selected and the first facility in the sequence is placed in the best possible location available subject to the constraints imposed, starting the search at this most likely position. Using a small search step, the next facility is placed at the best possible location remaining, subject again to the constraints. Continuing this process until all facilities have been placed results in one possible configuration. The total cost function associated with this configuration is constructed by evaluating the individual cost components for each facility at their respective positions. Repeating this process for another search sequence results in another configuration, with associated cost. When all possible sequences have been evaluated, the configuration exhibiting the highest efficiency is selected. While the results of this research indicate that often a better solution is obtained compared to exhaustive search (conducted at larger step) it should be apparent that this strategy is by no means complete. In no case investigated did the rapid search method prove to be less effective than an exhaustive search, however. On the other hand, there is no reason for not choosing the best results available, by either method. It is also noted that this problem is well adapted to parallel computation should that option be practical, and other optimization techniques could also be considered.

Finally, it is tempting to conclude that extreme accuracy either in location or placement is not realistic, so that searching with small step sizes is not required. In fact, if concerns about locational accuracy have been factored in to clearance rules then step size should be chosen as small as possible to improve the chances of finding the least expensive configuration.

RESULTS FOR THE PLANNING EXAMPLE

Using a search step size of 0.09 m, two situations were analyzed to examine the potential benefits of preplanning: Case A) optimal placement of the four utilities to be installed initially, then attempting to add the remaining utility (no preplanning, no regulatory surcharge), and Case B) optimal placement of all five utilities with preplanning (no surcharge). The results of these analyses are shown below in Table 3 and Figure 1. In all cases considered efficiencies are less that 100% indicating a congested corridor.

Table 3: Comparison of results for three cases considered (NM indicates not meaningful)

	Case		
Parameter	**A (Four)**	**B (Five)**	**C (Five)**
Efficiency	96%	94%	86%
Flexibility	0%	82%	51%
Balance	NM	85%	82%
Total Cost	2833 k$/km	3045 k$/km	3326 k$/km

The optimal configuration for Case A illustrated in Figure 1 actually has the small gas line closer to the right-of-way boundary than might be expected (relatively small differences in corridor size and facility diameters could lead to a completely different conclusion, however). Even though the original placement of four utilities is quite efficient, subsequent addition of reclaimed water is blocked due to organizational constraints. This situation could be rectified by preplanning, as shown for Case B. Here, the overall efficiency for all five utilities is high, yet a reasonable cost for later addition of reclaimed water is maintained, as indicated by the flexibility parameter (ratio of minimum possible cost to actual cost for the addition). Note that for this case reclaimed water will be located low in the corridor (installed by a trenchless method).

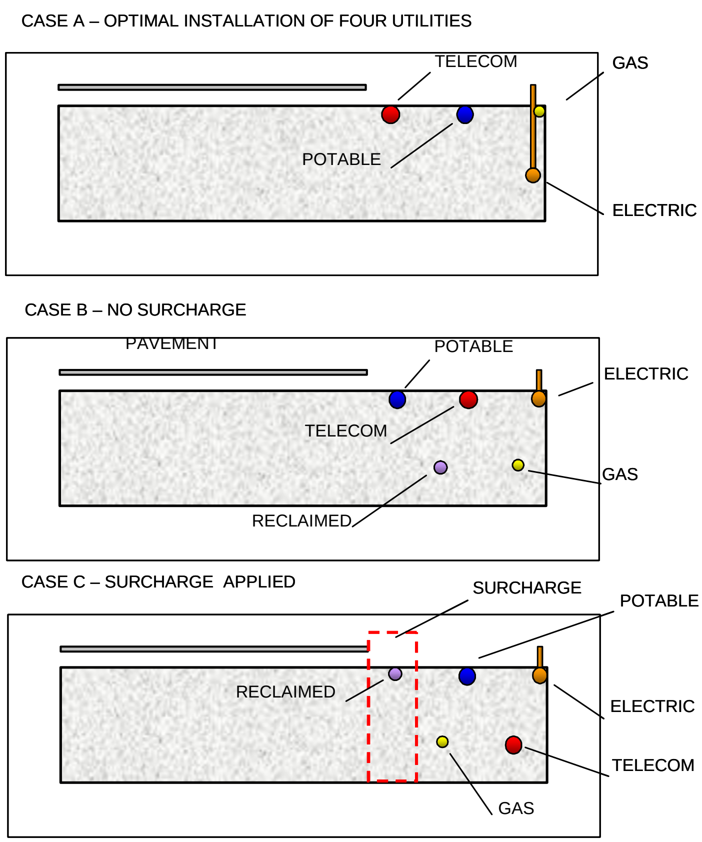

Figure 1: Optimal configurations for Cases A, B and C

Case C is the same as Case B except that a surcharge parameter S=15.5 k$/yr/km has been additionally imposed. An entirely different configuration is identified as optimal in this case, with the anticipated reclaimed water installed by open trench in the surcharge zone (as would be expected).

A balanced solution is one where no utility is placed at a location with an unfair cost advantage or disadvantage. A measure of equitable division of costs may be obtained in the following manner. First the ratios of individual costs divided by individual minimum costs are computed and an average value obtained. A balance parameter (mean of absolute deviation of individual minimums from the average cost) can then be defined

$$Q_{bal}=1-\frac{1}{\sum_{j}^{n} P_n}\sum_{j}^{n} P_n \left| \frac{\overline{MC}}{C} - \frac{MC_j}{C_j} \right| \qquad (7)$$

For Cases B and C, the balance parameter is less than one (indicating that some utilities are paying more on a relative basis than others for positions assigned by the program, but the parameter by itself does not explain how costs are distributed. In fact, the balance parameter is quite similar for the two sets of results, even though the efficiency (and total cost) differs substantially. With regard to this parameter, in the determination of individual costs some components may not be justified if not actually paid by the specific utility. Thus application of this parameter should be cautious.

It is apparent from this discussion that optimal configurations are not necessarily well balanced, in the sense that some utilities are forced into less desirable locations. This fact is partially the consequence of optimizing only for a single target, in this case the total cost. Even though the individual utilities may not be affected by some components of the total cost, it is still true that forcing and expensive location may generate resistance to corridor management. To rectify this situation, one possibility is to "rebalance" the individual cost components to achieve a uniform distribution of relative burden (so that the individual facility efficiencies are equal), making the balance parameter unity. The intent here would be to produce a more equitable distribution of costs by utilizing a compensation scheme; recognizing that at present, no authority to achieve this goal exists.

CONCLUSIONS

In order to facilitate better planning and management of utility corridors along the transportation right-of-way, an organizational and economic model has been formulated and applied to the problem of identifying optimal configurations for new corridors. A relatively simple set of examples has been presented to illustrate this methodology. Results show that by taking into account the possibility of future installations, overall cost savings as well as better use of available space can be achieved. The question of balancing relative costs between the various utilities seeking to install facilities has also been considered, however no attempt has been made to apply multivariate optimization techniques here, as for example to optimize efficiency, flexibility and balance simultaneously. While the benefits of applying these programs are primarily improved management of corridor resources, the results also provide additional documentation for the consideration of alternatives.

Finally, it can be seen that because any configuration can be examined for feasibility and cost, the model and programming strategy developed here can also serve as a useful tool for decision making. In this way, individual stakeholders can also utilize this methodology to better understand the impact of decisions on their interests. While some data required for this type of analysis may be uncertain on an absolute basis, the program methodology utilizes relative cost data and encourages sensitivity analysis.

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