Fair Policies for Travel on Neighborhood Streets

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***Abstract*— The residents of each street in a neighborhood can improve their travel times by forming agreements with the residents of other streets to permit mutual thoroughfare. However, this benefit comes with the cost of additional neighborhood traffic. The key problem addressed by this paper is that of determining a policy that is fair to each street's residents' desires to minimize their travel time by using neighborhood streets while also minimizing traffic on their street. We model this problem using a street graph and apply game theoretic methods in order to characterize solutions.**

I. Introduction

Consider a network of streets in a suburban or urban neighborhood. Such streets are often designed to discourage their use for any purpose other than travel to and from points in the network. Signs such as "local traffic only" suggest policies aimed at reducing traffic on neighborhood streets. At one extreme, we may consider a grid-like network of streets (Fig. 1) that strongly encourages using neighborhood streets to bypass highways when the latter are congested. At the other extreme, we may consider a tree-like network (Fig. 2) that makes thoroughfare impossible and restricts the use of neighborhood streets to traffic with origin or destination in the neighborhood. In general, the topology of neighborhood streets is somewhere between these extremes. Frequently, the restrictions on travel inherent in the topology are supplemented by traffic laws and local regulations.

If the only goal is the minimization of traffic on neighborhood streets, then the preferred policies are those that emulate the tree-like topology as closely as possible. On the other hand, if the only goal is minimization of travel times, we are likely to need policies that permit at least some use of neighborhood streets to get to locations that are also reachable by avoiding those streets. In formulating a neighborhood traffic policy, we may try to balance these opposing objectives in a global manner based on their relative importance. However, such a policy considers the neighborhood only in aggregate and does not adequately address the separate concerns of the residents of individual streets. For example, such a policy may permit thoroughfare on streets A and B, while disallowing thoroughfare on all other streets in the neighborhood. It is very unlikely that this policy will be considered fair by residents of streets A and B, since they are essentially bearing the traffic costs for the entire neighborhood while the benefits are shared by all.

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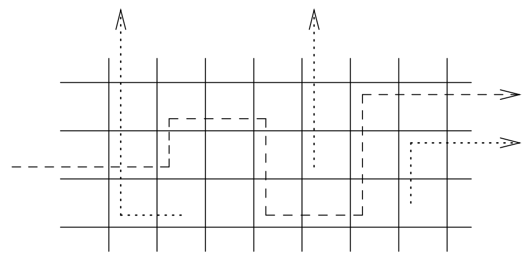

Fig. 1. A grid topology for neighborhood streets. (Line segments represent streets.) This topology makes it easy for traffic to wind through neighborhood streets. In addition to traffic with source or destination in the neighborhood (dotted lines) we also have thoroughfare (dashed line).

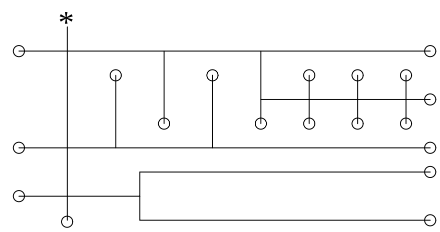

Fig. 2. A tree topology for neighborhood streets. (The circles mark dead-ends: points that do not connect to any other street. The point marked with a * is the only connection to streets outside the neighborhood.) Only traffic with source or destination in the neighborhood can effectively use the neighborhood streets.

We may think of this situation as a multi-player game with one player representing the interests of each street. Each player wishes minimize the traffic on its street while improving its travel times by traveling along other streets in the neighborhood. (We describe the model in detail in Section II.) Note that this model does not imply or require that real decisions about traffic policies are made by negotiations between representatives of each street in a manner reflecting the game. Rather, decisions are likely to be made by a smaller group of people representing large sections of the neighborhood, the entire neighborhood, or even larger administrative units, such as city and county. We expect the game theoretic model to be useful in justifying the fairness of policies proposed by the decision-makers, whoever they may be. The main idea is that if a policy provides a street with a cost-benefit trade-off that is close to what could be achieved in the game-theoretic setting by the player representing that street then one could argue that the policy is fair to the residents of that street.

Our exposition in this paper is based on small examples consisting of only a few streets because computations for larger examples, although qualitatively similar, are much more tedious and lengthy. The methods we describe are equally applicable to larger instances of the problem. Indeed, they are more interesting when the problem is larger since a manual analysis is impracticable in such situations. Similarly, the methods we describe do not depend on any particular topological features of the network of neighborhood streets.

Outline: We describe our model for streets, travel costs, traffic costs, and other problem features in Section II. Section III develops the key ideas underlying the solution. We discuss related work in Section IV and conclude in Section V.

II. Model

a) Street Graph: We model a network of neighborhood streets using a connected, undirected multigraph (called the *street graph* for that neighborhood) in which edges represent streets and nodes represent intersections. We shall henceforth use the term graph to mean multigraph (graph in which multiple edges between the same end-points are permitted). The nodes (street intersections) V are numbered sequentially: $1, 2, 3, \ldots, |V|$. Similarly, the edges (streets) E are numbered $1, 2, 3, \ldots, |E|$. The function $e : [1..|E|] \rightarrow \{(a, b) \in [1..|V|] \times [1..|V|] : a \leq b\}$ maps edges to their end points in the graph. (The condition $a \leq b$ ensures a unique representation for each undirected edge.)

A neighborhood's street graph represents only the streets in that neighborhood. Highways, streets belonging to other neighborhoods, and other streets are not represented explicitly and are called *external streets*. We assume, without loss of generality, that these external streets connect to neighborhood streets at one or more intersections in V. We use the term *external intersection* to refer to intersections that connect to external streets. In figures, external intersections are marked using asterisks (*).

Since we are interested in determining a fair policy for sharing streets within a neighborhood, we model only traffic that originates or terminates in the neighborhood. By symmetry, it suffices to consider only traffic that originates in the neighborhood. The traffic originating at some location on a street is called that street's *resident traffic*.

Example 1: Fig. 3 depicts a very simple street graph consisting of five intersections (nodes) and four streets (edges $1..4$) arranged in a star configuration. Each intersection other than the central one is an external intersection, as indicated by the asterisks. Fig. 4 is another simple street graph. It differs from the one in Fig. 4 by having streets $5..9$ interposed between street 4 and the center. ■

b) Cost Model: In order to keep the presentation manageable we use a simplified model of the costs of travel as well as the cost of traffic on neighborhood streets.

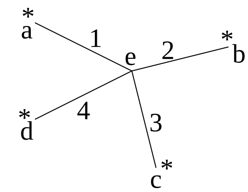

Fig. 3. A simple street-graph: Nodes represent intersections and are labeled with letters. Edges represent streets and are labeled with integers. Nodes marked with an asterisk represent external intersections.

- *Street travel cost*: l. In our model, each of the external intersections is essential in the sense that the resident traffic from each neighborhood street needs to travel to each of the external intersections (to get to different highways or off-neighborhood streets). Travel from a street to an external intersection may require travel along one or more neighborhood streets. Each street that is on the chosen (shortest) route from a street to an external intersection contributes l units to the cost of reaching that intersection. (To simplify the presentation, we include l units for the originating street as well, even though only part of it is traveled in such routes.) Thus, if the chosen shortest route from a street to an external intersection consists of p streets then the travel cost incurred by the street for that external intersection is pl. The total travel cost for a street is the sum of the travel cost from that street to each of the external intersections.
- *Baseline travel cost*: d. Recall that we wish to quantify the benefit of traveling to different off-neighborhood streets via the external intersections, which in turn are reached using the neighborhood streets, as permitted by an agreement between the residents on different neighborhood streets. For this purpose, it is necessary to quantify the cost of reaching off-neighborhood streets in the absence of any such agreement. We use d to denote this baseline cost of traveling from a neighborhood street to an external intersection. In a street graph with x external intersections, the default travel cost for each street is xd. This model does not distinguish between streets based on their distance to the external intersections. Further, the default route (in absence of a neighborhood agreement) may involve some travel along neighborhood streets and some along off-neighborhood streets or highways. We assume d reflects all these costs. Typically, d is much larger than l (and than c, described next).
- *Traffic cost*: c. We use c to denote the traffic cost incurred by a street s due to each other street whose resident traffic travels on s. Thus, if traffic from k other streets travels on street s, the cost to s is kc. This model does not distinguish between the case in which a street s uses a street s' to travel to only one external intersection and the case in which s uses s' to reach several external intersections. However, if s does not use s' at all, even though the agreement permits such use, then s' does not incur the corresponding charge.

Example 2: The baseline travel cost for street 1 in the street graph of Fig. 3 is the sum of baseline travel costs to each of the four external intersections: $4d$. (Recall that baseline travel may occur along off-neighborhood streets, which are not depicted in the figure. For example, traffic from street 1 may travel to each of the three remote external intersections, b, c, and d, via highways not depicted in the figure.) By symmetry, the baseline travel costs of streets 2, 3, and 4 are also $4d$ each. Resident traffic from street 1 can get to external intersection a by traveling along street 1 at cost l. (Recall that l is expected to be much smaller than d.) Now suppose streets 1 and 2 agree to permit resident traffic from each other to travel on their streets. Traffic from street 1 can now get to external intersection b by traveling along streets 1 and 2, at a cost of $2l$. Travel to intersections c and d does not benefit from this agreement. Thus the benefit of the agreement for street 1 is $(d - l) + (d - 2l) = 2d - 3l$. However, the agreement also imposes additional traffic on street 1 (resident traffic from street 2) at a cost of c. Thus, the net benefit, or utility, of the agreement for street 1 is $2d-3l-c$. By symmetry, this expression also gives the utility for street 2. The situation for streets 3 and 4 is unaffected by this agreement. Similar calculations may be performed for other coalitions of streets, such as $\{2, 3\}$ (streets 2 and 3), $\{1, 2, 3\}$, and $\{1, 2, 3, 4\}$. ■

III. Fair Sharing

As suggested by Example 2, a street accrues savings in travel costs as it partners with additional streets, but these savings may be offset by the costs of additional reciprocal traffic. Further, the savings will vary depending on the topology of the graph. This feature is not evident in the simple symmetric street graph of Fig. 3 but may be observed in asymmetric graphs such as the one in Fig. 4. Even without performing the detailed calculations, it seems intuitively obvious that a coalition composed of streets $1..5$ stands to gain nothing by admitting any of the streets $6..9$ into the coalition because the latter permit no additional beneficial routes.

The above discussion may suggest the coalition $\{1, 2, 3, 4, 5\}$ as a simple solution to the problem of sharing neighborhood streets for the street graph of Fig. 4. Indeed, we may verify that under reasonable assumptions about the values of the parameters d, l, and c, each of the streets $1..5$ has a net benefit due to its participation in the coalition. However, this fact is not sufficient for a satisfactory solution because several questions remain unanswered: Why should street 5 be included in the coalition while streets $6..9$, which are indistinguishable from 5 in function, are excluded? In light of the fact that each of the streets $1..4$ is essential in the sense that it controls access to one external intersection, isn't it fair that they receive greater benefit from the coalition compared with street 5, which is easily replaceable? Since street 4 is farther removed from the center of the neighborhood, perhaps it is not fair to treat it on par with streets $1..3$. Perhaps a break-off coalition of streets $1..3$ is more profitable to those streets.

Suppose we have a candidate scheme for sharing streets in a neighborhood. Each street must benefit from this scheme (else it would not participate). If a coalition of streets can achieve greater benefit for its members by cutting ties with the rest of the neighborhood, then the candidate scheme will not be perceived as fair. This idea corresponds to the game-theoretic notion of the coalition *blocking* the candidate solution. An important question in this regard is whether there exist any solutions that are not subject to such blocking by coalitions.

Before we address the above question, we introduce some terminology: We shall use the term *coalition* in this paper to refer to a set of neighborhood streets that permit resident traffic from each other, but not from other streets. By participating in such a coalition, each street derives a *utility*, defined as the reduction in travel costs less the traffic costs incurred. (See Section II.) We shall represent the utilities of members of a coalition $\{i_1, i_2, \dots, i_k\}$ using a *utility vector* $v(i_1, i_2, \dots, i_k) = (u_{i_1}, u_{i_2}, \dots u_{i_k})$, with the convention of listing coalition members in ascending order ($x < y$ implies $i_x < i_y$). For brevity, we shall also adopt the notational convention that, in a utility vector, "$\cdots$" stands for the value immediately preceding it. Thus, $(x, \cdots)$ means (x, x); $(x, \cdots, \cdots)$ means (x, x, x); $(x, \cdots, \cdots, y, \cdots)$ means (x, x, x, y, y); and so on.

Example 3: Recall from Example 2 that, in the street-graph of Fig. 3, the two-street coalition $\{1, 2\}$ results in a utility $2d - 2l - c$ for each street. We express this fact by writing $v(1, 2) = (2d-3l-c, 2d-3l-c) = (2d-3l-c, \cdots)$. Using reasoning similar to that in Example 2, is easy to verify that $v(1, 2, 3) = (3d - 5l - 2c, \cdots, \cdots)$ and $v(1, 2, 3, 4) = (4d - 7l - 3c, \cdots, \cdots, \cdots)$.

Using sample values $d = 10$, $l = 1$, and $c = 1$ for the problem parameters, we have $v(1) = (d-l) = (9)$, $v(1, 2) = (16, \cdots)$, $v(1, 2, 3) = (23, \cdots, \cdots)$, and $v(1, 2, 3, 4) = (30, \cdots, \cdots, \cdots)$. We see that neither coalition $\{1, 2\}$ nor coalition $\{1, 2, 3\}$ would not benefit by breaking off from the grand coalition $\{1, 2, 3, 4\}$. By symmetry, this fact also holds for the coalitions not listed above (such as $\{1, 3\}$ or $\{1, 3, 4\}$). Thus, the solution is stable. ■

We may generalize the arguments of the above example by noting that the above stability result will hold for all values of d, l, and c for which the individual utilities of streets in smaller coalitions (including singletons) are never larger than their utilities in the grand coalition. Thus the street graph of Fig. 3 has a stable solution if $4d - 7l - 3c$ is at least as large as each of $3d - 5l - 2c$, $2d - 3l - c$, and $d-l-c$. These three inequalities are equivalent to the single inequality $d \geq 2l + c$. This inequality provides a convenient characterization of stability for this example. However, such a characterization is not easy to obtain for more complex street graphs. As the following example illustrates, even a slight increase in the complexity of the graph may make it difficult to achieve a simple characterization.

Example 4: Consider the street graph of Fig. 4. If all streets permit resident traffic from all others, we have the grand coalition $N = \{1, 2, \dots, 9\}$. Resident traffic from street 1 can get to external intersections a, b, c, and d by following routes (respectively) $[1]$, $[1, 2]$, $[1, 3]$, and $[1, 5, 4]$, incurring travel costs (respectively) l, $2l$, $2l$, and $3l$. The

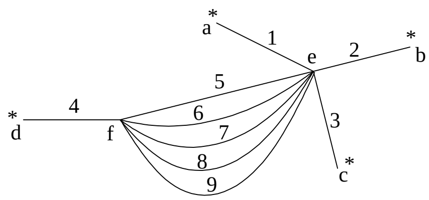

Fig. 4. The street-graph of Fig. 3 modified by addition of streets 5–9: This example highlights the fact that street graphs are multigraphs. Multiple edges (such as 5..9) between the same pair of nodes (e and f) are permitted.

total travel cost for street 1 is thus $8l$, yielding a benefit of $4d - 8l$ over the default. This benefit comes at the cost of extra traffic from 8 streets: $8c$. Thus the utility for street 1 (and, by symmetry, for streets 2 and 3 as well) in the grand coalition is $4d - 8l - 8c$. A similar reasoning for the other streets in the grand coalition yields (1) below. Let us now consider a coalition composed of streets 4 and 5 only. Street 5 may now reach external intersection d using path $[5, 4]$ at a cost of $2l$ yielding a benefit of $d - 2l$ over the default. In addition, resident traffic from street 4 does not travel on street 5, although such travel is permitted, because travel cannot continue to any external intersection in this manner. Thus street 5 does not incur any traffic costs in this arrangement and its utility is $d-2l$, as indicated by (6) below. On the other hand, street 4 incurs the cost of resident traffic from street 5 but derives not benefit. Similar computations for other coalitions yield the following:

$$
\begin{aligned}
v(1,2,\ldots,9) &= (4d-8l-8c, \cdots, \cdots, \\
&\quad\; 4d-10l-8c, \\
&\quad\; 4d-8l-4c, \cdots, \cdots, \cdots) && (1)\\
v(1,2,3) &= (3d-5l-2c, \cdots, \cdots) && (2)\\
v(1,2) &= (2d-3l-c, \cdots) && (3)\\
v(1) &= (d-l) && (4)\\
v(1,4,5) &= (2d-4l-2c, 2d-4l-2c, \\
&\quad\; 2d-4l-2c) && (5)\\
v(\{4,5\}) &= (d-l-c, d-2l) && (6)
\end{aligned}
$$

Let us now consider the stability of the solution consisting of the grand coalition $N = \{1, \ldots, 9\}$. The solution is stable if no break-away coalition can guarantee a higher utility to its members compared to their utilities in the solution. By comparing terms in the utility vector (1) of the grand coalition with the utility vectors of smaller coalitions, we arrive at a set of inequalities ((7)–(13) below) that characterizes the requirements for a stable solution. The equation, in addition to (1), that is used to derive each inequality is indicated to the left of each inequality.

$$
\begin{aligned}
(2) \Rightarrow \quad u_1 &\geq 3d-5l-2c && (7)\\
(3) \Rightarrow \quad u_1 &\geq 2d-3l-c && (8)\\
(4) \Rightarrow \quad u_1 &\geq d-l && (9)\\
(5) \Rightarrow \quad u_1 &\geq 2d-4l-2c && (10)\\
(5) \Rightarrow \quad u_1 &\geq 2d-2l-2c && (11)\\
(6) \Rightarrow \quad u_1 &\geq d-2l-4c && (12)\\
(6) \Rightarrow \quad u_1 &\geq d+l-c && (13)
\end{aligned}
$$

Recall that in Example 3 the inequalities corresponding to different break-off coalitions collapsed to a single inequality. In the current example, the situation is not as simple. Examining the inequalities, we note that (8) implies (10), and (9) implies (12). However, (7), (8), (9), (11), and (13) are independent.

We may verify that the parameter values $(d, l, c) = (10, 1, 1)$ (as used earlier) satisfy all the above inequalities, indicating a stable solution. However, other parameter values result in an unstable solution. For example, if we use $(d, l, c) = (70, 20, 10)$, the left-hand side of (11) equals 40 while the right-hand side equals 80 and the inequality is not satisfied. Indeed, we may verify that the corresponding coalition, $\{1, 4, 5\}$, can improve its utility by withdrawing from the grand coalition. ■

Example 4 suggests two interesting questions: First, how do we determine a fair scheme for sharing streets in situations that result in unstable grand coalitions? Second, is there a simpler characterization of the problem instances that permit stable solutions?

We address the first question below by allowing members of a coalition (including the grand coalition) to be reimbursed monetarily in an attempt to compensate for an inequitable treatment in a proposed solution. (The second question will be addressed by an extended version of this paper.) This version of the problem is similar to side-payment games or transferable-utility games studied in the game theory literature. Intuitively, permitting side payments weakens the requirements for stability by allowing a greater portion of the grand coalition's utility to be allocated to the streets that would otherwise benefit from withdrawing from the coalition. Instead of requirements on each street's natural utility (based on the model of Section II) we are permitted to use an adjusted utility that includes a side payment at the expense of some other streets. The requirement then is that the total utility of every coalition be no greater than the sum of its members' utilities in the the grand coalition. Using N to denote the grand coalition, $\mathcal{C}$ to denote the collection of all coalitions, and $v_i(C)$ to denote the utility of a street i in coalition C, we may express this condition as follows:

$$\forall C \in \mathcal{C} : v(C) \leq \sum_{i \in C} v_i(C) \tag{14}$$

By slight abuse of notation, we shall henceforth use the notation $v(C)$ to mean both the vector $(v_1(C), v_2(C), \ldots, v_k(C))$ of utilities for the coalition members $i \in C$ and also the sum of these utilities, $\sum_{i \in C} v_i(C)$. In the side-payment version of the problem, the latter interpretation, called the *worth* of the coalition, is more interesting since utility may be redistributed within a coalition.

Example 5: Recall, from the end of Example 4, that with parameters $(d, l, c) = (70, 20, 10)$, the grand coalition of all streets in the graph of Fig. 4 is not stable because (11) is not satisfied. We may compute the worth of the corresponding blocking coalition $\{1,4,5\}$ using (5): $v(\{1,4,5\}) = 6d - 12l - 6c = 210$. The right-hand side of (14) for this coalition is given by $\sum_{i\in\{1,4,5\}} v_i(N) = 12d - 26l - 20c = 210$. Thus (14) is satisfied and the coalition $\{1,4,5\}$ does not block the solution when side payments are allowed. ∎

When side payments are permitted, as in the above example, a natural question is how the total utility of a coalition is distributed among its members. Intuitively, it seems reasonable that streets that *bring more value* to the coalition should receive a greater portion than those that contribute little. In the street graph of Fig. 3, we may expect streets 1–3 to receive a portion larger than that of streets 5–9, since each of streets 1, 2, and 3 adds a new path to an external intersection while all but one of streets 5–9 is redundant. This intuition may be captured by using the *Shapley value* [1] of a game, which assigns the following utility ϕ_i to street i:

$$\phi_i = \sum_{C\subseteq N\setminus\{i\}} \frac{|C|!\,(|N|-|C|-1)!}{|N|!} \cdot \big(v(C\cup\{i\}) - v(C)\big)$$

Consider the sequential addition of streets to a coalition, starting with the empty coalition. There are $|N|!$ ways streets may be added in this manner. The fractional term above is the probability that the streets in coalition C precede street i in this order and the difference term is the value i adds to the coalition. Summing over all possible values of C yields the expected value added by street i. In addition to this intuitively reasonable motivation, the above utility assignment is also known to be the unique one that satisfies the properties of efficiency (no utility is unused), symmetry (labeling of streets is immaterial), linearity, and independence from effects of dummy players [1].

IV. Related Work

Several studies address traffic control and management [2]. SITRAFFIC is a traffic management system for urban traffic control that uses a decentralized, hierarchical method to optimize control of traffic lights in the network [3]. Work on dynamic vehicle routing and traffic assignment [4], [5], [6] is complementary to the work in this paper. In the context of neighborhood streets, once policies for use have been determined using the methods described above, the dynamic methods can be used to optimize the use of streets in response to changing traffic scenarios.

Work on access control for freeways [7] and freeway queue formation [8] may be used to better quantify the costs and benefits of various restrictions and may serve as an alternative to the simple cost model used in this paper. Similarly, work on route computation [9] may be used to better quantify the benefits of shared neighborhood streets, replacing the simple travel cost model used in this paper. Our travel model may also benefit from work on traffic flow theory [10], [11]. Methods for forecasting traffic, such as those using simulations in large networks [12], may also be used to improve the accuracy of the cost model used in this paper. An interesting approach to determining traffic speeds using transit vehicles as probes is described by Cathey and Dailey [13]. It may also be possible to adapt work on arterial speed estimation [14] for this purpose. It may also be useful to incorporate practical methods, such as those used by the MOBINET project for traffic estimation in Munich [15].

The work by Ishihara and Fukuda [16] on traffic-signal control algorithms that include emotional factors shares with our work the concern for social issues. Their method uses a model of drivers' mental states to control traffic signals with the goal of minimizing psychological stress. Another social issue related to ITS is explored by Naniopoulos [17], who describes a project that provides design guidelines and evaluation methods for ITS systems with elderly and disabled persons in mind. Work on congestion toll pricing [18] has addressed objectives such as minimizing the number of toll booths and minimizing the toll costs. The idea of collaboration to improve both individual and global traffic outcomes has been studied in the context of coordinated braking [19] and cooperative driving systems [20].

The problem of bargaining, in a general setting, has received considerable attention in the Economics literature. Perhaps the most famous result appears in John Nash's classic work on the two-person bargaining problem [21]: If the set of utility allocations is compact and convex then there is a unique optimal solution to the two-person bargaining game that is Pareto optimal, independent of linear transformations, and independent of irrelevant alternatives. This solution is the one that maximizes the value of $(u_1 - d_1)(u_2 - d_2)$, where u_i denotes the utility allocation for player i and d_i is the utility of the status quo solution. Although most assumptions leading to Nash's solution is quite natural, the requirement that solutions be independent of irrelevant alternatives is less so and has been the subject of much debate and follow-on work. Intuitively, this assumption states that if an alternative (potential solution) is discarded (as non-optimal or non-feasible) by some solution rule then the solution rule must yield the same final result if that alternative were absent from the original problem formulation. Although it seems innocuous, this assumption leads to unintuitive and indefensible conclusions in several practical problems, such as the problem of dividing a bankrupt company's assets among its creditors. Kalai and Smorodinsky addressed this shortcoming by replacing this assumption with a monotonicity assumption, yielding the so-called K-S line solution to two-person bargaining [22]. This solution is the farthest (from the origin, in the solution space) point along a line connecting the origin to the point (u_{1m}, u_{2m}), where u_{im} denotes the maximum (feasible) utility allocation for player i.

Multi-player games are qualitatively more complex than two-player games described above because of the possibility of coalitions blocking solutions. The key idea of a core of a multi-person game, which corresponds to our discussion of stability, is attributed to Edgeworth [23]. Balancedness of multi-person games was first studied by Bondareva [24]. Scarf showed that if the characteristic-function values of a game form a closed, comprehensive, bounded set such that a vector's membership in $v(C)$ depends only on the the components related to the elements of C, then balancedness of a game implies the existence of a core (stable solution) [25].

Shapley introduced the rule for side-payments in transferable utility games described in Section III.

V. Conclusion

We addressed the problem of determining fair policies for restricting traffic on shared neighborhood streets. Such streets are subject to two conflicting demands: On one hand, residents on each street would like to limit traffic in order to cut down on noise, pollution, and related ills. On the other hand, by strategically permitting use by some of their neighbors, the residents of each street may be able to improve their travel times, as well as the global travel times. The central problem is then that of determining rules for sharing neighborhood streets that all parties will see as fair. This problem is important not only because a solution enables effective and fair use of streets, but also because it permits better planning by enabling analysis of alternate traffic designs on new or existing streets. In addition, the analysis described in this paper may be applied in a semi-automated manner to quickly determine new policies when existing streets are disabled due to accidents or other problems.

We formalized the street-sharing problem as a multi-person bargaining problem based on a simple graph model for neighborhood streets. We first discussed a variant of this problem in which the utility of neighborhood streets is not transferable. We described an example that illustrates some of the challenges. In particular, it is not easy to characterize solutions or even to determine when solutions exist. We also discussed a variant in which the utility of neighborhood streets is transferable. In this version, side payments can be made to compensate for inequities in a proposed solution's utilities to different participants. We described how this feature makes it easier to characterize and determine solutions. In order to keep the presentation manageable, the examples in this paper are extremely simple. However, they illustrate the basic concepts and the methods of this paper are equally applicable to larger examples. Similarly, several assumptions made in our presentation, such as those related to the ownership model for streets and the metrics for traffic cost and benefit, exist only for ease of presentation and are easily removed.

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